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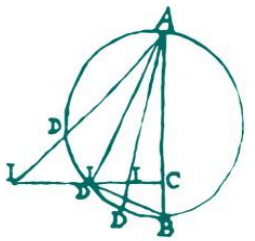
Uprooting the Tree of Physics:
John Wheeler between Black Holes and 'It from Bit'

Stefano Furlan

Submitted to the *Faculté des Lettres* (*Université de Genéve*)
in Partial Fulfillment of the Requirements
for the Degree of
Doctor in Philosophy



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χρὴ γὰρ εὖ μάλα πολλῶν ἴστορας
φιλοσόφους ἄνδρας εἶναι
– Heraclitus

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À quiconque a perdu ce qui ne se retrouve
jamais.

Preface: Archaeology of the Scientific Frontiers

Giorgio De Santillana, in the context of his vast and eccentric search for lost knowledge in ancient myths and its ties to the origins of science, once spoke of the forgotten Newtons and Keplers whose ideas shaped the picture of the *kosmos* underlying those tales (De Santillana 1966, pp. 11-25). Here the concern is not about the soundness of that specific claim: rather, what fascinates me is the way in which a peculiar figure gets thus introduced – the figure of the investigator of those worldviews, who tries to grasp and reconstruct the origins and early developments of powerful ideas that, later, become widespread and largely accepted to the point of not needing the name of an originator. This approach may be appropriate for the study of societies without a marked individualism or of non-authorial elaborations of knowledge such as myths; but it seems to me that, in some respects, a quite similar situation is found even in today's collective imagination about the "frontiers of science": exotic notions (usually reified without a second thought), expectations, speculations, ambitions are all intertwined in a captivating mixture whose elements are simply taken for granted ("Isn't that how things are?") and, especially in highly speculative realms in dire need of empirical support, spectacularized by adding more and more of those very same ingredients. New forms of matter, fundamental constituents, mysterious astrophysical entities, unimaginable features of the universe, even further universes: the origins of these notions are often very confused, if not ignored or dismissed with some childish "historical" reference (a name and a year); their transformations are often deemed irrelevant – *de facto,* at least, when speaking with a naïvely naturalistic attitude – or linearized in a march of progress towards the present day. A whole industry of "popularization", often with sensationalistic tones, spreads such imagery. Even the physicists themselves are involved, with the not-so-hidden aim of promoting specific research programs. Since all this is presented as the fruit of the great collective endeavor called "Science", names – names of people – can just move to the background (except, of course, when it comes to prizes or mass-mediatic *personae*), or simply get attached as an empty label to some distinguished result, which usually is then rephrased in more recent terms.

Who has not heard of "black holes", just to give a telling example? Many – physicists and non-physicists – have also heard of John A. Wheeler as the man who named them. But was it really like that? What did Wheeler actually do? Of course, we are not merely interested in the nominal identity of the actual "baptizer" or in such historical trifles, although we will see how the

answer to the Shakespearean question “What’s in a name?” can be quite interesting also in these areas of physics. What is truly important to highlight is rather how the man just introduced, John Wheeler, is, from a certain point of view, one of those relatively (but, luckily, not irreversibly) forgotten Newtons and Keplers in today’s imagination of the universe and the frontiers of physics. Very few seem aware of the extent and peculiarities of the influence that he has been exerting for decades, not just by means of his individual results, but also, if not mainly, due to his enormously impactful role in suggesting new directions, asking and framing questions, shaping expectations, crafting metaphors, narratives, argumentative strategies and pictures. All of these were employed to disseminate and somehow “popularize” – to a larger public, but even to students and fellow physicists – his ideas, always building on the previous successes of 20th-century physics. Given that many of the questions he asked are still open, and some of his expectations and hopes are still shared (often without realizing that they bear his distinctive imprint), the task of reconstructing the development of his thought is not just aimed at filling a historical gap: it is an “archaeological” and critical way of accessing the present – an uncertain and confused present – and of putting it in perspective. Moreover, precisely because Wheeler’s activities are somewhat more elusive than the clear-cut results that often monopolize attention when speaking of recent physics, and also more unconventional and flexible than the operations usually contemplated in overstuffed (and not rarely anti-historical) pictures of “how science truly works”, he represents at the same time a true challenge and an opportunity.

What I have just said not only applies to the historiography of physics, often torn between a parade of impersonal and “objective” results on the one side and a self-serving emphasis on “externalist” factors on the other, neither trying to see how the various dimensions affect each other, nor cogently showing their effective intertwinement. Wheeler represents a challenge also for the way scientists are usually portrayed nowadays – the theoretical physicist in particular – and for the way we think about such activities. Quite unexpectedly for a recent physicist, Wheeler, with his wide-ranging interests and carefree creativity, touched upon many disciplines (from history to philosophy, from the visual arts to literature) that are frequently invoked when trying to highlight the “cultural dimension” of science, but all too often with superficial pretexts or according to fashionable tools of “analysis”. Paradoxically, as we shall see, Wheeler’s genuine spirit of research and originality ultimately made him arguably more "humanistic” than many "humanities scholars". At the same time, he displayed a concrete, peculiar and quite well-documented way of correlating different fields – or, at least, offering suggestions on different ways of thinking about their relations. In this

sense, the resulting picture of Wheeler's activities can have its own cultural "thickness" without watering down science among generic cultural phenomena, nor ignoring its specificity; at the same time, it can also remain cogently anchored in the history of scientific thought and results. A challenge and an opportunity, again.

Perhaps other concerns may be directed towards the focus of this research on a single individual, as much as I have already hinted at the larger dimensions on which it will shed some light: this is, after all, an approach that is unfamiliar to many working on recent physics. However, even if one assumes that the "ultimate" level of understanding in these matters is supposed to be a collective or impersonal perspective, because of the collective or impersonal nature of science, this does not justify the blandness and quintessential anonymity of many "micro-historical" or biographical remarks in this field. Truisms (or trivialities) such as "science is collective", a compulsive focus on widespread practices in order to dissolve any claim of individuality, and similar trends – when they are proudly displayed with a rigid one-sidedness – may end up describing merely the infamous night in which all cows are black. When one deals with a very distinguished figure such as Wheeler, these approaches should provide, in my view, tools to better contextualize and appreciate his peculiarities and his various enterprises, rather than to try and dissolve him into some form of anonymity or to proclaim a sort of "death of the author". In this sense, and in contrast to the aforementioned dark night, I will here attempt to gradually reconstruct and interconnect the plurality of dimensions of Wheeler's activities and the multifacetedness of his thought, in order to recover the complexity - in the literal sense - of his scientific life. Given his relevance as an impactful actor close to many crucial developments, and since he usually offers some comment or insight from unconventional viewpoints, the value of exploring, ordering and interpreting the traces Wheeler left has some uncontestable value even for those who are not committed to studying science on an individual level. For sure, this is not a mere operation of doxography.

On these premises, the chapters that follow can be roughly divided into two groups. The first one may be characterized as the parable of "daring conservatism", Wheeler's heuristic approach, which roughly consists in relying on already well-established principles and pushing them to their extreme consequences, without extra additions if possible. He enunciated this methodology during a phase of crisis and transition around 1950, when he decided to dedicate himself to the exploration and daring-conservative development of general relativity, the legacy of his mentor, Einstein. The story of daring conservatism is thus also the story of the rise and fall of the ambitions of "geometrodynamics" (as Wheeler started to call general

relativity) and its universe. This attempt to take on (at least collectively) Einstein's mantle and extend his legacy, rather than just dusting it off, was catalyzed in peculiar ways by Einstein's decease in 1955. In chronological terms, this parable of daring conservatism and geometrodynamics covers the period from the early 1950s, which mark the beginning of the mid-phase of Wheeler's career, to the early 1970s, by which time the overall program appears to him as irrevocably flawed and insufficient. At that point, the transition to the late phase of his scientific adventure – which we could put under the aegis of "it from bit" – begins.

More in detail, after an extended **Introduction** that surveys historical epistemology as intended here, with specific reference to the history of recent physics, and offers some general background on Wheeler's peculiar engagement with history and philosophy, **Chapter 1, "Wheeler the Storyteller"**, will trace how the very attitude towards the past that underlies daring conservatism, far from being merely a sort of hypothetical-deductive method, manifests itself in Wheeler's manifold uses of history. We will thus identify the main ones among these uses, with special reference to Wheeler's relationship with Bohr (the "hero" of daring conservatism) and with Einstein (who provided the material to which daring conservatism got applied), and see how the past provided inspiration for Wheeler's ideas and support for his most ambitious endeavors, where empirical support was no longer given. After having realized that Wheeler's flamboyant rhetoric was not just an ornament, but was deeply linked to his heuristics, and having clarified the subject matter to which daring conservatism was applied, we will move to **Chapter 2, "Between Cold Matter and Frozen Stars: The Road Towards Black Holes"**, which reconstructs Wheeler's long and quite complex heuristic trajectory towards the acceptance of black holes. Wheeler soon realized the centrality of gravitational collapse as a research topic, but he remained skeptical throughout the 1950s about the pioneering results by Oppenheimer and collaborators, instead of pushing them daring-conservatively to the limit. Nonetheless, once he became convinced of their physical relevance in the early 1960s, he started to conceive the not-yet-named black holes as the most spectacular prediction of general relativity, thus atoning, in a sense, for his own previous lack of daring conservatism in that issue. **Chapter 3, "Beyond the Last Star"**, then follows Wheeler's daring (actually, from today's viewpoint, very daring) conceptual extrapolations of black holes, which brought him to radical conclusions about the very notions of time and physical law. The act of pushing the black hole's "lessons" to the extreme ended up convincing Wheeler that his geometrodynamical program could not be sufficient for building an encompassing view of nature. Daring conservatism, at least as applied to general relativity, had petered out. Starting a new cycle of

daring conservatism first required the identification of solid and deeper principles: we can see at this point a renewal of Wheeler's meditations on quantum foundations and, on other levels, a further enlargement of his interests and horizons, which, ultimately, would lead to the intricate, visionary synthesis that he left as a suggestion to posterity under the name of "it from bit". If daring conservatism survived as an attitude, it did not find, however, another implementation comparable to the one it received in geometrodynamics – and that is why its fate is so closely intertwined with the latter's. An **Appendix A, "Daring-Conservative Regrets: Katharine Way, Wheeler, and the Dawn of the Nuclear Age"**, to this first part will showcase another concrete example of Wheeler's uses of the past and construction of narratives, with specific reference to the role of women in the exploration of the atomic and sub-atomic realms (featuring Marie Curie as a heroine of daring conservatism) and Wheeler's early work on nuclei and fission with his first Ph.D. student, Katharine Way. Besides presenting another instance in which Wheeler apparently regretted (many years later, at least) not being daring-conservative enough, this is also another instructive case to display the kind of problematization and methodological expedients one has to deploy when engaging with historical sources such as Wheeler's recollections and narratives.

The richness and the many layers of the subject matter, already apparent in the relatively monothematic story of the vicissitudes of geometrodynamics, simply *explode* when trying to reconstruct Wheeler's later reflections. Retreading the complexity and the polygenetic elements of his ideas and inspirations represents a challenge to the very bi-dimensionality of the written page, making linearized and monocausal accounts highly inadequate. Furthermore, it would be naïve and simplistic to assume that daring conservatism could be enough to encapsulate all of Wheeler's activities and his overall method: the truly interesting part, after having outlined the features of his daring conservative compass, is to see how it interacted with other "practices" Wheeler resorted to throughout his career. In this sense, the task at hand not only focuses on his methodologies – plural – but naturally also calls into question the methodology of the person trying to reconstruct and write down a narrative about Wheeler. It is possible to follow his story over and over again from slightly different angles, underlining other features, other connections, other influencing factors, without exhausting the subject matter. As will become clear, this is not meant in the rather banal way that could be remarked in all cases, because of "historical complexity", contextuality and whatnot. The reason for this is not some great man singularity, either, but is rather due to the variety of ideas Wheeler often pursued in parallel, the open-endedness (but also the farsightedness) of his manifold suggestions, his long

and rich career, the great number of contacts he established (not only within the physics community), and of course the extensive archives he left us. Re-examining and re-telling the story with another filter in front of our eyes, or highlighting some other features, is, in cases such as Wheeler, a rewarding task: some of its possible fruits are offered in the second group of chapters, while providing new interpretative keys to his late phase as well. Such an operation obviously involves a degree of redundancy, which is not just for the reader's sake, but really for the sake of the argument, since – in a manner that Wheeler's own restlessly interrogative spirit might have liked – these are indeed different angles from which to question *immer wieder* those multifaceted developments, inspirations, and attempts. In the second group of chapters, then, each one needs, in a sense, to tell again not the whole story, but a good part of it, while avoiding any one-sided and schematic pretentiousness of exhausting the topic.

More specifically, **Chapter 4, "Merging Labyrinths: Leibniz in Wheeler's Quest"**, will identify and reconstruct Wheeler's complex and fascinating re-elaboration of Leibniz's thought, starting from a crucial moment in the story of geometrodynamics. We will see how this precious "intracranial colleague" represented for Wheeler an access route to the "it from bit" phase. At the same time, this chapter will try to forge proper tools to address some subtler interactions, often not perceived at all (as was the case for Wheeler and Leibniz) between the history of physics and the history of philosophy. After all, dealing with the long maturation and metamorphosis of individual ideas – as called for by Wheeler's intellectual development – is a task for which historical works on single philosophers may in some respects provide more inspiration than standard ways of approaching recent physics. **Chapter 5, "Aesthetics of Visionaries and Engineering"**, will focus on the Wheelerian balance between theoretical speculation and a much more practical and empirical dimension, which ultimately had its roots in Wheeler's long-standing relation to engineering. This will allow us to highlight other important factors in the metamorphosis he underwent during the mid-1970s, in the period between the crisis of geometrodynamics and the "it from bit" phase. We will thus identify another access route to his later meditations. **Chapter 6, "A Seeker in the Atomic Age"**, will re-read Wheeler's scientific experience in the light of a category taken from his own writings, that of the "seeker". It alludes to a dimension of research that transcends institutional boundaries and includes all the above-addressed protean ways in which Wheeler practiced science. This will also provide the chance to clarify and properly interpret the picture of the "universe as home for man" that Wheeler, in his late years, while in dialogue with a plethora of sources, tried to present even to a larger public. **Chapter 7, "The Modern Maestro of Matter"**, will then show how

the considerations developed in the previous three chapters cast light on (and get in turn corroborated by) a late and hardly known paper by Wheeler about the manipulation of matter, with various unexpected links to topics such as the preconditions for life or bionanotechnology. Besides contextualizing this episode, the chapter will provide once again an unfiltered glimpse into Wheeler's workshop, so to speak, with his recurring ideas and aspirations, his rhetorical exuberance, his uses of history and peculiar heuristics, and we will underscore how he was gradually able to explicitly incorporate his scientific *modus operandi* into the epistemology and the new physics that he was envisaging. **Appendix B, "The Smile of Mnemosyne"**, will address more specifically how Wheeler's pictures and uses of the past got intertwined in original and quasi-Warburgian ways, contributing to the dissemination of ideas, expectations, and communicative styles among different audiences. Finally, **Towards a Conclusion?** will refresh a few threads and make use of them to shed some light on today's situation at the frontiers of theoretical physics, both in terms of Wheeler's strictly "technical" impact and his imprint on contemporary scientific imagery and communication. It will also enucleate from Wheeler's reflections a series of original suggestions that may be addressed to philosophers and historians. One of the hopes of this work is that, at the end of it, the reader will at the very least agree with the following comment by Aleksandr S. Puškin (1837, §3): "Following the thoughts of a great personality is a most captivating study".[1]

1Curiously enough, Igor D. Novikov, whose results on black holes will make his name appear here again, also resorts to the same quote at the beginning of one of his books (Novikov 1998, p. xvi), translating it thus: "To follow the reasoning of a great personality is a most captivating and gratifying subject". In the referenced English edition of Puškin's prose tales, the translation reads: "To follow the thoughts of a great man is a most rewarding study". The original is "Следовать за мыслями великого человека есть наука самая занимательная". I have settled for a sort of middle way - hopefully, the "rewarding" or "gratifying" aspect will appear by the end of this work.

Introduction: Variations on Historical Epistemology

> Les historiens feront sagement d'y réfléchir.
> L'histoire mal entendue pourrait bien, si l'on n'y
> prenait garde, risquer d'entraîner finalement
> dans son discrédit l'histoire mieux comprise.
> – Marc Bloch, *Apologie pour l'histoire*

1. Which historical epistemology?

1.1 A question of method

Historical epistemology in its Berliner sense (embodied primarily, during the last decades, in the activities of the Max-Planck-Institut für Wissenschaftsgeschichte) is, at least in some respects, elusive. It is sometimes tempting to suggest that, in Berlin, everyone knows what historical epistemology is, but no one says it. Aside from the *boutade*, it could be claimed that each research director interpreted and shaped historical epistemology in their own way, which obviously entailed, among other things, a melting pot of influences and affinities with other approaches. There are, nonetheless, good attempts to offer a comprehensive overview, such as (Rheinberger 2007) or, more recently, (Braunstein et al. 2019) and (Omodeo et al. 2021), where the "polygenesis" of this type of approach is rightly emphasized. Now, it is by no means the purpose of this introductory section to go over or discuss the various forms of historical epistemology and their origins: the aim is simply to offer some coordinates, having specifically in mind the history of recent physics, whose situation is admittedly quite peculiar and not really accounted for in the aforementioned accounts.

The dynamic core of a historical-epistemological view of science may be seen as an attempt to hold together the multiplicity of dimensions (theoretical, material, cultural, socio-political, economical, etc.) that constitute the interweaving of human deeds, as opposed to monocausal claims or interpretations. At a more basic and indeed epistemological level, this entails a "spurious" or "impure" relationship between the subject and the object of knowledge, mediated by a variety of historical circumstances and factors.

> "If there is a common trait running through the wide variety of positions presented, we would say that it is an "impure" approach to the problem of knowledge. No form of knowledge, not even in its paradigmatic forms proper to the modern natural sciences, is based on a pure relationship between subject and object, although philosophy of

> science has often espoused such a reduction - one that Fleck, one of the masters of a cultural-historical epistemology would reject as *epistemologia imaginabilis* with reference to the theoretical positions of early twentieth-century Viennese neopositivism.
>
> Between the knowing subject and the known object is always inserted a third mediating element. This is a fundamental and indispensable element, which justifies a wide variety of historical-philosophical, sociological and praxeological approaches. In the wake of some recent revivals of neo-Kantianism we might designate it as a dynamic a priori or, in the wake of some important French developments, a historical a priori. This can be connoted in more or less idealistic terms, as in the Kantianism of Marburg or in early Foucault, or more decidedly social and material, as in Marxist-style philosophies" (Omodeo et al. 2021, p. 91; my translation).

Speaking in such broad terms of subject and object may not suit everybody's taste: for our practical purposes, we can then rephrase it as follows. The historical dynamism thus claimed involves a focus on practices (by which I mean both experimental practices and conceptual practices, such as mathematical techniques or specific languages and so on) that, at a certain time and in a certain context, define, constrain, and help constitute the scientific object or model. As these practices become stabilized, spread, and become an integral part of disciplinary training at that time, bearing certain theoretical virtues or values (at the expense of others), they also have, clearly, a kind of reverberation or retroflexion on what is considered the subject of scientific knowledge, that is the exemplary scientist or scientific persona who, in a given field and at a given time, masters certain techniques, shares certain assumptions and notions, has a certain horizon of expectations, and so on. For example, as we shall see in Chapter 2, thinking of Wheeler's struggle with gravitational collapse and Schwarzschild singularities during the 1950s along the lines of today's way(s) of teaching and presenting those topics would lead (and actually led) to a huge trivialization and distortion of his efforts and aims: it is important to realize instead, at the very least, the relevance of his background in nuclear physics, how he brought new problems to the field by coupling geometric aspects to the fate of matter in extreme situations, and all that followed from it.

This sort of interplay between subject and object of knowledge admittedly requires a mobile form of attention, which is best exerted when there is enough archival material to trace and document in detail such a dynamic process. As for the analysis of its "mediating" factors, rather than invoking *ab initio* the big labels listed in the quotation above (from Marxism

to Foucault and so on), it is perhaps fair to say that, in the case of the history of last-century physics, especially when dealing with its conceptual aspects, mediations are often not explicitly addressed in their intertwinement with an "internalist" dimension. In a sense, the technical difficulty of the topics, in some cases, just suggested to "prepare the ground" for further considerations, while other scholars opted for purely externalist considerations. If the latter option, when self-contained, goes against the spirit of historical epistemology as outlined above, the former should not entail giving up on holding together and interweaving a variety of aspects and factors. Speaking in full generality about some kind of mediation or interference (whether political, economical, sociological, ideological, and so on) may not be that insightful: it is perhaps more fruitful, as a start, to tie stringent knots with reference to specific circumstances, trying to cogently show the effects and conceptual transformations of some intertwinement. Otherwise, the risk is that of falling into the aforementioned *epistemologia imaginabilis* or, more prosaically, into bland paraphrases of technical papers - paraphrases which have very little historical sense, apart from a few chronological labels scattered here and there, and it is legitimate to have doubts about their theoretical breath as well.

These considerations are clearly not limited to historical epistemology and recent physics: if we now wish to better characterize their nexus, we may consider paradigmatic the work by Jürgen Renn and collaborators on Einstein's Zürich notebook, thanks to which they reconstructed, in all its heuristic complexity, the path that led him to formulate general relativity (Renn 2007). Clarifying the genesis of a theory is certainly not the end of the story: no less important is the examination of how it was then further developed and employed by different communities, in a changing technological and sociopolitical context - for instance the Cold War, if we speak of the full blossoming of general relativity itself (e.g. Blum et al. 2016). Something similar holds for the contributions of Renn and his department regarding the genesis of quantum mechanics (e.g. Blum et al. 2017; Navarro et al. 2017; Blum, Jähnert 2022). Nonetheless, precisely because of the attention required by the examination (and "deciphering") of preparatory notes, of specific issues, and of well-defined historical conjunctures, this kind of work is not intended to entirely offer some kind of methodological recipe to be exported pseudo-algorithmically, at the expense of a detailed understanding of the case under consideration. If we then deal with more recent physics (from the postwar period onward), the even more rugged terrain certainly makes this kind of investigation no less difficult, largely because of the specialized level and intrinsic complexity of the research topics, partly also because of the proliferation, among a wider audience but even within scientific communities, of distorted and biased narratives. That is why, in recent times (2018), the first

group of the Max-Planck-Gesellschaft inherently affiliated with two institutes, the aforementioned Institute for the History of Science in Berlin and the Albert-Einstein-Institut (Max-Planck-Institut für Gravitationsphysik) in Potsdam, was created. The group's name, "Historical Epistemology of the Final Theory Program", must sound enigmatic to proponents of the crass sensationalism about "theories of everything" and so on: why bring a historical dimension into play when we almost have, or are in the process of finding, a set of magic formulae that would explain "everything"? Of course, the purpose was instead to examine the various failed or partially successful attempts at unification, a tendency which is undoubtedly central in the ambitions of recent physics; but also the opposite tendencies, which, by a complex interweaving of factors (as much theoretical as related to issues of prestige and funding of other branches of physics), began to vocally deny the possibility of deriving "everything" from an allegedly fundamental level. Given the kind of technical skills required to interpret the published papers and archival notes of scientists who have worked on frontier issues in recent years, but also to appropriately identify and frame the questions of interest, scholars with advanced specialization are needed; at the same time, however, in order not to fall into the kind of mere “paraphrasing” mentioned earlier, scientific-technical expertise has to be combined with a historical-philosophical approach. It is not a mystery that, today, training in the former does not typically encourage a refined sensitivity in the latter: in this sense, the creation of a kind of special unit at the intersection of two institutes of excellence in their respective fields seems a sensible and almost inevitable move, although not much imitated so far.

Nonetheless, it would be somewhat misleading to read the work of this group by theoretically overloading its approach with philosophical references as those showcased in the above quote. It would be better characterized as a *modus operandi* to deal with the recent history of physics: its aim is not only to add specific details to some scientific story, but also, if not mainly, to clean up or bracket (as much as possible) a large part of the narratives and notions peddled nowadays by many more or less popularizing books and papers, which tend to crudely back-project today's textbook knowledge onto what was done in the past. The risk is otherwise a pseudo-history that, heedless of questions such as "how and why" or "on the basis of what questions and practices", just connects some dots and thus evokes a parade of progress toward some suggestive - but still vague or ungrounded - idea entertained today by a certain subcommunity of physics. The task at hand is instead a step-by-step reconstruction by going through both the published works and the archival papers (preparatory notes, working notebooks, correspondence and whatnot) of a few appropriately chosen figures, keeping one eye on the

diachronic development of their thought and research, and another eye on their network of contacts and interlocutors, the contemporary or competing approaches, the set of practices and the changing *milieu* in which they were immersed. There evidently follows a strong emphasis on heuristics[2] and historical metamorphoses or transformations. To aim at such a kind of reconstruction does not only mean to place oneself from an active and dynamic perspective, in a kind of re-enactment of the past which is very different from looking at well-defined and already stabilized results. It is also a non-trivial hermeneutic operation, because, alongside the "deciphering" of technical aspects, it is necessary to be able to repeatedly suspend the methods learned today and their *current* links to other problems or specific areas; at the same time, it is that kind of expertise, gained in the present (roughly speaking), that allows us to move the first step in such a process and to identify interesting angles, instead of being engrossed with details and complications following which would not be so fruitful. To echo a distinction by Federigo Enriques, once we master a mathematical language and know how to apply its techniques and algorithms, it usually becomes, under the film of familiarity, "dead thought" (Enriques 1921, p. 13), but I would like to underline how the operation of reconstructing and following a heuristic trajectory may instead turn out to be a peculiar exercise in "living thought" and mathematics. That is the moment in which, not out of routine but thanks to our understanding of a specific case, we make use of our mathematical repertoire to shrewdly alter, as the situation requires, tacit or unthought-of assumptions, and we creatively develop those techniques in a more or less new direction. It is a fluidification of acquired schemata and practices: in this sense, the emphasis here placed on heuristics undoubtedly has in turn a creative component. It may also represent a useful exercise for those who are working in areas where mathematical techniques have become crystallized and standardly transmitted, without the awareness of why some choice was made instead of others: when things do not seem to work that well any longer, breaking out of specialized automatisms and digging deeper in more or less unaware assumptions can be an important resource.

Not that this kind of heuristic reconstruction must always, or mainly, be mathematical: obviously, there are scientists who are more inclined to sketch their exploratory strategies in strictly mathematical terms and others who prefer, first and foremost, a conceptual approach (Wheeler was among the latter). Nonetheless, a competent exploration of the mathematical level can be much more insightful than usually assumed by historians not particularly keen

2In order to avoid misunderstandings, I emphasize that by “heuristics” I do not just mean a set of thumb rules for problem-solving. such as Pólya’s famous *How to Solve It* (Pólya 1945), but the whole dimension of intellectual research and attempts – in other words, science *in fieri*.

on mathematics:[3] it is important to vindicate the importance of this kind of approach even in the realm which is seemingly least tainted by the dust of history.[4]

Having thus given some rough coordinates to situate this work in the varied landscape of historical epistemology, I would summarize the message of this section by insisting on the *modus operandi* for reconstructing the heuristics as explained above - not in order to endorse some historicist claim to narcotically portray the past, *à la* Ranke, *wie es eigentlich gewesen ist*, and once and for all, but rather to combine that close reading of sources with a type of mobile attention to the changes in scientific practices and reflections. If we have to speak of this as history, then, it should be "a theoretically demanding history of science" trying to satisfy three conditions: "(1) History of science requires a permanent reflection on the concept of history. (2) It demands an epistemological reflection on the historically changing forms of knowledge. (3) An intimate knowledge of scientific practice is necessary, be it more theoretically or more practically oriented" (Rheinberger 2018, p. 417). Here, however, I would also like to anticipate a further step that will be taken in the next chapters. If the reliance on historical and archival documents is a procedure inherited from works such as those mentioned above, it is also true that in the latter the heuristic dimension is, so to speak, an appendix aimed at explaining some precise scientific result or better illustrate some alleged "logic

3That is also the lesson in (Blum 2022), which identified and clarified the impact of a calculation mistake on Einstein's opinion about gravitational waves.

4I wish to recall here the work of Vincenzo De Risi, where the historical-epistemological dimension of geometry is masterfully outlined (e.g. De Risi 2016; 2018). As an early personal inspiration, also for the meaning that I attach here to heuristics, I cherish some teenage memories when I was eagerly checking the Mathematical Association of America website to check whether there were new entries of Edward Sandifer's *How Euler Did It* (then collected in two volumes: Sandifer 2007; 2015), even if it is debatable whether they can fully count as historical epistemology in the sense specified in these pages. Needless to say, heuristic reconstructions are not always possible, especially when we are faced with highly fragmentary sources and/or theoretical practices to be contextualized in frameworks very different from today's. All the debates and misunderstandings about Greek mathematics are just an obvious example. In these cases, there is a strong risk of imposing from above a scheme that seems to account for the fragmentary pieces of information, but that also distorts what, on the basis of other disciplines, we recognize as the practices and conceptions of those times. In other words, the "reconstruction" ends up being just one of those math or physics exercises coated with some historical ornamentation that can be found in textbooks. Enlightening in this regard are the remarks of Ken Saito (1998), who points to Wilbur Knorr's overall trajectory as the turning point in this kind of study. With special reference to Euclid's *Stoicheia*, Saito is also known for his "toolbox conception", which does not try to divine the heuristic genesis of the work, but to properly identify for which applications it served as a toolbox, as far more recently reiterated by (Wagner, Netz 2023). That is, after all, one way of breaking free from coarse back-projections.

of science". The way in which I will make use of Wheeler's notebooks and papers, instead, is more radical and less result-oriented: what I will try to reconstruct, as far as possible, is his thought process, situated in his time and context, no matter how unorthodox it could appear to prescriptive views of science.[5] This kind of operation is not always possible or meaningful, but in a case like Wheeler's - precisely because his work is not reducible to a list of results - it can prove particularly fruitful.

1.2 Interweaving complexity

If the previous considerations entail a peculiar way (or attitude) of approaching historical-philosophical issues within physics, I would add that, especially when dealing with Wheeler, there is a further corollary of these premises, which shall be relevant especially when dealing with his ideas from the 1960s on. Once the work of reconstruction is done, as explained above, and thus we have a heuristic trajectory "synoptically" in mind, the possibility appears of relating the history of physics to the history of philosophy, for instance, in a solid - and hopefully fruitful - way, cogently pointing out where the interweaving or interaction between physical and philosophical notions have occurred. This is very different from vaguely commenting about the philosophical interests of some physicist or using some formalism as taught today to argue for some old debt to a certain philosophy.[6] Indeed, this has also the advantage of avoiding those naïve and "maximalist" claims that sometimes accompany the purported role of some philosophy in the genesis of a certain scientific result, as if the impact such philosophy may have had on the heuristics of a single individual should imply that, by direct promotion to scientific "universality", the philosophical doctrine in question must henceforth be taught to all scientists as inevitable. This is most often pretentious and gets punctually frustrated, ending up increasing distrust between the two fields, or at most generating a few *idées reçues* and platitudes

5That is also why the focus on heuristics here should not be mistaken for the emphasis on "practices" that is fashionable to hear in relatively recent history of science (even if what I am suggesting definitely includes that as well). It seems fair to say that the "practices" scholars would probably never venture into the kind of operation we are going to do here with Wheeler's intellectual evolution – of course, also because it is rare to have such a rich documentation available for a scientist (see otherwise the previous footnote with reference to Saito).

6In this regard, a paper easily comes to my mind, (Guzzardi 2023), where it is clearly shown how starting from the generic assumption of Mach's phenomenalism, as if it were a philosophical doctrine that characterized his whole life, can lead to distorting - or simply wrong - claims about his early experimental activities.

that actually impoverish the complexity of the historical and theoretical aspects of the matter. The overall message will be very different in Chapter 4, where we are going to examine Wheeler's confrontation with nobody less than Leibniz.

If historical epistemology allows us to intertwine these dimensions in a peculiar way, it does not do so just as a more or less arbitrary methodology chosen by someone and applied to a case study with some disciplines involved. Its aims can be more ambitious: not just to provide insights on those intertwinings, but also to frame them within a larger and *longue durée*-based "architectonics of knowledge". Even the Einsteinian syntheses of the *annus mirabilis* 1905 - Renn emphasizes (Renn 2006) – far from being a series of solitary and sudden illuminations, emerged at the intersection of various subfields of physics, with their active structures or "architectures" leading them to graze or collide problematically. At that point, a far broader consideration of conceptual aspects and their development (as Einstein's case may show) is required than the more or less caricatured reduction of science to problem-solving. That is where a space for conceptual and partly historical reflection emerges and can be effective within science – hence Renn's emphasis on a sort of self-reflective dimension of science, so to speak, which, in more recent years, led him and some collaborators to insist, not without ethical urgency, on the question of the Anthropocene (Renn 2020). After all, what we have pointed out in the beginning about the "impure" relationship between subject and object in historical-epistemological approaches is enough to suggest that, from such perspectives, naïve dichotomies about “Nature and Technology” and their relationship, when considered as given once for all, are not acceptable and have to be problematized (the latter conclusion, in a quite unexpected way and with very different issues in mind, was also reached by Wheeler in the late phase of his reflections, as we shall see in Chapters 5 and 7).

Still, even if we do not make the "leap" from specific situations or episodes of modern physics to the Anthropocene, these considerations on a self-reflective dimension within science are an important point to claim, not just against pictures of the scientific endeavor that portray it as a big machinery which advances through the automated application of some phantom "method". What I intend to suggest is that, even if we stay within the history of physics and we chronologically enlarge the scope, we can see a few meaningful moments in which a scientist such as Wheeler, while facing some period of stagnation or "crisis" (even if we just take it, according to its etymon, as a moment in which we are required to make a judgment and thus to consider various options), resorts to the past to look for elucidations, legitimacy, inspiration. These may have seemed "distractions" to some of his

productive colleagues (to make a bit of a caricature), but such moments of pause allowed him to consider other possibilities, neglected presuppositions, and had a concrete impact on his research. These moments were not taken by Wheeler only when he needed new suggestions, but, in some sense, he even theorized about them in his own way, when dealing with anniversaries: Mendeleev's or Marie Curie's or Einstein's centenaries were not for him just a more or less conventional or specious celebration, but an actual chance - requiring effort - to deeply meditate on their legacy and on what followed, as well as to dig into the past or consider alternatives for what was going on in the present. Thus, without necessarily invoking the urgent gathering of all sciences in order to face the challenges of the Anthropocene, we can see in Wheeler's case and in his manifold engagement with history (Chapter 1) that the transgenerational concerns usually associated with today's ecological crisis are also present and can be highlighted in other ways.

If claiming that, in his late reflections, Wheeler himself, starting from the issues he had been scientifically facing for years or decades, reached a sort of historical epistemology would be a bit far-fetched, nonetheless there are many insights on his part (on the preconditions of knowledge, on the role of the observer, on historicity, and so on) that are close to some kind of historical-epistemological sensitivity. The truly important point is that these were not marginal considerations, but had a vital nexus with his scientific research, as will be abundantly made clear, mainly in the second group of chapters. At the end of the present work, historical epistemology should then appear not as a methodological choice that I made more or less arbitrarily, but almost as an inner necessity, or at least invitation, coming from the subject matter itself.

More in general, it is thus important to identify and call attention to episodes in which, *within* science itself, the great collective machinery is momentarily defused, and previous paths not taken, or possibilities left unexpressed, are reevaluated. Taking note of such episodes, we can better realize that historical epistemology, if also accompanied by appropriate scientific expertise, is potentially capable of coming down from its metalevel of observation and analysis and, even today, interacting directly with scientists.[7] In this sense, it could be hoped that historical epistemology, in the flexible sense outlined above, would be configured as a place for serious encounter and debate, touching upon a variety of dimensions (all those that historical epistemology tries to keep tied together) which are otherwise left to

7A dialogue could perhaps be established with Hasok Chang's idea of a "complementary function" of philosophy of science, which "can seek to generate scientific knowledge in places where science itself fails to do so" (Chang 2008, p. 19). Of course, good intentions aside, the modalities of these attempts should be specified: an option is the one we are outlining in these pages.

themselves, excluded by scientists' routine work or put together in superficial, fashionable and sensationalistic ways that end up being counterproductive. One way to incentivize that kind of episode would consist, in concrete terms, in offering practicing scientists (or anyone else who feels the need to dig into why certain methods and procedures were adopted) a place for study and fruitful exchange, without a lifetime commitment to historiography or academic philosophy. A task of historical epistemology would then be to coordinate the various forms of knowledge and to know how to hold them together.[8] However, in front of such a complex task, there is no point in denying the risk posed by easy, superficial, and fashionable formulations, that can be reiterated (for a while, at least) *ad libitum* thanks to mass-trained people who are decidedly lacking in that synoptic and genuinely multidisciplinary gaze invoked above, when not lacking in a historical perception *tout court*. Nor can it be neglected that the pitfalls of a scientistic and ahistorical mentality, as well as the narrowness of institutional evaluation, accompanied by obsolete or limiting subdivisions (in some countries more than in others), are serious obstacles to those who would even nurture the intent to start such a kind of study. Suggesting that Wheeler's case can provide an answer to these issues would be, of course, a ludicrous exaggeration - nonetheless, following his vicissitudes may allow us to see something worth considering, where "see" has a meaning that will be specified in the next section.

8We should also notice that framing all this in terms of "mediating between disciplines" can be partly misleading and is somehow only derivative: precisely because of the *modus operandi* here outlined and all the caveats against back-projections, we should not think too rigidly, or primarily, of "disciplines" as static blocks – as they became defined more or less during the 19th century. Otherwise we would just fall into a rhetoric of promoting interdisciplinarity/transdisciplinarity, without however gaining many insights. We are instead interweaving complexity little by little, knot by knot. That is also why, even if – *prima facie* at least – the *modus operandi* of reconstructing heuristics may seem agnostic about an "episteme" or an underlying (and shaping) structure, there is actually a strong commitment to a Foucault-like "not anything can be said or done in any way at any time". While at first the emphasis on heuristics may sound like "anything goes" (as long as documented), *de facto* we are assuming the existence of some sort of underlying episteme, although without making (for now) strong statements about its actual features. To play a bit with words, this use of heuristics seems to imply also a heuristic level in investigating a certain episteme as well: in other words, there is much more interplay between the exploration of the individual case and the unveiling or outlining of some sort of episteme at the collective level. In the next section we will precisely address broader uses of what may appear as an individual focus or microhistory; after all, we have already pushed back any charge that this is a naively and merely individualistic history of science.

2. "Nichts zu sagen, nur zu zeigen": following Wheeler's worldline

This project actually began in a form quite different from the one it gradually assumed. Its intended title was along the lines of something like "Transfers of methods in quantum gravity". The emphasis on heuristics, the interest for analogical transfers, and the "archaeological" exploration of a situation which is still open and *in fieri* were already there, but then the actual encounter with John A. Wheeler's notebooks and papers simply *happened*. For sure, a consideration of his work and positions was already planned, given the prominence of his name in the areas in question; however, the individual focus on him should not be considered as a sort of "restriction" of the subject matter to an eminent figure, with the apparently unavoidable shift to a biographical approach. As already said in the *Preface*, however, this is not a systematic intellectual biography of a single scientist. Following Wheeler's "worldline" - if we adopt the metaphorical usage of Gamow (1970), who incidentally was a congenial friend to Wheeler - has not necessarily an individualistic connotation. Always close to the main developments, usually with an interesting and unusual angle to offer, Wheeler was also an exceptional witness who, with his long life and career, spanned almost a century (1911-2008). If that is not enough, he himself was well aware of the importance of historical documentation and research, leaving an archive which is a goldmine for whoever is interested in 20th-century physics and more than that, as shall be explained in the next pages. If today, not rarely, the name of the individual scientist - decorative purposes aside - gets watered down into a generic "median view" of what was circulating in a certain scientific community at a given time, that is certainly pretty far away from the content of the next chapters. I do not intend to put forward some romantic defense of the individual in science: rather, these remarks want to point out the frequent lack of any vital link between monolithic and impersonal attitudes about "what science is" and the mental life of its actors, simply dismissed as "psychology of research", "mystery of creativity" or whatnot.[9] In that gap there are whole

9Since the name of Charles Sanders Peirce will return in the last chapters, due to some affinity between him and Wheeler (and the latter's explicit interest in him), I would like to draw here, at the methodological level, a quite meaningful analogy between Peirce's anti-intuitionist stance (and subsequent considerations about abduction) and our focus on heuristics contra its dismissal as psychology of research or mystery of creativity. The starting point is Peirce's notion of "abduction", which, after all, seems to include a heuristic component (that of generating some hypothesis) that is often seen as exceeding the tasks of formal logic. "Peirce's treatment of abduction makes explicit its indebtedness to traditional debates on the scope and limitations of inferential reasoning. [...] [Previous logicians] had already understood that deductions and inductions alone do not suffice to give a complete account of our reasoning faculties, but they mistakenly assumed that the only alternative to these two kinds of reasoning is a non-inferential or intuitive faculty, one that brings about new cognitions in an immediate

conceptual worlds waiting to be explored; preparatory notes of scientists, testifying to a variety of influences, and allowing us to follow the genesis of ideas and results while they are still *in fieri*, before their crystallization (if any) in the contents of a textbook. In various contexts, all this does not seem even to be suspected as investigable (despite the fact that somewhat related archival research is regularly practiced with reference to other classes of thinkers, not necessarily more decisive or more profound). The urgency of confronting all these ignored aspects should be self-evident today, provided that philosophy and other disciplines (when not history itself!) wish to seriously relate to the physicists' thoughts, instead of relying on third- or fourth-hand news or cheap sensationalism. For such a task, an individual perspective may not be, admittedly, the best suited: it might be reminiscent of the old stories about "great men" and related visions of history and science. But that does not mean, of course, that exceptional or impactful individuals have to be ostracized from the writing of history - the point is rather to critically reflect on how to address their vicissitudes, how to employ their cases, what lessons to extract. In this sense, a problematization of an individual perspective is due: after all, at least ever since Canguilhem (Rheinberger 2007), the recognition of the relevance of various time scales for different kinds of analyses in the history of science has been clearly put on the table, as much as the watchword "*longue durée*" nowadays does not always get associated with a gaze capable of discerning, *à la* Braudel, different time scales and choosing the pertinent ones for what we intend to study.

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fashion. Peirce, on the contrary, wished to defend the existence of abduction as an outright logical inference, which obeys precise logical rules and therefore does not partake of intuitive immediacy" (Viola 2016, p. 252). What is important to underscore, however, is also a sort of diachronic dimension: "Later on, Peirce gradually stopped seeing his three classes of inferences as clear-cut syllogistic forms. Instead, he construed them as three stages of a broad inferential mechanism, which underlies all of our cognitive and perceptual processes. This inferential mechanism has an eminently practical nature, and runs in great part in a tacit way. Far from needing explicit beliefs to be formulated in the mind, it mainly hinges on the role of habits, which are the practical, embodied, and sometimes pre-conscious equivalent of the major premise of a syllogism, "if A then B". (That is, habits link a set of stimuli, or observations, to a set of "practical reactions".)" (ibidem, p.256). At this point, we have the elements to characterize such broader inferential processes, without falling into some formalistic *epistemologia imaginabilis*: "The theory of logical inferences inaugurated in this second phase of Peirce's thinking may therefore be called an *enactive* one, in the sense that it is realized in (and undistinguishable from) the manipulative and explorative activities of subjects within their environment" (ibidem, p. 257). I would say that Wheeler's notebooks and his archival papers, which have left so many "conventional" thinkers baffled, allow us to reconstruct those broad inferential mechanisms and trace the process by which he enacted them. In this sense, Peirce's perspective can synergically interact with historical epistemology; after all, his reflections about the uses of history and his confrontation with the history of science (Viola 2020) do not represent a minor topic.

After insisting on this, then, it is necessary to spend some words about the intended use (or one of the possible uses) of Wheeler's "worldline". Carlo Ginzburg, in *Latitude, Slaves, and the Bible: An Experiment in Microhistory*,[10] chooses to study the life of Jean-Pierre Purry, a little-known 18th-century Calvinist entrepreneur from the Principality of Neuchâtel (Ginzburg 2005). As such, Purry is clearly a character who resonates with some of the features identified by Max Weber in his famous *Die protestantische Ethik und der Geist des Kapitalismus* - were it not that he represents a challenge to other ones as well. At this point one may think of using Purry as a counterexample to a general thesis such as Weber's, or maybe even as an example for a reconsidered general assertion concerning some abstract "type", like the one outlined by Weber. What Ginzburg does, however, is quite different: further details are not of interest here, but the whole operation should not be regarded merely as making leverage on a counterexample in order to undermine Weber's thesis and possibly open the door to some other general statement. It is rather a way to *see* what Weber saw when he formulated his powerful ideas and what he was somehow able to catch with them, but, at the same time, to see their deficiencies, when considered as too strong or rigid a statement. "The particular narrative is exemplary not in the sense of its being typical but in that it is representative for the situation. Thus Ginzburg sharply differentiates his generic approach from idealized models like Weberian ideal types", notes M. Norton Wise (2016, p. 357), who adds: "Here again, we can learn a great deal from Ginzburg's historiography about the function of narrative as an investigative tool".

The case of Wheeler, because of the features already outlined (such as his being close to crucial events of 20th-century physics, but often from an idiosyncratic and frequently fruitful angle),[11] allows whoever follows his track to come across different and highly important situations. It seems to me that, in certain periods at least, he can be used as the analogue of Ginzburg's Purry

10In turn inspired by Erich Auerbach's 1952 discussion of the Goethean notion of *Weltliteratur* and the need for concrete *Ansatzpunkte* to reconstruct global processes from the particular to the "general" (Auerbach 1969) – perhaps not unlike that gradual and careful intertwining and restitution of complexity addressed above. Of course, the horizons of *Weltliteratur* have changed since Auerbach's time and, even if there has been a revival of interest in that work of his, also thanks to Ginzburg, methodological criticisms have not been missing. Some of them may be relevant to our case as well, all the differences between the fields notwithstanding: as Moretti (2022) emphasizes, such an approach may lead to fascinating suggestions or even powerful intuitions, but it often sacrifices a solid conceptual scaffolding and does not provide a reiterable method. Even if that is not necessarily a shortcoming, and we could object to that by vindicating an "artistic" element beyond method, as Auerbach did, or, speaking about the history of science, the role of "connoisseurship" underscored by Heilbron (2007), what we are going to do here is quite different. Yes, we are going to make use of traits of Wheeler's journey as *Ansatzpunkte* to move towards a more general picture, but we are also going to preserve the tension between Wheeler's peculiarities or original viewpoints and the rest of the community of physicists.

11"In the twentieth century theatre of physics, John Wheeler has stood at centre stage but always just out of the spotlight" (Galison 1999).

to ponder over general theses on the rise of quantum gravity approaches or issues in non-empirical fundamental physics, for instance. This allows us to appreciate some insights of existing views about these topics, without being blind to their shortcomings, and to see what they are capable of showing, and maybe why they show it, without however dismissing other aspects as mere *Staub der Geschichte*.

> "In the social sciences, theory is often tacitly identified with a broad approach *à la* Max Weber, and microhistory with a narrowly focused attempt to rescue from oblivion the lives of marginal, defeated people. If one accepts these definitions, microhistory would be confined to a peripheral and basically atheoretical role that leaves the dominant theories unchallenged. The case of Jean-Pierre Purry, that early prophet of the capitalist conquest of the world, stands a chance of knocking down some of the barriers thought to divide microhistory and theory" (Ginzburg 2005, p. 682).

In this sense too, the reconstruction of Wheeler's "worldline", as has been made abundantly clear, cannot be regarded as mere history or mere biography. What we will be able to "see" following his trajectory, of course, will become clearer in the process of reading the various chapters. For now, it is helpful to start introducing a rough but meaningful tripartition of Wheeler's path and see how even these first basic elements can lead us to some preliminary considerations on Wheeler's relationship with other scientific fields and philosophy.

Following a suggestion offered by Wheeler himself (Wheeler 2000, p. 64), we can consider three phases of his career: the first, which from the early days goes until the early 1950s, is associated with nuclear physics, albeit in a very broad sense. The second, which from the early 1950s goes up to the early 1970s, sees Wheeler refocusing his interests and devoting himself to dusting off and developing what he considered the main legacy of his mentor Albert Einstein, namely general relativity, of which he became one of the main authorities: in Princeton he led a research group of fundamental importance for the birth and early development of relativistic astrophysics (in which context one must cast his role as godfather of black holes). Finally, the last phase of his career, from the mid-1970s to the 1990s (even if there is some bibliographic entry even in the new millennium), is usually put under the aegis of "it from bit" and quantum foundations, but is actually characterized by a remarkable multiplicity of transdisciplinary dialogues with prominent figures, largely still unexplored, all aimed at the search and exploration of ideas that would allow him to glimpse a deeper level of the physics available back then.

Aside from the tripartition *per se*, which would be enough to suggest Wheeler's variety of interests, what can be already pointed out is the way in which his investigations, far from simply changing field of research, gradually

grew in scope and ambition from germinating questions and ideas that accompanied him for decades, across areas which can be considered quite disparate. This has a meaningful corollary: to properly understand the visionary and futuristic suggestions of the last period, for instance, one must keep in mind that those were not sudden and bizarre proclamations (which, placed in the mouths of less prestigious figures, would probably be dismissed by the scientific community as undue metaphysical speculations or worse), but the last link in a series of conceptual metamorphoses that have spanned a good part of the physics of the last century. As will be properly shown, "it from bit" and the fundamental role of quantum information, for instance, are not the oracular responses of some visionary who intuits the "secrets of the universe", as some supposed popularization of science punctually seems to suggest while addressing infatuated audiences. Rather, Wheeler's overarching trajectory is that of a young man who, fascinated by natural phenomena and technical devices (see Chapter 5 for his early background), first ventures (not without some theoretical breadth) into specific issues which at the time were at the frontiers of science, such as nuclear physics, and then gradually broadens his fields of inquiry, from the extremely small to the extremely large and back, and finally questions deeper (or even “metaphysical”, but in the sense to be outlined in a moment) principles. From this point of view, it is not difficult to see similarities with the speculative itinerary famously and somewhat archetypally evoked in the first book of Aristotle's *Metaphysics*: first the initial "thauma" in front of the marvels and mysteries of the world, followed by an extensive investigation of "tà physiká", to finally reach questions of principles beyond that, "metà tà physiká". This is a sense of “metaphysics” which is clearly different from those who assume from the very beginning some separate and transcendent world and, from that, pretend to derive "tà physiká".[12] We shall return to this “philosophical” reading of Wheeler’s worldline in Chapters 6 and 7.

Now, without trying to attribute to Wheeler a cultural background which he did not possess, and which he acquired in a peculiar and partial way only at a decidedly advanced age, we may still say that this is already enough to make Wheeler's overall development at least philosophically intriguing. There is, moreover, another "philosophical" aspect which is intrinsic to his activities, especially the later ones: it is worth emphasizing the always questioning dimension of Wheeler's bold proposals, even when not accompanied explicitly by question marks. After all, the importance of questioning is constantly

12“Metà tà physiká“ following Andronicus of Rhodes, obviously. Overall, I am also thinking of partly similar considerations by Giovanni Cerri, in his relatively well-known introduction to the *Perì physeos* of Parmenides, even if the evocation of Stephen Hawking mainly seems a concession to folkloristic pictures of contemporary physics (Cerri 1999, pp. 67-69).

underlined by him, as we shall see in Chapter 1, with reference to his inspiring example, Niels Bohr, and like him, for decades, Wheeler performed a truly "maieutic" function towards students and collaborators, continuing to offer fruitful suggestions. These are aspects of scientific activity that are much more elusive than those which monopolize attention around "results" or procedures that follow a protocol and regularly leave material traces. As will be repeatedly discussed, in this case we can however study them since Wheeler himself left us ample material to better (re)capture all these heuristic dimensions.

3. Wheeler's engagement with history and philosophy: a few caveats

As already anticipated in the *Preface*, there will be specific chapters devoted to Wheeler's relationship with history and philosophy, and to the peculiar uses he made of them. Nonetheless, it seems appropriate, both because of the idiosyncratic nature of his operations and in order to stay in line with the methodological premises of historical epistemology, to offer a few general caveats at the outset, and then to examine the specifics when the time comes. At first glance, Wheeler's way of relating to both history and philosophy (and in both cases I do not imply exclusively “of physics” or “of science”) can be characterized in terms of a spirited, even jocular dilettantism - precisely in the original sense of someone who takes *diletto*, delight, in tapping into areas of which they have no conventional and systematic expertise. Moreover, as will be reiterated, Wheeler did not have a kind of education behind his back like Heisenberg or Schrödinger did: his cultural-historical and philosophical references were in a sense conquered by him later in life, often on the basis of specific questions or curiosities. This should not be confused, however, with that sort of intellectual “surplus” that some of Wheeler's colleagues, in the age of mass-mediatic “scientific stars”, like to flaunt by repeating notions that are, in truth, often dry and rather anodyne or banal. When Wheeler steps outside his own areas of expertise, one can clearly sense the flicker of the amateur, who draws here and there in an unconventional but intelligent and creative manner. Rather than suggesting assiduous and well-ordered readings, diligently memorized and then poured out from his pulpit, Wheeler leaves the impression (corroborated even by simply looking at the references of his late articles) of a voracious as well as varied perusing of books. Here is already *in nuce*, or at least *in potentia*, that incessant unhinging and rearranging of disciplinary relations and traditions which is so peculiar of the late phase of Wheeler’s thought. We may also mention that such a relation with books was definitely fostered by the fact that John was the son of Joseph Lewis Wheeler,

whom some have gone as far as to call “the most important American public library director” of the first half of the 20th century (Wyllys 1993, p. 327), and had also the example of other family members who worked as librarians.

In general, both Wheeler's historical and philosophical references are to be framed within a relationship with the past that, unlike that of many scientists (and not only scientists) of recent times, does not consider it as an inert and dusty archive, perhaps punctuated with a few monumental highlights, nor as a graveyard of dead theories or similar amenities, which actually tend to reveal a pseudo-historical mindset (as if it were an abstract space of possibilities) rather than an authentic historical perception and understanding. After all, the very idea behind “daring conservatism”, Wheeler’s heuristic methodology that will be examined at length in the next chapters, is that the past still has an untapped potential, waiting to be unlocked, and that it can offer lessons which are still unexpressed or not yet fully appreciated. What is often overlooked, especially in popular depictions of Wheeler, is that he was a veritable two-faced Janus: he did not limit himself to visionarily pointing to the future, but always did so by looking at and indeed delving into the past. That is very different from those colleagues of his who, resting on their laurels, decided at some point to diligently tell the public “their” version of the history of Western science. In Wheeler there is in fact no scholasticism toward the past, nor is it a learned pastime or a “third mission”: history is to all intents and purposes a cognitive resource that we can draw on and transfigure according to new circumstances. For this reason, when trying to interpret the meaning of his often surprising and sometimes sibylline (or at any rate idiosyncratic) references, it is necessary to clear one's mind of naïve prejudices about ideas or problems that are supposed to remain invariant like neatly parceled packages across ages, or about authors whose name is supposedly enough to univocally evoke their traits. In other words, it is better (or, if nothing else, helpful) to keep what has been said above about historical epistemology in the background and to realize that Wheeler's “Leibniz”, or even “Einstein”, are not *the* Leibniz or *the* Einstein of some historiographical consensus (in reference to which using the determinative article would be in any case an approximation). The task consists rather in understanding how those names recur in Wheeler’s writings and notes, usually with remarkable internal consistency, as a kind of placeholder. Knowing the “common” or standard reference is certainly a prerequisite and an indispensable aid, but it can also prove to be an obstacle if one closes oneself off in the “proper information” one already possesses about the topic and thus mistakes the Wheelerian references for some superficial or “wrong” name-dropping.

In some cases, these tricky references condense around what we could really call a conceptual character, or (to borrow one of Wheeler’s expressions

that we are going to use many times) an “intracranial colleague”, while in others they remain at the level of a placeholder for an idea, almost a sort of (more or less vague) principle. Whichever the case, however, it is necessary to consider these placeholders in both a diachronic and a synchronic perspective. By the former I mean their recurrence in Wheeler's notes and writings, with a recognizable and sometimes variable function, but nonetheless with an internal logic that can be made explicit. By the second I mean their interweaving with the specific issues Wheeler was addressing at a given time, the analogies he was attempting, and so on. In this sense, there is an actual intertwinement between the succession of themes or problems of his scientific career (relatively easy to convey with intersubjectively recognizable words), and his personal, idiosyncratic thoughts always in the process of maturing, with some of its traits enduring, some others metamorphosing. This is obviously a much more elusive and complex task than, say, documenting the “influence” of a certain philosopher or philosophical current on him, or perhaps some debate he had with philosophers of science in his day. Here one has to reconstruct his thought at a decidedly more germinal and transdisciplinary (or perhaps better: pre-disciplinary) level, and that is possible with accuracy and cogency if there is a wealth of archival material as in Wheeler's case (as we have already remarked, this is not just a lucky contingency, since he himself was aware of the importance of leaving documents for this kind of research). Nonetheless, it is also a task that can be far more rewarding and enlightening than a game of labels: thanks to some historical-epistemological perspective and by giving proper depth to the development of scientific thought, one can indeed search for and find philosophy among "the folds of science", to echo Geymonat's expression, in places where the gaze of many did not even seem to suspect that something could be found. As explained when we were speaking about Wheeler's “worldline” and the stimulating parallax effect it can provide, this is also a peculiar stretching exercise of concepts and, in a way that will become even clearer in the second part, we could very well adopt Wittgenstein's words:

> “What I give is the morphology of the use of an expression. I show that it has kinds of uses of which you had not dreamed. In philosophy one feels *forced* to look at a concept in a certain way. What I do is suggest, or even invent, other ways of looking at it. I suggest possibilities of which you had not previously thought. You thought that there was one possibility, or only two at most. But I made you think of others. Furthermore, I made you see that it was absurd to expect the concept to conform to those narrow possibilities. Thus your mental cramp is relieved, and you are free to look around the field of use of the

> expression and to describe the different kinds of uses of it" (Malcolm 2001, p. 43).

Wheeler himself, after all, however much he personally interacted with or was aware of figures such as Popper, Kuhn, Grünbaum, Shimony, or Stachel, does not appear to have been particularly attracted to philosophy of science in the specialized sense that was gradually developing – as he stated in an interview,

> "Clemenceau, French prime minister in World War I, said that war was too important to be left to the generals. He took control of the situation. And one could say that philosophy is too important for science to be left to philosophers. But there are two extreme points of view. There is the point of view of a man who describes the philosophy of science as a tin can tied by a string behind the automobile of science. And while science goes on quietly, this tin can clatters on the road and is the one making all the noise. That is one point of view. But the other point of view is much deeper. Thomas Mann, in his lecture to celebrate Sigmund Freud's 80th birthday, said, "Science never takes a step forward until philosophy authorizes and encourages it to do so...." Well, you can choose between these two points of view!" (Bičák 2009, pp. 688-689).

Here again, then, we shall try to conform methodologically to features or inclinations already present in the subject matter: we will thus give it a voice and make explicit some of its remarkable lessons or suggestions, rather than sacrificing it on a Procrustean bed like a cherry-picked case study. It is therefore time to start looking in more detail at the ways in which Wheeler made use of the past.

Part I

You must say something new and yet it must all be old. In fact you must confine yourself to saying old things – and *all the same* it must be something new!
– Wittgenstein, *Vermischte Bemerkungen* (1980, p. 40e)

1. Wheeler the Storyteller

In this chapter we are going to examine Wheeler's peculiar relationship with the past, his multifaceted uses of history, some salient features of the documents he left in his archives (from which we are largely drawing upon), and his portraits of Bohr and Einstein, which are essential to understand the way he framed his own research projects from the 1950s on.

Was Ihr den Geist der Zeiten heisst
Das ist im Grund der Herren eigner Geist
In dem die Zeiten sich bespiegeln.
– Goethe, *Faust*

1. Personal experience and oral community

In 1936, shortly after Wheeler returned to the US from Europe, where he had fallen under the lifelong spell of a very special figure – Niels Bohr –, Walter Benjamin was writing:

> "Familiar though his name may be to us, the storyteller in his living immediacy is by no means a present force. He has already become something remote from us and something that is getting even more distant. […] Viewed from a certain distance, the great, simple outlines which define the storyteller stand out in him, or rather, they become visible in him, just as in a rock a human head or an animal's body may appear to an observer at the proper distance and angle of vision. This distance and this angle of vision are prescribed for us by an experience which we may have almost every day. It teaches us that the art of storytelling is coming to an end. Less and less frequently do we encounter people with the ability to tell a tale properly. More and more often there is embarrassment all around when the wish to hear a story is expressed. It is as if something that seemed inalienable to us, the securest among our possessions, were taken from us: the ability to exchange experiences" (Benjamin 1968, p. 83).

As many others (back then as well as more recently), Benjamin did not seem to conceive the possibility that a storyteller could make an appearance within the practices of science. In this chapter, instead, we will see how that fits the role played by Wheeler in the community of physics almost like a glove. We

will first examine his general attitude towards history, then discuss the nature of the primary sources I am drawing upon, and, after that, a couple of sections will be dedicated to Wheeler's two "mentors",[13] Bohr and Einstein – the pillars of his epic of unification. It would be easy to limit ourselves to considering the reception of Bohr and Einstein only in terms of the propositions or formulae explicitly taken up by Wheeler. In doing so, however, the result would be rather trivial: we would merely comment here and there that he was not a "philologically" unimpeachable witness, or we would be disappointed by the absence of particularly deep (and faithfully reported) dialogues with them. If we realize instead that names such as Einstein and Bohr recur frequently in Wheeler's texts and speeches not as conventional references, but almost as conceptual characters that he was evoking with specific functions and aims, in part out of his own personal experience and in part out of the grand vision he was pursuing at a given moment, then a far richer and deeper analysis is possible. We will thus examine Wheeler's relationship with Bohr and Einstein and highlight, as if in a sort of "psychobiography", which traits and lessons he claimed to have taken from them. To use again Benjamin's words, "the storyteller takes what he tells from experience – his own or that reported by others. And he in turn makes it the experience of those who are listening to his tale" (Benjamin 1968, p. 87). After all, if we just take another look at the years delimiting Wheeler's life (1911-2008), we can easily realize that, being active from the early 1930s to the 1990s, he did not only cross much of 20th-century physics as a first-row witness, but also acted as a relentless mediator between different generations. Mediator, as I mean it, is not just a guarantor for some sort of continuity, but also someone who puts in touch different "strata" of ideas, expectations, and scientific practices – thus possibly being in a privileged position to problematize widespread assumptions, novelties and fashions, and induce a change in perspective. It is hard to think of anyone better suited than him to be the *trait d'union* between the age of the Einstein-Bohr debates and today's situation in quantum gravity. In order to understand how Wheeler did it, it is first necessary to focus on his peculiar relationship with the past and on how he created a unique and fascinating mixture of personal experience, historical pathos, rhetoric and heuristics.

In these quasi-historical narratives (inasmuch the "quasi-" could also be applied to "narratives", since, quite often, we are not dealing with explicitly

13During an interview (Wheeler 1988a), Aaserud took for granted that Bohr was seen by Wheeler essentially as his "mentor". Curiously enough, he replied: "It's odd, I never thought of him as a mentor at all", then adding: "I thought of our not facing each other, but facing a common difficulty, to try to understand something". Aside from partly extemporaneous shades of meaning, we will see quite in detail the relationship between the two and how the word is not misplaced. "Mentor" as referred to Einstein, by the way, is instead in the title of a very late contribution (Wheeler 2006).

continuous tales), Wheeler will emerge as a "super-character", meaning that he represents at the same time the narrator, a character in his own right, and a hidden character which projects some of his own features onto others. The point, clearly, is not the historiographical soundness of what Wheeler was saying – even if that has not to be quickly dismissed, either (as we shall soon discuss) –, but its epistemic productivity, so to speak, within the scientific communities he was an influential part of. There would be plenty of examples, but, by focusing on the two major figures of Wheeler's personal experience and imagination, it is simpler to understand his process of creating the above mixture, using it in part for his own self-legitimization, and displaying a remarkable ability to convey the feeling of belonging to a tradition and to direct, with specific choices, the research interests of a group. Bohr and Einstein, moreover, are absolutely central to Wheeler's activities from the 1950s on, both content- and method-wise: identifying what Wheeler took (or claimed to have taken) from them, and thus what he meant, more or less implicitly, when he was referring to them, is also necessary to prepare the ground for the following chapters.

A friend of Wheeler's and himself a distinguished physicists, Viki Weisskopf, once stated in clear terms that

> "Like every intellectual pursuit, physics has both a written and an oral tradition. Intuitive modes of thought, inference by analogy and other stratagems that are used in the effort to confront the unknown are transmitted from one generation of practitioners to the next by word of mouth. After the work of creation is over the results are recorded for posterity in a logically impeccable form, but in a language that is often opaque. The beginner is expected to absorb this written tradition and only the survivors of this trial by ordeal are admitted to circles there the oral tradition is current. We could only hope to strive toward our goal by leaning heavily on the oral tradition. This is not meant as an apology, for we believe that this tradition plays an essential role not only in the creation of physics but also in the search for a deeper understanding" (Gottfried, Weisskopf 1984, p. vii).

Wheeler's rich documentation and heuristic transparency – as well as his peculiar communicative style, of course – allow us to get unique insights into this world. The emphasis on the human aspects of science, while dealing at the same time with the *contents* of frontier speculations in physics, may sound like an unusual couple: after all, Wheeler himself, in later years, would occasionally recall Marie Curie's sentence, "Physics deals with things, not people" (e.g. Wheeler 1990, p. 320). However, what is particularly intriguing

in his trajectory from the mid-1950s to the 1980s is that his *modus* (or better *modi*) *operandi* – his roles as a mediator, storyteller, group leader, organizer, teacher, all characterized by conviviality – are gradually becoming entrenched within his own physics and epistemology, and thus end up contesting Curie's seeming truism. We will document and discuss this in the chapters of Part II, but it is first necessary to understand its roots.

2. Wheeler's uses of the past

The extent to which Wheeler engaged with history and his uses of the past are certainly extraordinary when confronted with physicists, or more generally scientists, of his time. On the surface, however, his historical references may seem deceivingly simple, or even puzzling – but he was not so naive about historiography, and not just that of science. As we have said about philosophy, he may have not been refined about it, due to his education, but he gradually tried to compensate for that. Moreover, his wife and companion of a whole life, Janette *née* Latourette Hegner, had been trained as a historian, and that certainly had some impact.[14] Another completely neglected – but certainly not negligible – topic is the more or less mediated impact of the extremely distinguished German-speaking *émigrés* at Princeton, from Einstein himself to Thomas Mann, from Erwin Panofsky to Wolfgang Pauli, from Kurt Gödel to Hermann Weyl.[15] To do justice to the actual complexity of Wheeler's historical references, it is useful to recall Nietzsche (2015 [1874]) and, for the sake of simplicity, introduce here, on the blueprint of the *Second Untimely Meditation,* a tripartition of the uses of history into "antiquarian", "monumental", and "critical". Of course, the fact that all three of them can be found in Wheeler's texts, occasionally at the same time, makes them already a bit different from Nietzsche's, but that is not the point – these are useful labels that can easily convey some important trait.

Let us start with the "antiquarian": the preservation of the past for its own sake. A recent study by Anke te Heesen (2022) highlighted the role that Wheeler, during the 1950s (when he was still very active also as a scientist), had in setting in motion one of the largest projects in history of science of the last century, the famous *Sources for History of Quantum Physics*, then led by Thomas Kuhn and others. That Wheeler, together with van Vleck, was such an important promoter is in general hardly appreciated, and he himself does not

14More specifically, she had studied the Italian *Risorgimento*, but was also a great admirer of classical culture – one of the reasons she (and Wheeler too) was fond of Heisenberg, as one of their sons confirmed me.

15Some guidelines are offered in Appendix B, also with reference to the *Kahler Kreis* and the broad historical views therein discussed.

mention it in his autobiography (Wheeler 2000). In his archives there are, of course, many folders documenting it, as well as the "Preface" he wrote to the whole project (Wheeler 1971a). Among Wheeler's main motivations we could mention a feeling of *vanitas* (Wheeler 1963a): the creators of 20th-century physics were dying or getting old – Planck had already passed away, followed by the premature deaths of Kramers and Fermi, then Einstein, Weyl,[16] Pauli, and, at the beginning of the new decade, Schrödinger. Bohr's turn would be in October 1962, right after a quite heated interview with Thomas Kuhn (Bohr 1962); shortly before that, Wheeler himself[17] had insisted on moving the base of the project from the US to Copenhagen.

If Wheeler's respect and devotion to his predecessors and inspirers are easy to understand, that does not make his organizational efforts less remarkable, while he was at the same time busy revitalizing a branch of physics which he had only recently started to study seriously, teaching it, supervising students, developing his own creative view, and being a leader of military projects. Still, some other aspects of his involvement with the *Sources* project are even more intriguing. For instance, he got the idea of the format of the interview by reading the newly published (1953) *The Paris Review*, a literary magazine which also contained a section called *Writers at Work.*[18] As the name suggests, well-established writers – the series would include illustrious names ranging from Borges to Eliot, from Nabokov to Calvino – were interviewed by younger writers about their creative process. By analogy, Wheeler was envisioning something similar coming from the mouth of the creators of quantum physics – and time was in short supply, before such testimonies went lost forever.

Similar efforts were made by Wheeler to promote historiography at various levels, we could add: he did it here and there in the middle of other activities, but with regularity and commitment, as his archives can abundantly testify. Just a few examples, some of which we will discuss later on: Wheeler himself, while being Lorentz professor in Leiden in '56, managed to get important documents such as the Einstein-Ehrenfest correspondence and went to talk with people that had met Einstein there; he was also an early promoter of the edition of all Einstein's papers, even if the project was delayed for many years, and later he would be part of the editorial board, as well as actively look for historians to hire; he promoted or helped biographical works such as Ruth Moore's life of Bohr (Moore 1985) and Patricia Rife's biography of Lise

16One of the texts that introduced the young Wheeler to quantum mechanics (and to the German language!) was Weyl's *Quantenmechanik und Gruppentheorie*, as we will discuss in Appendix B.

17As the recently departed John Heilbron, part of the team, once wrote me.

18See also Appendix B.

Meitner (Rife 1999);[19] he actively took part in historical symposia to better delineate some period or topic in the history of physics, such as the one organized by Roger Stuewer in Minnesota, in '77, for nuclear physics (Stuewer 1979); he supervised the organization of Joseph Henry's papers at the American Philosophical Society Library;[20] and, already in the '70s, he donated the collection of his own papers to the same institution, setting the example for other distinguished colleagues as well.[21]

From what we have anticipated at the beginning of this chapter, it is not difficult to guess that all this had also a "monumental" side to it – not much in the trivial sense of building monuments, but. again, in that of pointing out those deeds to younger generations and collaborators, in order to incite them to try something comparable. Taking a look at this quote is enough:

> "Animating these men we see the spirit which goes back to a much earlier age and which is described nowhere better than by the great Dutch historian of the Middle Ages, Huizinga. He tells us how similar were the rites of initiation of the knight and the scholar. The knight-to-be, after going through all the stated trials, kept watch beside his armour through the hours of darkness to dawn and then took the pledge to defend right at the cost of life itself. […] The scholar, having probed one issue deeper than anyone before, took a stand on it and defended his thesis against all attacks from a distinguished board of examiners. No one has forgotten how Martin Luther, following in this great tradition, nailed his ninety-five theses to the door of the cathedral. Nobody will forget [...] great searchers after eternal truth, and the theses that they nailed to the door of the Cathedral of Science" (Wheeler 1967a, p. 28).[22]

However, Wheeler did not just intend to spur people in a generic way, but in

19See Appendix A.

20Joseph Henry, besides being in a sense the dean of American physicists, was also the eponymous of Wheeler's professorship in Princeton.

21The story of Wheeler's engagement with the American Philosophical Society – of which he also served as president for a few years – has still to be written. Not only did he involve the Society in the historiographical activities he was promoting and personally contributed to the collections of its library, but also promoted events and dialogues in the spirit of high popularization among distinguished specialists, and arguably even made a diplomatic use of its membership, to be granted to scientists outside the Western world (e.g. Zel'dovich). Among the other archival collections that are now in possession of the Society, we could mention – to stay within Wheeler's circle of friends and acquaintances – Val Fitch's, Stanislaw Ulam's, and much more recently Freeman Dyson's.

22Huizinga's own way of proceeding through an *accumulatio* of meaningful anecdotes in order to evoke a *milieu* and its typical mindset, as beautifully exemplified by *The Autumn of the Middle Ages*, may have left some traces in Wheeler's storytelling style.

some direction he himself was deeming pursuitworthy. In other words, his historical pathos, as expressed in grand preludes or anecdotes, is quite often specifically aimed at building a narrative capable of providing plausibility and legitimization to his own visionary speculations. Claiming that a suggestion or research strategy had originated with Einstein or Bohr, for instance, did not only provide it with a sort of pedigree (in absence of other corroborating factors), but also represented a form of self-reassurance, arguably. In any case, we will see in detail these more circumstantial aspects of "monumental" history once we start examining Wheeler's geometrodynamical program, later in this chapter and in the next ones.

As for the "critical" use of the past, which is perhaps the most cryptic denomination of the three, it refers to a *selection* of some elements from the past, with the healthy oblivion of others. That is, when faced with a current situation, one *evaluates* (that is the etymological meaning of "critical", after all) which aspects may turn out to be helpful. If we apply the basic idea to science in its historical dimension, it means being able to draw on the something from the past to develop its untapped potential, without being stopped by its now outdated features. Of course, the adjective may be easily misunderstood if we take it as in the relatively frequent couple "historical-critical", more or less alluding to the development of a sort of *longue durée* perspective on issues that are still open, but that were framed or phrased in partly different ways. This certainly cannot be said to be a typical move on the part of physicists, especially active ones. Even in Wheeler's case, it would be rather misleading to imagine such an operation being conducted in a systematic manner.[23] His most interesting and original "critical" use of history is indeed a different one: we could very well say (and we will have many opportunities to highlight it) that Wheeler was possessed by the "demon of analogy", both in transferring notions from one field to another and in seeking affinities between various historical situations. That is, of course, a method that does not offer many *a priori* guarantees – "Die monumentale Historie täuscht durch Analogien", Nietzsche says,[24] but that can also apply to selective

23Nonetheless, the epigraph he chose for his preface to the *Sources* project is quite telling (and surprising, given the author being quoted – Benedetto Croce): "We are products of the past and we live immersed in the past which encompasses us. How can we move toward new life, create new activities without getting out of the past – without placing ourselves above it? There is no other way out: except through thought which does not break off relations with the past but rises ideally above it and converts it into knowledge... Only historical judgment liberates the spirit from the pressure of the past; it maintains its neutrality and seeks only to furnish light – it alone makes possible the fixing of a practical purpose; opens a way to the development of action" (Wheeler 1971a).

24That is, incidentally, the epigraph of the first chapter of Enzo Melandri's remarkable treatise on analogies (Melandri 1968). The rest of Nietzsche's paragraph is instructive as well: "Die monumentale Historie täuscht durch Analogien: sie reizt mit verführerischen Aehnlichkeiten

analogies which end up being quite different from what we would commonly call “critical”.

Two letters from Wheeler's archives are enough to provide a vivid picture of this kind of analogy-drawing (inasmuch the actual articulation of these analogies will be dealt with only in the following chapters). One was written to Debye and is dated 12 April '54 (that is, a period in which Wheeler was still struggling with the confusion deriving from the "particle zoo" and in the middle of developing his own geometrodynamical view):

> “Some time ago one of your former students mentioned a lecture of yours about the explanation of the van der Waals force: how everyone had ingrained in him the belief that these forces were of some mysterious chemical origin; that on this account psychological factors made it difficult even to examine the hypothesis that the van der Waals forces arise from the coupling of fluctuating electric dipoles; and that incredulity met your explanation or the mysterious interaction in terms of known phenomena. This bit of history could not help but make me reflect on our present problems about elementary particles and the forces between them.
>
> As a guide and stimulus to myself and my students working on these latter day questions, I would appreciate reference by you to anything in writing about the psychological situation in the days of one of your great discoveries”.[25]

The other letter is to Max Born, dated 29 September 1967 (the year in which Wheeler's geometrodynamical view began to show some cracks, even to his own eyes):

> “It is not a new experience for you to have a far away admirer write to you. I write only because the years go by and I never seem to find the opportunity to visit you in person to pay my respects, often though I have dreamed of doing so. You are one of the few persons who have contributed through your work and through your leadership to the elucidation of both general relativity and the quantum principle. Of all the questions I would like to ask you some day if I have the good

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den Muthigen zur Verwegenheit, den Begeisterten zum Fanatismus, und denkt man sich gar diese Historie in den Händen und Köpfen der begabten Egoisten und der schwärmerischen Bösewichter, so werden Reiche zerstört, Fürsten ermordet, Kriege und Revolutionen angestiftet und die Zahl der geschichtlichen ‘Effecte an sich’ das heisst der Wirkungen ohne zureichende Ursachen, von Neuem vermehrt” (Nietzsche 2015, p. 263).

25John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 7.

> fortune to visit you, none stands higher than this: Which of these two principles do you rank as the "deepest" (in the sense of being closest to the heart of the mystery that we are all trying to fathom)?"[26]

Faced with this pilgrimage fantasy, we may recall that, among the titles considered for Wheeler's autobiographical account of his long career, there was – also with some allusion to Bunyan's *The Pilgrim's Progress*[27] – "A Pilgrim in Physics".[28] In these specific cases, Debye and Born did not happen to add fuel to the fire,[29] but in principle it is now easy to imagine how, in the wake of analogies with glorious times gone by and thanks to the indications of such distinguished figures, a grand narrative to support what Wheeler had in mind around a certain issue was potentially ready. From what we have said and from the tone of the letters we can surmise that we are not dealing just with a shrewd strategy to better sell one's own ideas: this is the result of Wheeler's peculiar attitude towards the past and consequent inquiries.

At this point ,we are also in a better position to integrate the previous remarks about Wheeler's organizational and promotional role in the *Sources* project. Possibly he was not too keen on establishing details in a historicist way, *à la* Ranke: "it is not necessary to describe each victory if one wants to describe Napoleon's campaign; in the same spirit we can list only some of the conquests of the quantum idea without detailing them" (Wheeler 2001, pp. 109-110) – and, according to an aphorism occasionally repeated by Bohr, "when telling a true story one should not be overinfluenced by the haphazard occurrences of reality" (Casimir 1983, p. 2).[30] What Wheeler seemed to have in mind, also in the light of the inspiration he drew from *Writers at Work*, was not a simple archive, but a sort of heuristic repertoire, which one could draw on not only for more conventional (or antiquarian) historiography, but also to be inspired by great first-hand accounts and to find suggestions by analogy. As T.S. Eliot, who appears from time time in Wheeler's pages, once put it, "[w]e need an eye which can see the past in its place with its definite differences from the present, and yet so lively that it shall be as present to us as the present. This is the creative eye" (Eliot 1957 [1920], p. 77). A historical phenomenology of scientific creativity, in other words. Later, Wheeler would make it more explicit:

26John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 5.

27See Chapter 6 for a proper interpretation of these seemingly religious elements.

28John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 187, folder "Recollections".

29Cf., however, about the Van der Waals analogy, (Wheeler 1968c, p. 271).

30This, by the way, also gave the title to Hendrik Casimir's own autobiography, *Haphazard Reality* (Casimir 1983).

> "Do analogies form themselves out of thin air? Does our problem click by magic into parallelism with another idea from our own area, or with a thought from quite another field? Not by magic alone, but magic plus the prepared mind, Abraham Flexner reminds us. We recall the leader of industry who went to Arthur D. Little for something in writing on the proper organization of a research laboratory. He came away with John Livingston Lowe's inspiring book, *The Road to Xanadu*. And where could one see better than in that study of where Coleridge got his ideas how *the storehouse of the imagination* is stocked by conversation, story, book and observation?" (Wheeler 1985, p. 16; my emphasis).

As for Coleridge, the choice is certainly eloquent about the way Wheeler conceived of creativity (including his own), as opposed to timid and stuffy schemes on how science should work, even in its heuristic dimension. Wheeler's own notebooks and archives, as we shall discuss in a moment, became a storehouse of conversations, stories, books, annotations, and so on: there is enough material to keep even the most recalcitrant passer-by spellbound, like the wedding guest in *The Rime of the Ancient Mariner*.

We can perhaps get a further glimpse of Wheeler's intentions considering when he personally interviewed Yukawa in Kyoto for the *Sources* project: granted that the available transcription is far from being polished (Yukawa 1962), it starts almost *ex abrupto* with Wheeler asking about Yukawa's recollections on the period when he postulated his mediator particle and the path which led him to that idea. Even if the tools of oral history may not seem the most appropriate to investigate issues dating back to three, four decades earlier (hence Kuhn's notorious frustration over some of the answers of the physicists that were interviewed), it made complete sense for what Wheeler had in mind; and purely "antiquarian" efforts were partially met also by complementing the interviews with the collection of documents. Having thus identified these axes of Wheeler's uses of the past, then, we have still to make a few considerations on the source material we are often going to use, not least because, as fleetingly mentioned, it was made available by Wheeler himself: his is a consciously established archive, not merely a posthumously organized gathering of papers.

3. The archive and the notebooks

Wheeler the storyteller drew upon his personal encounters and research experience, his own recollections and vision for the future, and thus created a

peculiar mixture that defies the conventional communicative boundaries of that "oral" (or insiders') community sketched by Weisskopf. Luckily for the historian, his tales were to a good extent also put on paper – largely by Wheeler himself. There is a remarkable coherence in the way characters are presented over the years, accompanied by some revealing episode or "Plutarchean" anecdote, or simply by some stylized recurring traits.[31] It would be misleading, however, to suggest that this display of coherence over decades was the result of a carefully planned writing operation. The vividness of evocation and the personal element, rather, seem to genuinely gush out of his memory and impressions. That is just to say that, when I am going to sketch Wheeler's portrait of Einstein or Bohr, it is in general legitimate to draw upon texts from different years: the result is not meant to be a more or less tendentious *papier-mâché*, but to offer some interpretive guidelines also for other texts that we are not going to specifically examine (not in this chapter, at least). Meaningful changes in Wheeler's storytelling are not the norm and, when they happen, they are related to some bigger issue, as we shall analyze in the interesting case of Appendix A. It may be tempting to even suggest that the recurring elements of his tales bear some loose similarity to the "formulae" that Milman Parry taught us to recognize in the performance of storytellers of the oral world (Lord 1960, p. 4), as much as we know that our storyteller also used to write.[32] Indeed, in this section we are going to highlight some non-trivial aspects that the act of writing had for Wheeler.

The considerations we have made so far allow us to frame the great names and ideas on which Wheeler used to hinge a story, but, in order to do the cogent and detailed work of reconstruction of his heuristics that we have anticipated, the personal evocations of his speeches are certainly not enough: we have to draw upon other kinds of transcription – and we can access a vast archive of 150 linear feet.[33] For our purposes, we may characterize the John Archibald Wheeler Papers kept in the American Philosophical Society Library (Philadelphia) as consisting mainly of correspondence, research notebooks, teaching materials (not always comprehensive, unfortunately), drafts, as well

31In Appendix B we shall make even a brief comparison with mnemonic *loci* and remark about Wheeler's partly combinatorial method of composition, with the seeming re-use of presentations, descriptions, and so on (possibly dictated also by the very large number of his commitments)

32And he was not conditioned by metrical constraints. If we do not wish to overstress the "storyteller" category, perhaps we could just say that there are easily recognizable *Leitmotive*, whether we are dealing with Bohr asking "Socratic" questions or Heisenberg walking. "Wir sind fast alle in der einen oder anderen Weise in eine [...] stilisierte Vergangenheit verliebt" (Hofmannsthal 1987 [1894], p. 57).

33Part of his papers are also kept at the Briscoe Center of the University of Texas at Austin, but their status and their availability – every time some request was made in recent years – seem at the moment unclear.

as other people's papers. "Correspondence", actually, can be occasionally a misleading label: it is rather a series of “personal files” or folders containing materials pertaining to a specific person. Actual letters are often included, but there are also (or, in same cases, only) clippings, abstracts, and so on: even a folder named "Leibnitz", for instance, is categorized as correspondence, although it just contains a copy of the corresponding entry in the *Encyclopedia Britannica* and Fontenelle's *Éloge de M. Leibnitz*.[34] Speaking of which, to suggest a Leibnizian scale for Wheeler's correspondence would be an exaggeration, but it is certainly rich and varied – and a silver mine for the historian, from which we have already drawn something. What is truly a gold mine, however, are Wheeler's research notebooks.

Considering them as mere logbooks would be as wrong as calling them diaries – but they do have elements of both. Towards the end of his life, Wheeler mentioned that his habit of keeping a notebook was “inspired by Enrico Fermi's example as well as by rules laid down at Los Alamos”, and so “I started keeping my thoughts in bound notebooks” (Wheeler 2000, p. 182). In an earlier interview, actually, he had already commented on that: “And there I learned from Fermi the system, to leave the first four pages blank, to put an index in when you get to the end. But he was much better than I, because he went further and he had a card index, so for any given item in his card index, he could say, notebook so and so, page so and so, notebook so and so, page so and so” (Wheeler 1988b). However, an important difference that we can spot is not just about the degree of organization: while Fermi famously used his notebooks as a sort of handbook with approximations and formulae to solve problems almost on the spot, Wheeler opted for a sort of midway between the working notes of a physicist and a commonplace book, in which he used to write down names, conversations, attempted calculations, conference notes, drafts, new ideas, anecdotes, quotes, and so on. Clippings and ironic (or even self-ironic) cartoons are included, too.[35] In a sense, since, in order to effectively employ Fermi's system, one requires a certain ability in analogy-making to relate problems or physical situations to those already filed in the repertoire, Wheeler's idea of a “storehouse of imagination” is not so remote. The self-reflective dimension that he would give to his own notebooks, however, is entirely his, idiosyncratically and preciously unique: even Gregory Breit, for instance, with whom Wheeler worked in the early '30s

34John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 16. Nonetheless, this – symbolically, at least – is not entirely a funny mistake of categorization, since, as we shall discuss, Leibniz became an “intracranial colleague” of Wheeler's.

35This contributes to a visual variety that, as we shall mention more than once (but especially in Chapter 5 and Appendix B), is also related to Wheeler's penchant for visualization and his style of understanding physical phenomena.

for his first postdoc, used to keep notebooks (now at Yale), but any comparison immediately makes that peculiarity of Wheeler's stand out.

This gap arguably widens depending on the subject of the notebooks and on their period. His “Astro- and Geophysics Notebook”, for example, is quite conventional in its contents: with a few exceptions, it just contains notes or clippings about issues that had momentarily caught Wheeler's attention or about other people's ideas. Likewise, the 7 “Nucleonics Notebooks”, composed between 1950 and 1966 (that is, the period in which his main research interests had turned to general relativity and its implications), at first glance look more like the notes of an expert in the field and have less thrill of discovery than the coeval “Relativity Notebooks”. The latter, in particular, are an outstanding historical and intellectual document: they constitute a series of 19 notebooks, which open with the 40-year-old Wheeler in the process of reinventing his well-established career as nuclear physicist and of learning a new subject by teaching it, as we shall see in Chapter 2, and significantly close in the early 1970s, when he felt that the grand vision he had pursued was insufficient and needed new fundamental ideas. This crisis initiated in turn a series of 24 “Research Notebooks”, up to now hardly explored, in which Wheeler's self-reflective writing is even more pronounced and the variety of topics is truly transdisciplinary (this “transition” is partly mirrored in the present dissertation by the division of the chapters into two groups). It is also worth mentioning an unfinished notebook called “Essays I”, with annotations between 1949 and 1966 (that is, in parallel to the “Nucleonics” and the “Relativity Notebooks”), which has an entirely meditative dimension and it contains drafts of speeches or reflections inspired by the Unitarian community Wheeler used to attend (like his friend Wigner, for instance). As we shall explain in Chapter 6, Wheeler's Unitarians are not those of, say, Isaac Newton, concerned with denying the dogma of the Holy Trinity, but are rather Unitarian Universalists, believing that all the traditions of the world have something worth listening to, and that reason offers proper guidance. The “social” factor may thus easily overcome the strictly religious attendance, as in Wheeler's case, but an emphasis on morality and community, as well as some stylistic form of exhortation, may easily persist. In this sense, Wheeler's “Essays” are perhaps closer (also for obvious cultural reasons) to Emerson than to Montaigne, although they do not lack the kind of ever-evolving self-portrait that characterizes the latter. But this is just to say that the exploratory journey documented by the “Relativity Notebooks”, with all the self-reflection they contain, somehow lies in between “Nucleonics Notebooks” and “Essays I”.

Thus, the “Relativity Notebooks”, one of our main sources, do not only offer us insights into the conceptual and mathematical means being adopted,

or into traces of conversations and debates that took place in the insiders' community: we almost have the trajectory of Wheeler's mind. Another thinker such as Charles Sanders Peirce, with whom, as we shall discuss in the second group of chapters, Wheeler had quite a few resonances, used to recommend (Peirce, 1992 [1898]) taking and preserving notes about one's own thoughts and theoretical explorations: that is precisely what Wheeler did, and advised his students to do. Speaking of his students and collaborators, their presence is also relevant to understanding some features of the notebooks. Wheeler clearly valued these notes, almost jealously, as can be seen by the way they were written and kept (and by the promise of reward in the event of loss, as stated at the very beginning of each notebook), but, at the same time, everybody around him knew about their existence, could see him writing down some idea or just some name, and could also (albeit carefully) borrow and consult them (Misner 2010, pp. 18-19). In this sense, they were even, at least in part, rough group protocols of some sort. That is also why, besides reasons of personality, there is no self-aggrandizing pose in them: Wheeler was not afraid of reporting the criticisms he had received, his own doubts, interrupted calculations, and so on. Heuristic transparency, once again – and not only for posterity, but also for those joining his crew. If Wheeler's historical awareness was also a self-awareness, he certainly did not use a "monumental" tone when speaking about himself. All this, moreover, does not just contribute to the notebooks' qualification as historical (and human) documents: the very act of writing down conversations, objections, and one's own changing views or uncertainties may have the effect of a kind of mirror that widens one's heuristic awareness, instead of fostering the illusion of a single possible road to pursue – and Wheeler, indeed, enlarged the scenario he was contemplating to the point of promoting research in various directions that were contradicting his own expectations at a given moment. Those who like to speak of an "extended mind" would certainly find an interesting case study here. All the ideas he disseminated and the research he promoted would come back to him and correct or enrich his own perspective, as it did especially in the case of gravitational collapse and black holes (see the next chapter). As Wheeler himself once put it, "I did not let … [my] vision become an obsession. Every once in a while, I would pull out a notebook or just sit back and think, reexamining the problem, trying to come up with new ideas. Then I would lay that work aside and go on with other research, hoping that the next time around the right insight would dawn" (Wheeler 2000, p. 173). This alone would be enough to sweep away any caricature of the scientist who makes a well-defined one-shot attempt, sees if it works or not, turns page, and moves on. In Wheeler's notes, instead, we can experience the slow and gradual maturation of ideas, their metamorphosis and, occasionally, even their

exaptation into matters far removed from those for which they were initially formulated. There are also relatively frequent moments in which Wheeler takes a break, so to speak, and dedicates a couple of pages to state his overall vision anew and sketch the plan for the road ahead – something that, in the Introduction, we have indicated among the hopes of a historical epistemology that could be relevant to contemporary science.

If, on a personal level, we can detect this sobriety of self-reflection, as stylistically opposed to the pathos of his historical evocations, nevertheless the contents of the notebooks are often as grand as Wheeler's speeches and papers, in terms of visionary ideas and ambitions, even if there is no trumpet constantly announcing that. As much as I have used the expression "heuristic transparency", that does not mean that today, after a few decades have passed and we interpreters are unavoidably outsiders of some sort, we can easily access Wheeler's bold thoughts, often pursued along mutually contradictory (or at least distinct) lines. Nor do his annotations only require a minimal hermeneutic effort on our part (although that arguably applied even to his own collaborators back in the day – but they could ask him). Thus, these notes do not simply represent a privileged resource, but are a benchmark for a subtler and richer understanding of Wheeler's ideas. Who takes them at face value or cherry-picks from them may fall into gross mistakes, as we shall mention in Chapter 6 about Wheeler's “religious” references. That is why it is an illuminating exercise to go back and forth between his published papers and his notebooks, so as not to forget the big picture. Faced with Wheeler jumping from topic to topic every other page, it is easy to feel disoriented: one needs a filter, a thread to follow, a reading hypothesis to clarify and test. That is another reason for that *immer wieder,* or re-telling of some aspects of the story, that we are going to display in the second group of chapters, as anticipated in the Preface.

In several cases, as already hinted at toward the end of the Introduction, names or words seem to be used by Wheeler as a sort of signpost, whose meaning we have to guess thanks to a large survey of their appearances in his published and unpublished papers – as in Wittgenstein's linguistic games – and thanks to the soundness of one's heuristic *Einfühlung*, so to speak. "Bubbles", for instance, may stand for Gamow's cosmological model, visualized via pictures of underwater explosions (Blum, Furlan 2022) and rephrased through a few Shakespearean lines; "Leibniz", as we shall see in Chapter 4, is a complex and original conceptual character rather than one of the portraits that can be found in some history of philosophy. Especially in the case of famous names, this decryption can be hampered by the fact that Wheeler's references look deceivingly simple and one has to “rhabdomantically” identify where a deeper dive into the notebooks may reveal the submerged part of an iceberg –

his unappreciated re-elaboration of Leibniz is again exemplary, as is, after all, the whole case we have been discussing, that of Wheeler's historical references. If we do not underestimate Wheeler, then, and we do not quickly dismiss his thought when we see some standard or basic reference (such as the entry “Parmenides” or “Berkeley” in the *Encyclopedia Britannica*), since we may expect that it will be soon transfigured in an original way, we can easily admit that his efforts, at a relatively advanced age and at the height of his prestige, to humbly ask anywhere for suggestions, or to gather pieces of information about a topic or a thinker that caught his interest, certainly leave quite a strong impression. That applies all the more to the digging he repeatedly tried to do in the cultural and philosophical background of his two great mentors, Einstein and Bohr: let us see why.

4. Of role models and heroes

Bohr and Einstein, quantum physics and relativity: these are the two pillars of 20th-century physics, as well as of Wheeler’s way of conceiving its history. Besides being, today, a quite typical manner of presenting the situation, especially in quantum gravity, it is also a central point in the following curious passage by Wheeler himself, intended for the last chapter of *Gravitation*, which is worth being quoted at length not just *qua* an exemplary instance of his writing, but because it reveals much of his way of relating to the past:

> "One great quarter of the ever abuilding city of science has been explored in some detail, from districts where new towers are in lively use to other areas where foundations have been poured and the ring is heard of trowel and hammer. The exploration has ended with a survey of some of the newly developing areas of general relativity. Among them all none more compels attention than quantum geometrodynamics; and among the pressures for solid new construction in this district of the city the greatest comes from the phenomenon of gravitational collapse. What happens to matter, matter that is so conclusively quantum in its constitution, as gravitational collapse crushes it at an ever rising pace to ever higher densities? And what implications does gravitational collapse have for the nature of matter?
>
> No building rises here. Masons and carpenters stand waiting. Architects and builders in small groups pace the site in puzzlement. The plot is central, hemmed in as it is between the two skyscrapers that overtower every other structure in the city: one, Einstein's geometrodynamic law; the other, the quantum principle. Will some

> small structure rise here? Or are the two skyscrapers destined to merge across the gap and grow into a single towering pinnacle? Last question unanswered and exploration ended, take the path out of town and up the hill to the park where the statues stand of the great builders of the city of science. Look in turn at the busts and quotations that recall Newton and Einstein, Riemann and Cartan, Planck and Bohr. Come to a pause before the bronze of Mendeleev. Legend has it that any one of these figures may come to life and speak about the past of his own quarter, and sometimes even say something about the future of the whole city, if only he is addressed on an anniversary by a small group of those who care. A century ago Mendeleev found a guiding principle in the mystery of matter. What new guiding principle will clarify the interlinked mystery of matter and collapse? Mendeleev's anniversary is fresh. Speak to him and see if he will answer!" (Wheeler 1969, pp. 846-847).

Incidentally, we can begin to notice that Wheeler had a taste for anniversaries and busts – functional to prosopopoeia, of course –, and that his "geometrodynamics" is here attributed to Einstein *tout court.* Now, it would be easy to think that, given Einstein's and Bohr's impact and iconic status in the community, Wheeler used their names symbolically, standing for everything related to relativity and quantum physics. On a trivial level it is certainly so, but what I intend to stress is the extent to which, for Wheeler, the challenge of quantum gravity was indeed, at a deep level, a personal matter in an attempt to reconcile or play out the conceptual tensions between his two mentors and inspirers. Even in his old age, having entered a new millennium, Wheeler had no doubt about the centrality of their debates:

> "On the windowsill of my home on an island in Maine I keep a rock from the garden of Academe, a rock that heard the words of Plato and Aristotle as they walked and talked. Some day there will arise the equivalent of that garden where a few thoughtful colleagues will see how to put it all together and save us from the shame of not knowing "how come the quantum". How could the proposed academy best function, have the great questions brought to mind over and over day after day, bring Bohr and Einstein and the others back to life to stimulate and inspire their endeavors?" (Wheeler 2001, p. 115).

It is as if Wheeler were painting anew Raphael's *School of Athens,* unhesitatingly placing Einstein and Bohr at the center of perspective, in the place of Plato and Aristotle. As a matter of fact, I would even go as far as suggesting that the cover of Wheeler and Zurek's source anthology, *Quantum*

Theory and Measurement (Wheeler, Zurek 1983), is a subtle play with perspective (Fig. 1):

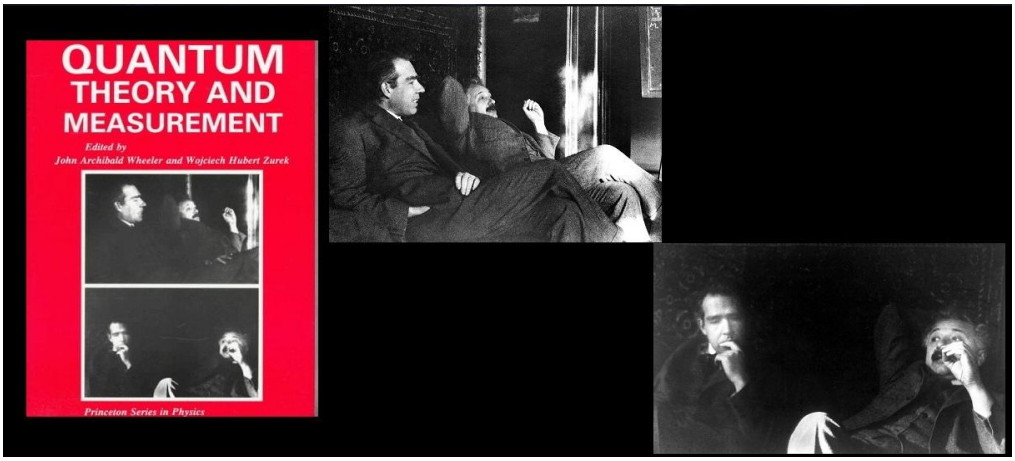

Fig. 1. Cover of (Wheeler, Zurek 1983).

Here we are seeing Einstein and Bohr on Ehrenfest's sofa in Leiden from different angles, pretty much like Wheeler kept looking at their discussions from different viewpoints.[36]

In the quote about the "new Academy", moreover, there are a couple of seemingly innocuous expressions worth commenting. "Bring back to life": we may recall that, during the Renaissance, in addition to the attacks against scholastic Aristotelianism, there was also the tradition of the *Aristoteles redivivus* (Del Soldato 2020) – that is, people imagining what Aristotle would have said differently in the new age (which, of course, presupposes that things had changed). Likewise, on a much smaller temporal scale, Wheeler kept wondering what Einstein and Bohr would have thought in front of new results and new issues: for Einstein's centenary he even wrote a dialogue with Albert's spirit about the current situation of physics (Wheeler 1979a) – *Einstein redivivus*, we could say. Around the same period, he had a conversation in Tübingen with Hans Küng who helped him understand the role of Spinoza for Einstein (Wheeler 1980a, p. 374); and, to make another example, he wrote to

36More in general: "Should scientists care about new insights or different ways of looking at things if nothing new is predicted that can be measured? Yes, they should. We need to be always looking at what we already know in new ways. It's like an artist examining a piece of sculpture from every angle. The scientist, like the artist, might get a new idea or at least a deeper appreciation of what is already "known." There is no limit to depth of understanding. Different ways to describe the same set of equations can add insight. Maybe one way is clearly more economical, more "elegant" than another. Then we adopt that way. Maybe having two ways enriches our understanding by letting us examine the same domain of nature in two different ways. Maybe using one description will sometimes seem clearer at one time or for one purpose while using an alternate description will seem clearer at a different time or for a different purpose" (Wheeler 2000, p. 270).

Jørgen Kalckar in Copenhagen to know whether, in the last months of his life, Bohr had been thinking about consciousness and computers, or had changed his mind about the alleged role of consciousness in quantum mechanics (Wheeler 1978, p. 20).

This "update" of Einstein's and Bohr's views, accompanied by a more or less "historical" investigation into their documents and cultural background, was so urgent for Wheeler because of "the great questions brought to mind over and over day after day", as aptly conveyed by another expression of the above quote. Far from restricting himself to a "mere" rumination on the technical aspects debated by Einstein and Bohr,[37] Wheeler clearly perceived the tensions at play on multiple levels – a clash of philosophical worldviews, in a sense. "Einstein, I think, described himself rightly as a follower of Spinoza who, in the great tradition of ontology, asked what is. Bohr, I feel, is rather a follower of Kant who asked what we can know; Bohr's questions are epistemological, Socratic", as Weizsäcker once wrote.[38] "It will always remain a spectacle with a great symbolic quality and of world-historical import, how two of the greatest minds of all times strove to unify a fragmented world": what Simmel (2007 [1906], p. 174) wrote about Kant and Goethe could be applied *verbatim* to Wheeler's consideration of his two mentors discussing. During the celebrations of Einstein's centenary in East Berlin, Wheeler even stated that there was "kein nobleres Thema für einen Dramatiker, Dichter oder Künstler" than the Bohr-Einstein debate (Wheeler 1979b, p. 392).[39] What he did was to internalize their viewpoints, so to speak, and keep those tensions within himself as a sort of dialectical dynamo, now oscillating more toward one, now more toward the other.

This sort of inner continuation of the Einstein-Bohr debate, not just at a purely intellectual level but also in terms of role models, is somehow made explicit by Wheeler himself:

37Otherwise (except for the delayed-choice experiment and the anthology with Zurek), they would have had not much to say about many of the new frontiers Wheeler had been exploring – instead, he always put them at the center of his reflections.

38C.F. von Weizsäcker Papers, Max-Planck-Gesellschaft Archiv, Berlin, "Heisenberg's Philosophy".

39Wheeler, nonetheless, could also make some ironic comments about that: "In 1971, on an earlier visit to Moscow, I visited a studio in the basement of an apartment house where two sculptors were making sculptures of artists and poets, and great thinkers, and great scientists. There was a sculpture of Bohr and Einstein debating. It was wonderful to see that. But I did not tell the sculptors about one of the times when Bohr came to visit the house of Einstein that I just mentioned. He went up the stairs to the second floor where Einstein's study was and – it was a terribly hot day – he found Einstein lying on the sofa with not one piece of clothing on. Well, they continued the debate in that frame of reference. The sculptors did not know that" (Bicak 2009, p. 685).

> "Of all heroes, Spinoza was Einstein's greatest. No one expressed more strongly than he a belief in the harmony, the beauty, and – most of all – the ultimate comprehensibility of nature. […] In later years, Einstein was asked to do a life on Spinoza. He excused himself from writing the biography itself on the ground that it required "exceptional purity, imagination and modesty", but he did write the introduction. If it is true, as Thomas Mann tells us, that each one of us models his or her life consciously or unconsciously on someone who has gone before, then who was closer to being role-creator for Einstein than Spinoza?" (Wheeler 1980b, pp. 101-102).

This passage almost spontaneously calls for a "triangulation" with the following two:

> "Just as in many sports a player goes through warming-up exercises before entering the arena, so Bohr would relive the struggles which it took before the content of quantum mechanics was understood and accepted. I can say that in Bohr's mind this struggle started all over every single day. This, I am convinced, was Bohr's inexhaustible source of identity. Einstein appeared forever as his leading spiritual partner – even after the latter's death he would argue with him as if Einstein were still alive" (Pais 1982, p. 6).

> "It is not possible to write in any detail about John Wheeler without mentioning the central place Niels Bohr held in his esteem and how Bohr's influence shaped him. Others have told me that this influence extended to facial expressions and mannerisms" (Taylor 1972, p. 475).

Wheeler's was an exercise in gradual assimilation and in rethinking his own experience: it is clear, for instance, that he did not go around imitating Bohr right from the 1930s, but it was a long (and daily) process of conforming himself to an internalized image – which, as such, became more and more relevant after the model's physical death. The result is thus rooted in Wheeler's personal experience, but at the same time it is hard to entirely disentangle what is Bohr's, or Einstein's, and what is Wheeler's, unless we adopt a sort of strict documentary "positivism" as criterion. That, however, would impoverish our horizons and make us miss the role that Wheeler played, and may still play, in the reception of his two mentors. The storyteller takes from his own experience; and, as we have remarked in the beginning, he is not just a narrating voice or a character among others, but a super-character that ascribes some of his own features to others. Although an element of self-legitimization

is undoubtedly present in this, especially when, during the 1950s, Wheeler reinvented his career by taking a gamble (we will better reiterate this in the next chapter), it should be now even more obvious that his "philological" inaccuracies are not the result of some sly self-advertising,[40] but the outcome of some deep personal reworking.

Before analyzing Wheeler's Bohr and Einstein, it is suggestive, in the light of all we have said, to take a look at a picture of the old Wheeler (circa 2003) sitting next to their busts (Fig. 2):[41]

Fig. 2. Credit: AIP Emilio Segrè Visual Archives.
https://repository.aip.org/islandora/object/nbla:310951

5. *Bohr*

5.1 Der Sokrates der Physik

It is hard to overestimate the influence that Bohr had on the physics community during his lifetime. On the other hand, it is easy to underestimate his importance for Wheeler, as much as the bond that tied the latter to Copenhagen is well-known. From Wheeler's perspective, Bohr was not only the charismatic quantum leader:[42] "Bohr's own deep understanding of human

40It is to be noticed that Wheeler never claimed Einstein's or Bohr's legacy on a personal level, but as part of a community or collective effort.

41Incidentally, Wheeler himself had been involved more than once in matters concerning monuments or sculptures in honor of Einstein and Bohr (Wheeler 1995).

42In Wheeler's own words: "And then Bohr, Bohr the greatest leader of physics and father-figure of all physicists..." (Bicak 2009, p. 684).

problems, and his powerful influence over those around him, make one certain that men like Jesus, Lao-Tse, Confucius, and Buddha really lived" (Wheeler 1963b, p. 45). Wheeler's mentioned sympathy with the pluralistic openness of the Unitarian Universalists does not make this sentence, written in the aftermath of Bohr's death, any less impressive – and rather contrasting with some caricatures in vogue nowadays. Wheeler has also been called "the apostle of Niels Bohr at Princeton" (Gleick 1993, p. 93): his devotion was simply evident to anyone who knew him. In the Philadelphia archive, the second folder labeled "Bohr, Niels Henrik, 1885-1962"[43] – one of many containing materials related to the great Dane – opens with a condolence card *to* Wheeler when Bohr passed away, sent him by the psychologist and poet Marjory Bates Pratt: "How I feel for you! Losing Bohr must have been like losing a father and more than a father".[44] Was Wheeler's inner dialogue with Bohr until the end of his own days – and he still had more than four decades to live – a kind of grieving? Perhaps, but Bohr's presence and role in Wheeler's mind is certainly not reducible to that, not least because it was a process recognizably set in motion about a decade before Bohr's death.

Let us go back to the starting point of this chapter. In 1933-34, Wheeler was working as a postdoc with Gregory Breit; during that time, he applied for a second year of his National Research Council fellowship to go to Copenhagen, at Bohr's court. In the application, as he recalled more than once in later years, he wrote as a motivation that Bohr "sees further ahead than any man alive" (Wheeler 1988a) or that "he has the power to see further ahead in physics than any other man alive" (Bicak 2009, p. 684); he actually wrote:[45] "Bohr is the best man under whom to investigate the nucleus. He is the man with the great mind and imagination who stimulates and foresees all the others" (more on that "stimulates" in the following). *Vision* is a feature that Wheeler (1968a) would later ascribe to Einstein as well (we are dealing with tensions between scientific worldviews, after all), although with different connotations, but in the 1930s Einstein did not seem exactly far-sighted when it came to the new nuclear physics the young Wheeler was interested in. "Most of the friends I talked with about my wish to work with Bohr encouraged me enthusiastically. At the same time, they were a little awestruck. It was as if a little-known, fledgling sculptor in 1523 had stated his intention to go and work with Michelangelo" (Wheeler 2000, p. 124). His wish was granted and, thus,

43John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 165.

44Psychologically speaking, it is worth remarking that Wheeler's actual father, the eminent librarian Joseph Lewis, one year older than Bohr, was still alive (1884-1970): that was still an unknown experience to him.

45John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 151; and (Wheeler 2000, p. 123).

“[t]he summer of 1934 saw me saying 'Good-bye, Professor Breit', 'Hello, Professor Bohr', good-bye to learning how to answer questions, hello to judging what to ask, good-bye to regarding the quantum as handed down from heaven and hello to the question how come the quantum” (Wheeler 2001, p. 114).[46]

This last passage is worth comparing to some words by a longtime friend of our storyteller's, Freeman Dyson (2004, p. xviii), according to whom there was “the prosaic Wheeler, a master craftsman using the tools of orthodox physical theory to calculate quantities that can be compared with experiment”, and there was “the poetic Wheeler, who asks outrageous questions and takes nothing for granted”. Dyson was considering the “two Wheelers” as two poles of his friend’s style of thinking, of doing physics and of writing, but not in a diachronic way, as if they had always been co-present: “The prosaic Wheeler and the poetic Wheeler are equally essential. They are the two complementary characters that together make up the John Wheeler that we know and love” (Dyson 2004, p. xix). There is certainly an element of plausibility to it, but, in this way, the significance of the 1934 turning point indicated by Wheeler

46Interestingly enough, at least according to the recollections of Murray Gell-Mann (1997), who was later a student of Breit's, the latter was not exactly question-friendly and used to advise students precisely against what, in a sense, was going to epitomize Wheeler’s last fifty years: “He permitted no questions. If anyone asked a question he left the room and wouldn't come back until some of his students that he had brought with him from Wisconsin went out into the hall and begged him to return, saying, ‘Well, these Yale students don't understand the rules, they don't understand how wrong it is to ask a question, and they promise never to ask any more questions. Please, come back and teach some more’. Then he would come back and teach. Another thing that wasn't permitted was reading books. Sometimes after class, when it was permitted to ask a question, someone would ask him a question, and he would say, ‘I can tell! You've read a book!’ For example Bethe's Little Book [of Scientific Principles] was forbidden and… another thing you mustn't do was to learn about general relativity. He said it was very bad for young students to learn about general relativity. They get all sorts of big ideas and they want to combine general relativity with quantum mechanics and so on and so on, and they get led off into paths that lead nowhere. They… they go off on paths that lead nowhere and it’s very bad. And so, if anybody asked him a question connected with general relativity, he flew into a rage”. Nonetheless, it is also relevant that, in supporting Wheeler's applications, "Breit [...] wrote favorably of my abilities in physics and mathematics, and added that I didn't show *the 'nervous irritability frequently met with in men of high theoretical ability*'" (Wheeler 2000, p. 125; my emphasis). In any case, Wheeler himself made the distinction between his two postdoc mentors quite clear: “And of course there was a completely different spirit between Bohr's approach to nuclear physics and Breit's – Bohr looking over the whole thing without getting down to detailed calculation on any one aspect and always looking for a paradox that would throw light on a whole new approach, and Breit, on the other hand, focusing on a very careful comparison of a detailed model with experiment and the soul of integrity and giving one the feeling that any part of physics should in principle, if one understood it properly, be subject to calculations so you could really hope to check the theory against your experiment and not just talk” (Wheeler 1967b).

himself fades away. If, on the other hand, we recall his quote about the importance of role models, we could rather consider his "Breit side" (no pun intended) and his "Bohr side". While even in Wheeler's first phase there were audacious conjectures and other "poetic" elements (see Chapter 7), it seems quite safe, at least at a coarse-grained scale, to remark that the first Wheeler was dominated by the more calculating, "prosaic", (relatively) down-to-earth Breit side; then, gradually, the Bohr side, asking questions and looking far ahead into the future, took over:[47] it is a development already visible in Wheeler's "Relativity Notebooks" and simply evident in the papers from the '70s on. The meeting with Bohr can thus be regarded as a decisive moment of a latent process, which became fully manifest only a few decades later.[48] This, for sure, was not just obeying some exclusively personal path of evolution: there were common factors as well – quite predictable ones actually, such as Wheeler's aging, the role he could then play thanks to his academic position, the need for mathematical updates. The result was his increasing reliance on calculations and mathematical expertise brought by the young people working with him, which prompted him to offer in return a Bohr-inspired mentorship, providing suggestions and stimulating questions.[49] To sum it up, "Breit taught me new mathematical and calculational techniques. Bohr taught me a new way of looking at the world, a new way of raising questions. Undoubtedly, my style of doing physics owes something to both Breit and Bohr. It might be

47When referred to the "historical" Bohr, that would be obviously an oversimplification, since "both" aspects had belonged to him: "Niels Bohr, as creative a scientist as any in the twentieth century, dared to speculate, too, on the meaning of the quantum, on the role of the observer in determining reality. I was privileged to work with Bohr on a topic of startling immediacy, nuclear fission, and also to watch him wrestle with the paradoxes of the quantum as he looked toward what the physics of the future might look like. "Wrestle" was a term he liked. Physics was a battle. Nature was a worthy opponent. I have unquestionably been influenced by Bohr in the ways that I approach both the immediate, where, little by little, the frontier gets nudged back, and the hazy future, where questions far outnumber answers, where only intuition and vision guide progress" (Wheeler 2000, p. 356).

48"As I look back now at that paper written when I was a twenty-one-year-old student, I am startled to find in it approaches to physics that have appeared again and again in my work throughout the rest of my career. First is my way of tackling problems (the practical doer in me). Second is my way of thinking about nature (the dreamer and searcher in me)" (Wheeler 2000, p. 100). He is referring to his very first published paper (Wheeler 1933).

49Bohr too used to be surrounded by people with a "powerful command of mathematics without losing sight of the physical facts": it has been said of Rosenfeld (Jacobsen 2012, p. 45), for instance; but it is also worth recalling what Rosenfeld himself once added: "My first task was to lecture Bohr on the fundamentals of field quantization; the mathematical structure of the commutation relations and the underlying physical assumptions of the theory were subjected to unrelenting scrutiny. After a short time, needless to say, the roles were inverted and he was pointing out to me essential features to which nobody had as yet paid sufficient attention" (Rosenfeld 1979, p. 414).

better to say *styles*" (Wheeler 2000, p. 139).

With these considerations, we have at once identified one of the main features of Bohr as a character and showed how deeply Wheeler had also tried to put it into practice. Let us just better illustrate it with some other passage (to which we shall return in a few paragraphs) from Wheeler's storytelling:

> "Then came the famous work of Niels Bohr on the hydrogen atom. Following his student research, Bohr went to Cambridge University to work with J.J. Thomson, the discoverer of the electron. The shy young Dane, not yet fully at home in English, had brought along with him Thomson's book on the electron and, opening it up, pointed to passages that were doubtful, or even wrong, and solicited Thomson's response. The young Bohr, seeking only to show by his questions how thoroughly he had read Thomson's book and how much he appreciated it, got off in this way to an awkward start for his intended year with Thomson. Fortunately fate brought to Cambridge from time to time a young visitor from Manchester, in the shape of Ernest Rutherford…" (Wheeler 2001, p. 110).

A few years later (inside the time of Wheeler's narrative, as well as in that of history), Bohr, now the guide of the pioneers of quantum mechanics, had one of his meetings with the Danish philosopher Høffding and they were discussing the double-slit experiment: "Høffding put his finger on the diagram and inquired: 'Where can the electron be said to be?' Whereupon Bohr replied: 'To be? To be? To be? What does it mean, to be?'" (Wheeler 2001, p. 112). After Hamlet and Kierkegaard, Denmark was still the land where "to be" was to be questioned.[50] Then, like the divine wanderers of Nordic mythology, this questioning character seems to disappear for a while in the mist of time, only to reappear later in the form of Wheeler himself, at an advanced age, asking *the* question: "How come the quantum?"[51]

To sum up: this rough sketch of the impact that Bohr had on the young Wheeler allowed us to identify one of the two main "functions" that Wheeler

50It is relatively common to hear about Kierkegaard's alleged influence on Bohr's ideas: here we are not concerned with the usual traits of this *vexata quaestio*, if it deserves that name, but rather in a comment that Bohr once made about Kierkegaard and may be relevant in a few paragraphs, when illustrating the other main feature of Wheeler's Bohr: "His honesty and willingness *to think the problems through to their very limit* is what is great. And his language is wonderful, often sublime. There is of course much in Kierkegaard that I cannot accept. I ascribe that to the time in which he lived. But I admire his intensity and *perseverance*, his *analysis to the utmost limit*, and the fact that through these qualities he turned misfortune and suffering into something good" (Nielsen 1963, p. 27; my emphasis).

51We do not have to forget that, when telling these bits of the story, Wheeler was almost 90, even if that question became his focus from the mid-1970s on.

ascribed to his mentor and that actively shaped his own *modus operandi* and heuristics: asking questions and, more generally, a dialogic dimension of science. "Asking questions", without further specifications, would in turn raise questions, of course. As we have seen, what Wheeler emphasizes is Bohr's ability of putting the finger on crucial or fruitful points[52] – his questions did not just solicit technical refinement or corrections. In this sense, his was a "maieutic" questioning, hence the comparison with Socrates, such as in (Weizsäcker 1985).[53] Bohr's constant and almost painful awareness of the problematic nature of the issues he was facing and of their attempted solutions could baffle – or irritate – those who wanted solid ground and precise answers, but could also inspire the development of an analogous "maieutic" spirit, as it did to Wheeler. Arguably, part of the elusiveness of both Bohr's and Wheeler's importance and role within the community of physics is due to such a volatile, provisional dimension, easily forgot once "the results" are obtained.[54] More in general, all this points to a markedly dialogic character of making science, we have said: a dialogue between its practitioners, but also a dialogue with experiment.[55] When Wheeler referred to the Copenhagen school he was

52As Rousseau wrote in *La nouvelle Heloïse* (V, 3), "L'art d'interroger n'est pas si facile qu'on pense: c'est bien plus l'art de maîtres que des disciples; il faut avoir déjà beaucoup appris de choses pour savoir demander ce qu'on ne sait pas" (Rousseau 2002 [1761], p. 639).

53*Der Sokrates der Physik* is actually the title of Bohr's obituary written by Weizsäcker, that can be found in his archives (C.F. von Weizsäcker Papers, Max-Planck-Gesellschaft Archiv, Berlin). Not everybody seemed to agree, however: "They liked to call his method Socratic, but they didn't know those ancient dialogues very well" (Snow 1981, p. 59). Granted that the parallelisms with ancient philosophers have not to be taken too systematically or literally, obviously, it is doubtful whether various personalities from the German cultural world, associated quite closely with Bohr, knew the Platonic dialogues worse than C.P. Snow – what at least to me seems sure, on the other hand, is that I have rarely found a more distorting and vacuous use of "classical" notions than Snow's attempt at applying them to Dirac's mind (not to mention the main reason why his name gets repeated). Nonetheless, we will find in the following a phrase about Bohr that resonates with Wheeler's words.

54Wheeler too was aware of that: "Because of Bohr's style and his special role as stimulator and guide in Copenhagen, it is difficult to know how many significant achievements by others were built on his original ideas. Many, I suspect. Neither then nor at any time later did I ever hear Bohr breathe a word of regret that someone else got credit for an idea of his. In his mature years, at least, he seemed genuinely indifferent to personal credit. Margrethe was more sensitive to the issue, and sometimes hinted that others had borrowed her husband's ideas without giving credit" (Wheeler 2000, p. 129).

55In his Vanuxem Lecture (1981) Wheeler would even go so far as to say that "quantum physics has become 'dialogue' physics" (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 189 – I quote from the rough transcription, p. 14): "Dialogue physics in a sense that you ask the questions and then the experiment, or nature in the form of the experiment, gives the answer" – and this is in turn strictly related to one of Bohr's lessons, complementarity, or deciding which aspect of nature one wants to ask

certainly not alluding to some doctrine or interpretation of quantum physics:[56] the *Kopenhagener Geist* represented for him a peculiar *modus operandi*, or better *investigandi*, that he first experienced at Bohr's institute and that he tried to partly recreate in his role as a teacher and group leader (and both aspects are deeply intertwined with heuristics, in Wheeler's case). That is certainly a picture very different from the folkloric *Bohr the Inquisitor,* even if Wheeler himself, during the Everett "incident", did not exactly experience an openness to dialogue from Copenhagen's side (that is a case in which his role as a mediator was not very successful).

We have already anticipated that some features of Wheeler's way of practicing physics would gradually become encapsulated in his own physics. As we shall repeatedly discuss in the second group of chapters, his emphasis on asking questions would play a crucial role in the "it from bit" phase and its preparatory years. Accompanying that, there is not only the memory of Bohr's example – needless to say – but also a sort of "eschatological Bohr": this new physics is going to be indebted to his lesson (and thus Bohr's importance will be fully appreciated only in times to come), but he is also, in a sense, a shadow or hidden character of the storyteller (Furlan 2020a). When Wheeler anticipates the moment in which we will find out the answer to "How come the quantum?", he also says that we will exclaim: "Oh, how could it have been otherwise!" (Wheeler 1990, p. 322) – and, if we have been listening attentively to his stories, we can recognize Bohr's words when they first heard about nuclear fission:

> "Just as Bohr was leaving Copenhagen on this trip, taking along his assistant, Rosenfeld, and his son, Eric, he received a visit from Frisch, the refugee from Germany that I had met six years before, telling about

questions about.

56A late exception, possibly adapted to what was at that point common parlance, is the following passage: "Under Bohr's leadership, the "Copenhagen interpretation" of the new quantum mechanics was hammered out in the late 1920s. It was that interpretation that Bohr defended in his famous on-again, off-again debates with Einstein. It is that interpretation that has withstood every onslaught since, but which is still debated – and is still a source of uneasiness for many physicists, myself included. Some are uneasy because the Copenhagen interpretation sweeps away certainty at the core of physics, replacing it with uncertainty. That's what Einstein couldn't accept. I am uneasy for a different reason. I see no bedrock of logic on which quantum mechanics is founded. What is the underlying *reason* for quantum mechanics? I keep asking myself. It has to flow from something else, and that something else remains to be found" (Wheeler 2000, p. 123). Just a few pages after that, Wheeler uses another expression for what we have been referring to, "culture of questioning, searching dialogue": "Although Bohr never had a hard word for any other person and could always find something good to say about anybody's work, he did expect visitors to Copenhagen to adhere to the institute's culture of questioning, searching dialogue" (*ibidem*, pp. 126-127).

> the discovery of the Fission of Uranium. And Bohr immediately said: "Oh, how could it have been otherwise! Oh, what fools we've all been!" (Wheeler 1996a).[57]

Bohr was then at the beginning but also at the end of what Wheeler was imagining; but he was not absent from the path in-between, even if Wheeler was dedicating himself to topics apparently marginal among Bohr's interests, such as the astrophysical and cosmological implications of general relativity. As a matter of fact, when Wheeler decided to work in that direction, he chose Bohr as one of the heroes of the heuristic methodology he came up during his transition from nuclear physics to gravitation: "daring conservatism".

5.2 Hero of daring conservatism

"Taking well-established theories and (daringly) applying (and trusting) them far beyond their traditional domain" (Blum, Brill 2020, p. 142): the enunciation of Wheeler's "daring conservatism"[58] is deceivingly simple, but there is no point in trying to articulate it much more now, in the abstract – in the following chapters we are going to see its implementation and its various facets from the 1950s on. It is not surprising, in the wake of all we have been saying (and also of the juxtaposition between Bohr and the founders of religions), that the *summa* of the first years of daring-conservative explorations of geometrodynamics (Misner, Wheeler 1957) opens with a decidedly unusual epigraph for a physics paper: "I transmit but do not create; I am sincerely fond of the ancient", attributed to Confucius.[59] Let us start, however, with a few passages that characterize Bohr[60] as the hero and, later, even the father of daring conservatism.[61]

57Wheeler's own phrasing is not irrelevant, since Frisch recalled it similarly but without the expression we have been commenting: "I remember how he struck his head after I had barely started to speak and said: 'Oh, what fools we have been! We ought to have seen that before'" (Frisch, Wheeler 1967, p. 47).

58"Dynamic conservatism" – another variant of the name heard in Wheeler's circle (the enunciation of this heuristic methodology mainly belongs to an oral community) – was also a slogan by Eisenhower. While this is a half-jocular nod that does not hide Wheeler's political sympathy, see (Wheeler 2000, p. 225; 284-286) for his more complex relation with Eisenhower.

59The other great "ancient", if not the main one alluded in the *contents* of that paper, is of course Einstein; but the underlying attitude, inspired by Bohr, is highly relevant too.

60"Bohr, with his characteristic mixture of cautiousness and daring..." (Snow 1981, p. 56).

61See also the previous footnote about Kierkegaard and thinking problems through to their

Towards the end of “Relativity Notebook 3” (p. 300), which covers a period between 1954 and 1955, we can find an excerpt from some unspecified review. If, however, we confront its content with the titles mentioned in the previous pages, it turns out that the book being reviewed was the second edition, in two volumes, of Whittaker’s *History of the Theories of Aether and Electricity*.[62] Here is the quote that caught Wheeler's attention:

> “Probably the most important theme of the books is that the great and “radical” theories were often the fruitful acceptance of an earlier suggestion or, more commonly, a successful amalgamation of various aspects of currently competing theories. […] Bohr’s atomic theory is described by Whittaker as being based on nine fundamental principles, the first eight due to Conway, Nicholson, Rutherford, Ritz, Planck, and others, and the ninth, he renunciation of any classical explanation of electronic transitions, the one new element that Bohr added to create a successful theory”.[63]

A few years later, Wheeler himself would thus summarize Bohr’s daring-conservative feat:

> “Don't give up Coulomb's law of force between charged particles. Don't deny that an accelerated charge radiates. Accept instead the consequences of the inescapable quantum of Planck for the motion of an electron in an atom. With this daring conservatism Bohr resolved the crisis of 'atomic collapse' and opened the door to the understanding of atomic structure” (Wheeler 1971b, pp. 266-267).

Finally, more than thirty years later, in a sort of self-assimilation to the character of his own story (and inner model), he would even venture to ascribe the paternity of “daring conservatism” to Bohr in person:

> “Niels Bohr liked to speak of “daring conservatism” in pursuing physics. That is what I see in this volume. Nearly every chapter reveals a scientist who is hanging on to what is known and what is valid while, with consummate daring (or should I say derring-do?), pushing beyond the limit of what current observation confirms onward to the outer limit

very limit.

62Incidentally, it would also become a required reading for the participants in the *Sources* project.

63See also (Blum, Furlan 2022, p. 284) for another eloquent passage – by Wheeler himself – than can be found in his archives.

of what current theory allows" (Wheeler 2004, p. xi).

When Wheeler could still speak to Bohr "face to face", however, he had a different – meaningfully different – tone. In a letter to him dated 24 April 1956,[64] Wheeler wrote:

> "Not having been able to discover yet any sign that this [sic!] what I call conservative and invention-free approach is crazy, I struggle on stupidly like a freshman. He thinks he has in his textbook all the principles for the solution of his problem, and has the right numerical answer at the back of the book, and only has to juggle things together to come out with this answer".

And in the same letter he added: "To this question I have no answer except like the freshman to fumble stupidly ahead from step to step hoping that the veil will be lifted little by little".[65] Almost half a century later, this kind of language and imagery was transferred upon Bohr himself in Wheeler's narrative, as we have seen when the young Bohr visits J.J. Thomson. If everything seems to fit well together, a couple of comments are now in order, however, concerning (1) the relation between daring conservatism and Wheeler's uses of history; (2) the relation between the daring-conservative Bohr and the Socratic Bohr.

Regarding the former point, as much as it is easy to perceive a resonance in attitude, there is no logical necessity tying the two: one could in principle adopt daring conservatism as heuristic methodology, trying to push some available successful formalism to the limit, without caring about its history. In a sense, we could say that, in Wheeler's case, his general attitude towards the past fits naturally, when restricted to formalism and technical aspects, with daring conservatism; but perhaps we can suggest something else in the wake of Bohr's own example. In 1963, the laconic Dirac, during the "Commemoration of the Fiftieth Anniversary of Niels Bohr's First Papers on Atomic Constitution" held in Copenhagen, recalled Bohr's tendency to start a

64John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 5.

65It is also quite revealing that in the mid-'50s, regardless of their long-standing relationship and all the time they (and their families) spent together, the letters are still addressed to "Professor Bohr", as proper for a "freshman". Nevertheless, Wheeler's downplaying himself in front of Bohr in this way should not be over-emphasized – for instance, in "Relativity Notebook 4", p. 45, also from 1956, he wrote: "About Apr 5 talked with Feynman. He felt that what I call the freshman approach is rather forced". In any case, Wheeler was also aware of "the touch of formality that did enter into my relationship with Bohr" (Wheeler 2000, p. 143).

speech telling the story from "Adam and Eve".[66] While this could be considered just a rhetorical feature (that somehow was also passed down to Wheeler), in the light of the stimulating but largely unappreciated work of Ulrich Röseberg (1994) we could instead see this as sign of Bohr's deep awareness of the historical path of scientific reason or, with a less grand expression, of the choices that had been made in the first phases of a theory still *in fieri*. Thus, to recall this historical trajectory (not arbitrarily back in time, as Dirac's ironic expression may suggest) meant to keep in mind that new developments were still taking place within a heuristic framework, that Bohr himself, by the way, had been to quite a large extent responsible for establishing and then directing. We may call it a paradigm in a sandbox, which, however, can be easily forgotten once a series of results is obtained. That was close to what Wheeler, from the mid-1950s, started to do within his own circle of students and collaborators: a polytropic pursuit of ideas, yes, but within a controlled framework (or a guiding vision that coordinated the various efforts). At this point, we are already in the position to guess that the hero of daring conservatism was not merely making "truth-preserving" deductions, but thoroughly exploring options that had not entirely abandoned their questioning character. We will further remark on this interrogative side of daring conservatism – as applied to geometrodynamics – in Chapter 2.

The way the features and functions of Bohr as a character merged together, as much as they are distinct, was actually even tighter. In the same way Wheeler was drawing an analogy in the letter to Debye, he was also seeing a similarity of situation between the great problem he soon identified in his new field – that is, the issue of gravitational collapse – and the context in which the daring-conservative Bohr had performed his feat, namely the paradox of the electromagnetic collapse of the atom (since a moving electron, according to the physics of that time, was supposed to radiate and lose energy, and thus collapse on the nucleus). It is an admittedly idiosyncratic and partial analogy, perhaps best explained if, as we shall see in the following chapter, we keep in mind that Wheeler too, with his daring conservatism, was trying to prevent the final stages of gravitational collapse as pioneered by Oppenheimer, Volkoff and Snyder. However, as we are going to see when examining the issue in detail, things were not that simple, nor did Wheeler's acceptance of the formation of black holes prevent him to push the analogy between "collapses" in bizarre ways to raise new (and not rarely fruitful) questions: Jan Oort, after listening to Wheeler's *From Mendeleev's Atom to the Collapsing Star* (Wheeler 1971b), approached Janette and expressed

66John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 90.

genuine concern – out of friendship – for the mental health of her husband.[67] Regardless of the effect that Wheeler's analogy-making could have on others, that was part of the way in which he was thinking about his own endeavors. Thus, this tells us that Wheeler was not only adopting a methodology inspired by, or even learned from, Bohr, and then applying it at his own discretion: there was a historical analogy that warranted its application to the laws of gravity. Therefore, even if there would be much else to say about Wheeler and Bohr, we should now turn to the man who provided the best theory of gravitation.

6. Einstein

Before Bohr, before Breit, there was Herzfeld – if Heisenberg could say: "From Sommerfeld I learned optimism, in Göttingen mathematics, from Bohr physics" (Mehra, Rechenberg 1982, p. 3), Wheeler could have started an analogous sentence with the name of his now-not-so-famed Ph.D. advisor in Baltimore.[68] Herzfeld's contributions to physics – which include topics such as the theory of metals, the study of states of aggregation, the electronic structure of polyatomic molecules, and ultrasonics. – are of little interest here: what matters is that he taught the young John to feel in his heart an unshakable optimism in the comprehensibility of nature.[69] That was also what Wheeler perceived in Einstein during his very first meeting with him, in 1933, notwithstanding the young man's skepticism regarding his lines of research. Wheeler noticed Einstein's alienation from the developments in nuclear physics; he would reproach him for his lack of knowledge and interest in this field, in the following years and for the rest of his life. But more important for Wheeler was a peculiar trait of Einstein's – a broad and deeply unitary vision, a powerful physical insight, and a sense of elegance guiding the play with equations.

> "In October 1933, only a month or so after I started to work with Breit, Albert Einstein came to America. Then fifty-four, Einstein was so

67See "Relativity Notebook 18" (pp. 18-19).

68As Wheeler recalls in the obituary of his advisor (Wheeler 1979c) – that he found himself writing when he was about to enter Einstein's centennial celebration –, from time to time Herzfeld was actually substituting for Sommerfeld in Munich.

69"Physics for Herzfeld was not a secular, but a religious calling; it aimed, in his view, to make clear the structure and beauty of God's creation" (Wheeler 1979c). As much as Wheeler did not share the Catholic faith of his Austrian advisor, his conception of physics as an investigation that transcends academic or laboratory boundaries was to characterize his whole career. See Chapter 6, as already hinted at.

> famous that his first scheduled talk in Princeton that fall was not publicly announced, for fear of an overflow crowd. Eugene Wigner called his friend Breit to invite him to attend. Breit accepted and took me with him. That is how I first met Einstein. It was my impression, based on listening to him that day, that he was no longer at the frontier. He seemed to be pursuing his own idiosyncratic track in a direction veering away from the main stream of physics. How strange that I, a youngster, should so cavalierly dismiss the greatest physicist of this century" (Wheeler 2000, pp. 111-112).

Even so, the confident and radiant trust in the intelligibility of nature left its mark in that first encounter:

> "There was one extraordinary feature of Einstein the man I glimpsed that day, and came to see ever more clearly each time I visited his house, climbed to his upstairs study, and we explained to each other what we did not understand. Over and above his warmth and considerateness, over and above his deep thoughtfulness, I came to see, he had a unique sense of the world of man and nature as one harmonious and someday understandable whole, with all of us feeling our way forward through the darkness together" (Wheeler 1980b, pp. 99-100).

Einstein's "Raffiniert ist der Herr Gott, aber boshaft ist Er nicht" became a favorite of Wheeler's: he would see it chiseled in stone above a fireplace in Fine Hall (now Jones Hall) at Princeton (Wheeler 2000, p. 25). A quite remarkable comparison can be made between the above quote and a few words by Oppenheimer (who, after meeting Einstein in his youth for the first time, was even less impressed than Wheeler, to say the least). Since Wheeler and Oppenheimer, as we shall mention more than once, were not very frequently on the same wavelength, their convergence is all the more significant and shows that, on this point at least, Wheeler was not so idiosyncratic, after all.

> "Even above his humanity and kindliness, even above his immense analytical power and depth he had a quality that made him unique. This was his faith that there exists in the natural world an order and a harmony and that this may be apprehended by the mind of man. He left us not only the greatest contribution in evidence of that faith, but the heritage of that faith itself".[70]

70J. Robert Oppenheimer Papers, Library of Congress, Washington DC, Box 256, Folder "Einstein, Albert – Article for Princeton *Packet*"; as quoted in (Schweber 2008, p. 275).

Here we can already find one of the main features of Wheeler's Einstein, then: faith in the comprehensibility of nature. A simple point, apparently, that was however re-elaborated by Wheeler and meshed with Leibniz's *harmonia praestabilita* as well as with the appropriation of the phrase by the great Göttingen mathematicians at the beginning of the 20th century (see Chapter 4), with specific reference to the relation between mathematics and the physical world.[71] In a sense, that also seems somehow presupposed by the confident boldness of daring conservatism (if not as a metaphysical or ontological thesis, at least as a pragmatic one: physics, with its mathematical language, works);[72] and even Wheeler's expectation about the simplicity of the answer to "How come the quantum?" reveals a similar belief, after all.

The seeming contradiction between the powerful personal effect that Einstein could make and, at the same time, the strong perplexities about his later activities is easily explained by the aura, so to speak, that he must have emanated – an aura stemming from his great deeds back in the day, of course. In other words, he was a hero, but he was history. Unlike Bohr, Einstein was not portrayed by Wheeler as an *exemplum* of daring conservatism – rather, it was his "vision" that was turned into a subject matter of daring conservatism (if not *de facto*, at least for quite a long time, *the* subject matter).[73] "The vision that animated Einstein throughout his later years – a vision I had many an occasion to discuss with him – was a vision of a totally geometric world, a world in which everything was composed ultimately only of spacetime" (Wheeler 2000, p. 234).[74] If that became a shared aspiration between the two

71Of course, when speaking of Einstein himself, the most obvious reference for this correspondence between mathematics and physics would be Spinoza: *ordo et connexio idearum idem est ac ordo et connexio rerum.* Wheeler, however, was not much knowledgeable about Spinoza, even if, as we shall see in a few pages, he actually made some "research" to better understand his role for Einstein,

72"That every mystery can be unveiled is not of course a theorem to be established by logic, but an article of faith, to be justified by its consequences" (Wheeler 1956, p. 362).

73As already remarked, it is no coincidence that Wheeler began to enunciate and elaborate explicitly his methodology in the moment in which he redirected his research interests and decided to revitalize Einstein's most beautiful theory. The way Wheeler would very soon link it to other developing branches of physics – updating it to the new situation, in order to unleash its potential – is already an instance of *Einstein redivivus,* even a little before the latter actually passed away. "What I learned in teaching the course was that the riches of Einstein's theory had been far from fully mined" (Wheeler 2000, p. 231): that was the task he took upon himself and his group.

74Even if we have largely suspended judgement with reference to the "philological" correctness of Wheeler's stories, here – especially since he is referring to many conversations – we cannot but perceive some quite strong tension with what was claimed by Lehmkuhl (2014) about Einstein not endorsing a geometrization of physics. This may deserve some further investigation, both on the Einstein side and on the Wheeler one. Lehmkuhl was considering Einstein's statements until the late '40s, so that it does not exclude, in principle,

of them, that does not mean that Wheeler's doubts about Einstein's unified field theory had been resolved – on the contrary. Wheeler, like many others, considered Einstein's late activities as marred by the rejection of quantum physics; that does not imply that he did not attempt to convince him – famous is the story of Wheeler taking Feynman to Einstein's home to illustrate his "sum over histories" and try to make quantum mechanics palatable to him (Wheeler 2000, p. 167) – or that he just dismissed his work after the 1920s without serious consideration. In Chapter 2 we will mention a couple of specific points in which the confrontation with Einstein's positions or results is quite explicit. Here, however, we may just say that, quite soon, Wheeler seemed to reach a conclusion: in his notebooks (more precisely "Relativity Notebook 2", p. 42) we can find even an *obituary* of unified field theories.[75] He instead addressed his own attempts of that period as "already unified field theory": the daring-conservative Wheeler had identified his starting point in the Einstein-Maxwell Lagrangian and, from that, he intended to build as much as he could – possibly everything. He thought he had found the way to read both gravitation and electromagnetism in pure geometry, as we shall reiterate in Chapter 2, and thus he did not need to bring them together with some formal device. It is of course a point of radical departure, but there seems to be little doubt that there was some shared aspiration between Einstein's and Wheeler's theorizing.

> "Things did not go in the world as Einstein had hoped. Things did not go in physics as he had desired. Determinism stood in ruins. His search for a unified geometric theory of all the forces of nature came to nothing – though today, with a new and wider concept of what geometry is, in the sense of a so-called "gauge theory," marvelous new progress is now being made toward his dream of unification. He left us in general relativity with an ideal for a physical theory that has never been surpassed. He showed a unique talent for finding the central point in every subject to which his philosophical antecedents gave right of entry.

some further concession to geometrization in the final years (Wheeler vaguely speaks of "later years", after all, as much as the emphasis given by that "throughout" does not seem to limit them to the very last decade of Einstein's life...). Otherwise, it may very well be that Wheeler just heard what he wanted to hear; or that Einstein did not object too much to a geometrizing reading of his results (after all, even Lehmkuhl, at the end of his paper, recognized that theoretical possibilty); or that Wheeler was later back-projecting, as we have already seen. A mixture of these factors is of course possible, too. In any case, if we follow Lehmkuhl's reconstruction, it turns out that Wheeler's geometrodynamics is actually much closer to Weyl's views: that is certainly another plausible element, given the debt Wheeler (1986b) recognized towards him – although in that case too we can see the storyteller at work, with some quite peculiar attributions to Weyl...

75See also (Blum, Brill 2020).

> He did as much as any man who ever lived to make us face up to the central mysteries of this strange world" (Wheeler 1980b, p. 113).[76]

We thus realize that, behind the phrase "Einstein's vision" (Wheeler 1968a), there is actually a personal act of selection: no wonder that, after Einstein's death, as we have already noticed *en passant*, Wheeler spoke of Einstein's "geometrodynamics" *tout court,* in a process of assimilation similar to Bohr becoming the father of daring conservatism. Pangeometric aspirations – but just with the tools of general relativity – are thus the second central element that we can identify in this storyteller's character. There is not much need to dwell now on these points, as we will discuss them in detail in the following chapters.

A sort of corollary of these two elements is represented by the grand style that Einstein's *exemplum* inspired in younger theorists, such as Wheeler himself: a powerful and ambitious guiding vision for the future, faith in the understandability of nature, as well as the historical success of the (younger) Einstein. If, from what we have just sketched, the "philosophical" breadth of horizons in this way of thinking about physics is obvious,[77] the fact that Wheeler began to deal with Einstein's theory and its prehistory arguably broadened also the historical scope that was immediately relevant to his work, and thus catalyzed his construction of grand narratives. For instance, the idea of "geon" – that is, a mathematically possible solution of general relativity (see Chapter 2) – could be thought of, at least at the peak of Wheeler's initial enthusiasm after formulating it, as the completion of a grand trajectory starting with Newton and going through Einstein, since it seemed to offer "for the first time a completely classical, divergence-free, self-consistent picture of the Newtonian concept of body" (Wheeler 1955, p. 511).

> "Through Albert Einstein's work the horizon of mankind has been immeasurably widened, at the same time as our world picture has attained a unity and harmony never dreamed of before. The background

76The curious remark about "gauge theory" can also be found in the imaginary conversation with Einstein's spirit (Wheeler 1979a). I redirect to the Conclusions for more insights into that.
77Incidentally, the curious expression "intracranial colleagues" comes from Wheeler's reflection on the importance of the philosophical authors that influenced the young Einstein's way of thinking, from Spinoza and Hume to Schopenhauer and Mach, as well as other great physicists whose lesson and viewpoint Einstein had been keeping *in mind*: "That unique experience with things and how they work joined forces in him with a love of studying or discussing with the great thinkers. No one could speak to Einstein without feeling that Maxwell and Maxwell's struggles and Maxwell's great words lived in his mind; and not only Maxwell but an entire travelling intracranial cast of daily colleagues: Leibniz, Newton, Mach, Boltzmann, Ehrenfest, Planck and Bohr" (Wheeler 1979d).

for such achievement was created by preceding generations of the world community of scientists, and its full consequences will only be revealed to coming generations".[78]

As quite typical of Wheeler's case, all these elements tended to gel together: let us see it concretely.

"Bern, Switzerland, gets its name from an open-air bear pit. There one can watch the bears go round and round on all fours with head to the ground. A young patent office clerk named Albert Einstein liked to take his visitors there. Only very rarely, he pointed out, does one of the animals rear up on its hind legs and look around for the wider view. To Einstein that bear represented the thinker. To us, let it symbolize, by extension, one who rises to the larger view – and from that vantage point recognizes what is missing, and fills the gap. [...]

What did Einstein mean by harmony? You will know if you have seen his words of admiration for Niels Bohr and for Bohr's ability to see amid a maze of distracting evidence the quantum nature of the atom – "He has the highest form of musicality in the sphere of science". What did Einstein mean by harmonious structure? He meant what his mentor, model and hero, Benedict de Spinoza meant: a universe that is beautiful, simple and understandable – even if not yet understood. As Josiah Royce puts it, speaking of Spinoza, but for us speaking of Einstein, he is one who "sees everywhere an all-pervading law, an all-conquering truth, a supreme and irresistible perfection" and, even if he himself does not yet have, nevertheless envisages us all as someday having "a clear vision of the supreme and necessary laws of the eternal world". Discover new unity! That is how Hutton, Darwin, Mendeleev, Einstein and Bohr made their contributions" (Wheeler 1979e, pp. 396-397).[79]

78This flows well with the rest of the quotes and it does sound like Wheeler... but it is actually a passage from Bohr's article for the *Unesco Courier* issue celebrating Einstein's 70th birthday (Bohr 1949, p. 1)!

79We may also add that Wheeler used to take note of expressions of mutual esteem between his two main inspiring figures, as he would comment with satisfaction: "Oswald Veblen, one of Bohr's hosts at the Institute, told me of his surprise when the gladiatorial combat he had been expecting between the two giants did not occur. No jumping up and down. No pounding of fists. Einstein sat quietly, listening to Bohr lecture, saving his discussion for their private meetings" (Wheeler 2000, p. 21). Even more: "The early quantum work of Bohr and Einstein is almost a duet. Einstein, 1905: The energy of light is carried from place to place as quanta of energy, accidental in time and space in their arrival. Bohr, 1913: The atom is characterized by stationary states, and the difference in energy between one and another is given off in a light quantum. Einstein, 1916: The processes of light emission and light absorption are governed by the laws of chance, but satisfy the principle of detailed balance. Bohr, 1927: Complementarity

This is clearly an example of (creative!) monumental history, but it is not mere rhetoric. It is taken from Wheeler's "manifesto" about the notion of the "seeker" (see Chapter 6), who transcends institutional and disciplinary boundaries trying to grasp the secrets of nature. But we can also see an element of intellectual genealogy, so to speak, that in other passages becomes much more explicit – thanks to a few "links of the charismatic chain" (Wheeler 1963a) – and represents, not so covertly, a sort of pedigree of Wheeler's own ideas. After all, when speaking about role models, we have already commented on Wheeler's interest for what Spinoza could represent for Einstein (and the quite generic sentence from the last quote should not be taken in an overly "bookish" way, e.g. to evaluate up to which point Spinoza's thought may have actually shaped Einstein's physical cosmology and his prejudices, and so on). That is just one element, however. Here the whole process is even more evident:

> "I think back to Bernard de Spinoza [sic!] in the seventeenth century; to Bernhard Riemann, William Kingdon Clifford, and Ernst Mach in the nineteenth; and to Niels Bohr in the twentieth. Spinoza's belief in the harmony, the beauty, and the ultimate comprehensibility of nature had a profound effect on Einstein. What else could have led Einstein to express his sympathy for the Good Lord if general relativity proved to be wrong? Through Einstein and his followers – Dirac, Murray Gell-Mann, Feynman, and others – it has become an article of faith in twentieth-century physics that if a theory is simple enough, comprehensive enough, "beautiful" enough, it must be right. More than half a century before Einstein, the great German mathematician Bernhard Riemann dared to speculate that the geometry of physical space need not be God-given Euclidean space, but could well be some other geometry and should be determined by experiment, not by hypothesis. William Kingdon Clifford imagined that space could be a dynamic substance capable of deformation that could propagate like waves. Later, Mach postulated that inertia "here" results from mass "there". Einstein brought all of these speculations into the realm of "real" science. And it was not mere coincidence. He was influenced by the thinking, at least, of Riemann and Mach" (Wheeler 2000, pp. 355-

prevents a detailed description in space and time of what goes on in the act of emission. Here Bohr and Einstein parted company. Einstein spoke against Einstein. The Einstein who in 1915 said there was no escape from the laws of chance was insisting by 1916, as he did all the rest of his life, against the evidence and against the views of his greatest colleagues, that 'God does not [play] dice'" (Wheeler 1980b, p. 110).

356).

Perhaps with a slight overreading, we may suggest that the *lapsus* on the name of Spinoza – who received instead that of Riemann –, besides revealing Wheeler's vague knowledge of him, is quite eloquent about the storyteller's way of positioning the two of them into these narratives, almost as if Spinoza were as a sort of philosophical equivalent, for Einstein, of the mathematical "forerunner" Riemann. At first it may even sound like name-dropping, but this is actually the "charismatic chain" that runs down history and that is forged via the assimilation of "intracranial colleagues": "No one could speak to Einstein without feeling that Maxwell and Maxwell's struggles and Maxwell's great words lived in his mind" (Wheeler 1979d). If the link between Maxwell and Einstein is typical of narratives of unification, for obvious reasons, it is worth remarking that Wheeler, when he resorted to that (and contributed in his own way to the epic of unification that later became mainstream), meant something more, especially from a human and intellectual point of view. He himself tried to give new life to Einstein's "struggles and great words", not least by speaking of *Einstein's* geometrodynamics while illustrating a phrase that later became over-abused, "Einstein's Dream":

> "Thus Einstein gave geometrodynamics to the world in November 1915 as Maxwell had established electrodynamics fifty years earlier. Einstein dreamed of more, of all matter and all forces as constructs out of pure geometry and nothing more. Today the gap appears to be wider than ever between the beautiful geometrical simplicity of Einstein's vision and the wealth of structure revealed in elementary particle physics. However, the union of the quantum principle with Einstein's geometrodynamics opens out new pathways for progress, and Einstein's dream of matter as a state of excitation of a dynamic geometry remains very much alive".[80]

And thus we are back to the challenge of quantum gravity as Wheeler's personal attempt to develop and reconcile the legacy of his two great mentors and models, not just by looking back in time, but trying to guess what lies ahead in the future:

> "Arthur Wellesley, Duke of Wellington, in the long years of activity in England that followed Waterloo, from time to time for relaxation would take a companion along for a carriage ride of hours through a distant

80Relativity Notebook 14, p. 42. That is the abstract of an unpublished speech, "Einstein's Dream As Seen Fifty Years Later", delivered by Wheeler more than once during 1966.

> countryside unfamiliar to them both. The Iron Duke was accustomed to draw his companion into his favorite game. From the look of the terrain up to this moment, predict what new panorama will be seen as the carriage tops the next long hill. Wellington generally produced the winning forecast of the lay of the land. Einstein traveled through a different countryside. His ability to sense ahead of time the upcoming landscape of physics is well known. Today we find ourselves traversing a new realm. It contains such strange features as the black hole, the gauge or phase field, and complementarity. What lies beyond, over the hill? If all strangenesses of a landscape made for Wellington the best indicators of the new terrain, the same was true, we know, for Einstein and the same surely holds for physics now. There is no hope of progress, we often say, until we are in possession of a central paradox, a difficulty, a contradiction. However, in our hearts we know it takes more. We need two paradoxes. Only then can we play off one against the other to locate the new point. Two strangenesses stand out with special prominence in the landscape of the physics of our day: one is the Bounds of Time; the other, the Quantum" (Wheeler 1980a, p. 341).

Should we add, at this point, that even this method of the paradoxes was inspired by Bohr (Wheeler 1971b, p. 289)? It no longer seems necessary: we know that the Einstein-Bohr dialogue went on for many decades in Wheeler's intracranial symposium, which, especially from the 1970s on, was enriched by other distinguished colleagues from centuries past (see Chapter 4). There is an adjective that Coleridge coined specifically for Shakespeare: "myriadminded" – *si parva licet,* there is no physicist of the last century who seems more fitting to having it applied. Perhaps not without some *coquetterie*, late in his life Wheeler would even regret that, in 1939, he had to work with Bohr on understanding fission, thus taking him away from his dialogues with Einstein (Wheeler 2010): the war years came, and "one of the greatest debates in history" died down irreversibly. Wheeler, in other words, paints himself as the proverbial businessman from Porlock, whose intrusion forever deprived mankind of the completion of *Kubla Khan*. After all we have been saying in this chapter, we may very well object to this self-portrait, but perhaps it is better to consider it according to the subtitle of Coleridge's fragment: "A vision in a dream". We can now begin a more detailed analysis of Wheeler's "visionary geometrodynamics".[81]

81In the light of what we have underscored in this chapter about the making of narratives, as well as back-projections and rhetorical-strategic forms of anchoring, we may offer some insights also on today's quantum gravity approaches. As is well-known, the latter are dealing with issues that have been staying open for a while (Wheeler himself was raising a number of these questions as early as the 1950s or 1960s, for instance). It seems natural, therefore, to

focus on heuristics, as well as on historically-informed perspectives on the conceptual strategies that the various approaches have tentatively adopt; it is therefore interesting and relevant to pay attention to the ways these approaches have been trying to legitimize, in absence of empirical tests, their own ideas, proposals, and alleged successes. Given all that, we are already moving into a very different order of considerations than the machinery that Dawid (2013) developed to claim "non-empirical" – or, as he later put it (Dawid 2020), "meta-empirical" (this shift was actually first announced at the MPIWG workshop "Non-Empirical Physics from a Historical Perspective" in March 2019) – confirmation for string theory. If we take Dawid's ideas as he presumably means, however, we would just end up insisting upon upstream differences in our conceptions of how science works and how philosophy of science thinks (or should think) about that – in other words, the debate would not be very productive (answering issues of historiographic setting with a Bayesian calculation is an excellent example of a dialogue of the deaf). Nonetheless, there is little doubt that the way Dawid is using history is simply untenable, and the narratives or compilations that, in the case of recent physics, he seems to mistake for historiography are distorting, superficial, and partial. Of course, history typically does not seem to play a big role in *that kind* of philosophy of science, so that one might dismiss these remarks as nuances for historians. However, there is also an implicit, and arguably unaware, reliance on history and historiography that *does* play a big role in endorsing a narrative about the successes of a certain approach, its key developments, and so on. Since these are supposed to provide the basis for the seemingly logical operation called "meta-induction", it is no trivial matter. In these quick remarks we cannot prove that this is indeed what is happening when Dawid is referring to episodes (or to the overall development) of string theory; hopefully, it will soon become clearer once serious historiography about string theory will be available: see e.g. (van Leeuwen 2024), whose considerations on the shifting role (and meaning) of the "empirical" in some phases of the history of string theory are arguably more than sufficient to open very different horizons from Dawid's (and arguably more interesting, too). Wheeler's way of building narratives to support his own "non-empirical" speculations, giving them a pedigree, pushing research activities in certain directions, and creating a feeling of cohesion and belonging (a "monumental" use of history), is, so to speak, a particularly flamboyant and unfiltered version of analogous narratives that each quantum gravity approach has been creating, not just for internal use but also for a larger public, as the plethora of more or less popular books on the frontiers of physics (each one telling a partial and one-sided story) can attest during the last two or three decades (Furlan 2020a). Another eloquent and rather illustrious example is represented by (Polchinski 2002), where the distinguished string theorist, for the Heisenberg Centennial Symposium in Munich (December 2001), tried to establish links between some rather generic aspect (or ambition) of Heisenberg's late proposals and string theory. Polchinski presents in a surprisingly favorable light the 1958 *Weltformel* as a precursor to the numinous M-theory:

sure – it could be said – Heisenberg's attempt is definitely a precursor in terms of ambitions, and during a celebration in his honor it is not so surprising to hear someone speaking in positive terms of the boldness (at least) of such an endeavor. That is not where Polchinski stops: far from it. He explicitly builds a pedigree (Heisenberg-Chew-Veneziano-strings) for string theory and, then, in a footnote (p. 8), he even adds a further "historical" certificate, a confidential remark he got from Helmut Rechenberg confirming and even making those ties stronger. The actual aim, however, is not establishing a link to the Heisenberg of the Weltformel, but to the young Heisenberg of matrix mechanics - hence Polchinski's invitation "On to Heligoland" (p. 8)! (After all, Helgoland has been instrumentalized in no less obvious ways in even more recent times...). "Today many of us believe that there is a Worldformula. That is, there is a physical-mathematical structure that incorporates quantum mechanics, special relativity, general relativity, and the particles and their interactions, and which is beautiful and unique. We do not know the final form of this theory; *we are like the quantum mechanicians in the early twenties, discovering the theory a piece at a time*" (Polchinski 2002, p. 1; my emphasis). Just a few years later, John Schwarz, in turn, at the joint Yukawa-Tomonaga centennial, began by stating: "String theory builds on the great legacy of Yukawa and Tomonaga" (Schwarz 2007, p. 214). Of course, this is not to suggest that we are in front of some kind of sneaky move: we can easily imagine someone really convinced about string theory being the culmination of previous developments in physics to say something like that, depending on the physicist of the past being celebrated... Besides suggesting these examples, which of course would deserve a more extensive analysis, we can be slightly more analytical about the general lesson for "meta-inductive" arguments in the way Dawid is framing them: nobody has access to a privileged, metahistorical point of view, especially for situations still *in fieri*, on a clear-cut space of possibilities (while philosophers that like to ape mathematics may easily accept this purported "space", such a way of thinking, in this case, seems already an anti-historical extrapolation, mimicking the kind of investigation and exploration of families of theories by varying one or more parameters, as is done in the string framework). "Meta-induction", in cases such as quantum gravity approaches or other highly speculative areas, ultimately seems to rely on recent history as told by involved physicists or by rather superficial compilators: it contains much rhetoric, rather than being some logical-mathematical operation based on a direct contemplation of a clear-cut space of possibilities (even more so – again – for confused situations that are still in the making). Even if we were to play with the same jargon, when the historical accounts one draws upon are partial, biased, and (more or less implicitly) teleological, a meta-inductive argument is as fallacious as an induction based on a set of observations that are selected or biased beforehand. We should rather ask: *how is a meta-inductive argument actually built for a theory still very much* in fieri*?* What we have highlighted in the present chapter about the construction (and use) of narratives of success should offer some powerful insight, although as a proper historical-

critical analysis has to depend on the specificities of the single case (moreover, Wheeler's own daring conservatism can easily be said to have some meta-inductive overtones). Finally, we should notice that this does not compromise the heuristic side of Dawid's arguments (but, from such a point of view, they are nothing really new). In a discussion with Dawid himself during the aforementioned Berlin workshop in 2019, I pointed out how, heuristically speaking, the best situation would be when his three arguments (meta-induction, no alternative, unexpected explanatory power) form a sort of "safety net", supporting or covering the shortcomings of each other; at that point, however, one realizes that the meta-inductive argument also seem to have an overall anchoring function. A very similar strategy was indeed pursued, less than one year later, in (Dawid 2020), with the already mentioned change in nomenclature ("meta-empirical") and slightly different enunciations of the arguments, as well as a new emphasis on their synergy (even if it is suggested – not very credibly, from my perspective – that everything was meant exactly like that already seven years earlier: the historical dimension seems once again poorly perceived...). If we are taking a historical-critical view to meta-inductive narratives as sketched above, though, this possibly ends up facilitating the task of undermining the whole "justificatory" claim.

2. Between Cold Matter and Frozen Stars: The Road Towards Black Holes

In this chapter we are going to follow – or, better, reconstruct – the story of Wheeler's initial resistance against the most surprising theoretical results about gravitational collapse and, then, his conversion, which would turn him into the enthusiastic baptizer and popularizer of black holes that we all know. In order to do so, however, it is necessary to frame his doubts and proposals within his geometrodynamical view and properly outline the latter's salient traits and main functions. This overall trajectory, lasting about a decade, shows well how any account that, more or less tacitly, considers a physics problem as if it were taken from some a-historical textbook (in this case, along the lines of "Make physical sense of the Schwarzschild solution") turns out to be grossly misleading and poor.

> For occasion (as it is in the common verse) turneth a bald noddle, after she hath presented her locks in front, and no hold taken; or at least turneth the handle of the bottle, first to be received, and after the belly, which is hard to clasp.
> – Francis Bacon, *Of Delays*

1. A pursuitworthy matter

Wheeler is well-known today as the man who named black holes, but the story of how he managed to take on that role is far less known. In fact, it is a quite intricate matter spanning more than a decade, from the early 1950s to the second half of the 1960s. Rather than just depicting Wheeler's conceptual struggles and idiosyncrasies, this story is worth considering as it provides a concrete example of the complexity (and richness) of his heuristic trajectory, thereby challenging oversimplified accounts of the history of modern physics (or even of the creative process of its actors). As I already suggested elsewhere (Furlan 2022), such reconstruction of Wheeler's path – from skeptic to a leading authority and enthusiastic black hole popularizer – may be thought-provoking for whoever is reflecting, especially in highly speculative fields, on the notion of "pursuitworthiness" (Šešelja, Straßer 2013) or, to better suggest the idea of a prolonged effort, "worthwhileness" (von Neumann 1947). Far from considering the latter as a sort of conceptual label to stick once and for all to some idea or program, we have to appreciate how Wheeler's struggle with the issue of gravitational collapse had more than a single change in direction, characterized by his sagacious way of managing resources and

coordinating the research of various people within his circle. Speaking of pursuitworthiness immediately shifts the discussion to the heuristic level, of course, but this is not meant to stick a sign on the ground that says: "From here on, anything goes": we rather intend to use Wheeler's assessments – implicit[82] or explicit – of pursuitworthiness at different moments as a sort of wind vane. In this case, one main direction (out of metaphor, a guiding vision or regulative idea: the French *idée-force* comes in handy here) remained approximately the same, but we have to compose it from time to time with velocities of the wind (more circumstantial expectations about specific problems or results) that were not totally aligned and that *did* change. Wheeler's daring-conservative enterprise was certainly not a linear chain of deductions. A sensible notion of pursuitworthiness should be flexible enough to take into account these shifts and the interplay of manifold factors: in order to do that, a close dialogue with some kind of historical reconstruction that does not merely back-project today's established results is necessary.

Expanding on the metaphor of the wind vane, I would suggest or specify at the very outset that, *de facto*, we can distinguish between different levels of Wheeler's research. In the background, during the two decades of geometrodynamics, we have, as a guiding (and organizing) idea, or perhaps as a mirage, an extremely ambitious pangeometric vision, that was admittedly a very long shot – or perhaps better: a *moonshot*, capable of directing and inspiring the efforts of a whole group. That was "Einstein's" vision and, in general, we can detect here that component of "monumental history" discussed in the previous chapter.[83] At a more concrete level, nonetheless, Wheeler also knew how to assign tasks that could lead to solid results in the shorter term and would not jeopardize the career of his students and collaborators. After all, those years were just seeing the first sparks of the "Renaissance of General Relativity" (Blum et al. 2016): the field needed new problems for people to work on, but these new problems had also to appear

82That is, when there was an actual change in course, even if not fully declared.

83Charles W. Misner – Wheeler's former student, trusted collaborator and co-author – once introduced a cautious but helpful distinction: he spoke of a "mathematical" geometrodynamics as distinct from a "physical" and from a "visionary" one. While part of his own work fell into the former two – exploring a general relativistic universe made out of fields as if it were a mathematical model, and evaluating the physical relevance of the insights thus gained –, he left the third entirely to Wheeler (Misner 1974). The guiding view we will be referring to quite often is clearly Wheeler's "visionary" geometrodynamics. Cf. the following passage: "Einstein, above his work and writing, held a long-term vision: There is nothing in the world except curved empty space" (Wheeler 1968c, p. 273). Even if we have said that it constantly remained "in the background", that does not literally mean that it did not change nor become better articulated: we will comment on that in Chapter 3, but one just needs to make a quick comparison between the sketchy paper (Wheeler 1957) and the lectures delivered a decade later, from which the above quote is taken (Wheeler 1968c).

interesting and relevant enough to the rest of the community. As Wheeler himself would recall,

> "In earlier years, I had feared that a student trained in general relativity might have trouble finding a job where his or her training would be an asset and where further work in the field would be encouraged. That is why I had shied away from working in relativity myself in my younger days. I was afraid that students drawn into the work might not be well served. And I could not picture serious work in a field by myself without students. I had seen too many "one-legged" young physicists working with Einstein at the Institute for Advanced Study. I didn't want to promote any similar imbalance at the university. But after teaching that first course in relativity at Princeton, my outlook changed. I began to see a wealth of possible projects, and to see that we might confront theory with experiment as we learned about the universe and its history" (Wheeler 2000, p. 253).

Wheeler was not just the right physicist to identify and promote those new problems, but also the right thinker to coordinate the smaller "blocks" of his collaborators' work within his more ambitious framework; and even the right "politician", so to speak, to find and handle the necessary resources (in terms of people, technology, money, prestige, and so on) and make all that possible.[84] This leading role alone is as important for the story of black hole research as any first-rate contribution, but, of course, it is not a result that gets encapsulated in a formula bearing someone's name.

No less remarkable is the fact that, on specific points, Wheeler actively promoted research in directions that contradicted his own expectations at the time: they would ultimately pay off, since, thanks to the new results he had fostered, he himself became convinced of the physical relevance of the pioneering considerations of Oppenheimer and collaborators. Science corrects itself along the path. The flexible way of thinking about pursuitworthiness that can be suggested by Wheeler's example is arguably related to a robust but not too rigid correlation of these different planes of research. As he put it, "*Whatever the outcome*, one feels that he has at last in gravitational collapse a phenomenon where general relativity dramatically comes into its own, and where its fiery marriage with quantum physics will be consummated" (Wheeler 1964, p. 204; my emphasis). The investigation of the final phases of gravitational collapse certainly seemed pursuitworthy to Wheeler and this, at least, did not change, even if at each step he may have taken a slightly different direction without entirely denying what was previously done.

84We shall return to this point toward the end of Chapter 5.

These considerations are not exclusively related to my own emphasis on the heuristic aspects of the story: Wheeler's daring conservatism itself can be put in dialogue "from within" with the notion of pursuitworthiness. If the inner dynamics of the heuristic process is not grasped, and is instead canceled by a pseudo-historical narrative that lists some milestones and then joins the dots (being thus teleologically directed at the present), the very notion (and use) of "pursuitworthiness" seems to me close to a more or less empty platitude – surely any scientist pursuing an idea that is not immediately achievable does so with the belief and attitude that it is worth of the pursuit. The way we are going to comment on pursuitworthiness and Wheeler's heuristics, on the contrary, is not just meant as a praise of flexibility or of his ability as a group leader: identifying the changes in direction and their factors, while at the same time keeping a powerful guiding view in the background, allows us to appreciate an internal or "proper time", so to speak, in the maturation of Wheeler's ideas. That is already important *per se,* given Wheeler's historical role in this kind of research, but it may also stimulate further considerations when compared with the trajectory of other relevant personalities (as we will sketch in Chapter 3).

This being said, the chapter is structured as follows. The second section, with its two subsections, is a cursory overview of Wheeler`s geometrodynamical program. That is not merely an extended preamble: its content, even if not directly related to black holes, is actually crucial to realize that Wheeler's way of framing and developing subsequent inquiries was very different from the current textbook stories of early black hole research. This part is important also for our considerations on pursuitworthiness, since the tools and questions that Wheeler pursued in that context, at first with dubious success, ended up being successfully exaptated to investigate black holes. The third section, then, illustrates how Wheeler's conversion to black holes came to be and how he abandoned his previous reservations. The daring-conservative exploration of general relativity would thus lead Wheeler to fully accept the challenges posed by the black hole notion, as we shall examine in the next chapter. In this story, overall, it will also be possible to read between the lines – in view of today's quantum gravity situation – some remarks about the risks of procrastination in highly speculative areas.[85]

2. Putting Einstein's vision at work

2.1 What to pursue? Daring conservatism and the particle zoo crisis

85We will expand on that in the Conclusions of the dissertation.

As we have already reiterated, at the beginning of the 1950s Wheeler underwent a professional metamorphosis that pushed him to gradually set aside his well-established career as a nuclear physicist and invest instead in general relativity, Einstein`s great legacy (Blum, Brill 2020). That was not, as one could assume today, an ordinary move: studies about the "Renaissance of General Relativity" (Blum et al. 2016) have underlined how it was only from this period on that a revival of the research interest in that field actually took place, and Wheeler was certainly one of the key figures in the process, for reasons that we have already mentioned. Here we shall refresh a few points, in order to suggest some further considerations.

First of all, it is necessary to keep well in mind Wheeler`s heuristic methodology, daring conservatism – that is, rejecting all free novelties in theorization, while being faithful to already well-established principles and taking them to their extreme consequences, without additional elements. Actually, we shall have occasion to remark how daring conservatism, besides this quite simple and straightforward description, took other interesting shapes, or better represented a background attitude that favored some fruitful theoretical practices. We may first of all notice that it also embodied, with its "minimalist" assumptions, a reaction to the proliferation of the "particle zoo" of those years, called by Wheeler, with a note of contempt, "pion industry" (Wheeler 2000, p. 172; Furlan, Gaudenzi 2021). That was indeed a period of "crisis", in the sense that physicists had to take a moment and reflect upon the balance between theory and experiments, or how to deal with the overflow of new and unaccounted-for experimental data. Some were just adding *ad hoc* terms or building phenomenological models without much theoretical breadth, depending on the latest empirical inputs, and that was a way of doing physics that did not appeal to Wheeler, at all. So, in this situation of uncertainty, he decided to take a gamble and devote himself to the task of dusting off Einstein's legacy – but with a methodology that he supposedly learned from his other great mentor, Bohr. This was, presumably, also a form of self-reassurance, but not in some authoritative form: Wheeler also displayed a remarkable awareness of the tentative, almost "artisanal" character of his own research. For example, in the brachylogy of his own working notes in the mid-1950s we can read:[86] "Our approach is like that of man trying to build bridge out center of well with boards, great in number, but all shorter than diam. of well; we keep going around, working our way towards the center". Given Wheeler's creativity and tendency to pursue different ideas at the same time, I would even suggest that, at a psychological level, daring conservatism could be seen as a way of properly channeling his theoretical exuberance.

This self-awareness of the heuristic character of his own attempts did

86Relativity Notebook 3, p. 63.

not prevent Wheeler from assertively enunciating his viewpoint: for instance, in the sketch of a comprehensive course that he would teach in Leiden, he resorted to the picture of the "tree of physics"[87] to illustrate the risk of mistaking roots for branches, or better to turn upside down the hierarchical scheme presupposed by the practitioners of the "pion industry", who were considering many of the new particles that were being discovered as roots, instead of seeing them only as branches of something deeper. Daring conservatism was thus meant to be *radical.* It was a reaction to the particle zoo, yes, but it was not merely "reactionary": Wheeler's "conservatism" was not aimed at fixing or preserving an old view as an embalmed whole – hence the oxymoronic phrase "daring conservatism". He was actively using well-established (but far from fully-employed) principles to cut through a plethora of confused proposals and outline a future that nobody really knew how it would look like. There is thus a peculiar balance between looking towards new scenarios and preserving something valuable from the past, that still has some untapped potential. Pursuitworthiness too, in a sense, identifies something to be preserved and aspires to see its full realization in the future. Wheeler's daring conservatism, with its attitude towards the past, is using tradition as a generator of hypotheses, inspirations, analogies, while the notion of pursuitworthiness, *per se*, does not have anything similar and seems to presuppose the idea or project one wants to defend and invest on. So, daring conservatism can also be seen as a way to judge if some suggestion or approach is worth pursuing: either the latter is based on established principles "protected" by daring conservatism, or it is a free novelty that, at least for the time being, does not deserve much attention.

2.2 Geons and wormholes

By looking at the Relativity Notebooks from that time, we can notice that Wheeler did not get enthusiastic agreement or support for some of his ideas from other distinguished physicists.[88] However, instead of seeing them as one-shot attempts that may or may not have succeeded, he believed strongly in their value and continued to pursue them. We have already remarked how Wheeler, after he started to teach relativity at Princeton in the academic year 1952/1953 (Blum, Brill 2020), soon realized that "the riches of Einstein's

87Relativity Notebook 4, p. 90. See Appendix B for the actual picture, as well as for a more "iconographical" discussion.

88See for example a conversation with Pauli, in Relativity Notebook 2, p. 131, or with Dyson, in Relativity Notebook 3, pp. 235-236. Besides some doubts about Wheeler's new ideas, what is striking in those comments is the sense of general tiredness and a lack of a clear and ambitious direction – quite in contrast with Wheeler's.

theory had been far from fully mined" (Wheeler 2000, p. 231). What were the first results of Wheeler's daring-conservative exploration of general relativity, then? We should at least mention "geons" and "wormholes" (in the beginning "woodchuck-holes"), which also provide an example of his verbal inventiveness.

A geon – "g for 'gravity,' e for 'electromagnetism,' and on as the word root for 'particle'" (Wheeler 2000, p. 236) – is a mathematically possible solution to the Einstein-Maxwell equations, but, as it soon turned out, its physical relevance is very doubtful, due to its instability. It is a wave that, self-gravitating due to its own energy, stays confined in a region of space, as if it were a body (Wheeler 1955). At first, Wheeler, excited, had great hopes for this new[89] idea: an unknown physical entity that could be seen as the "missing link" between the geometric field and individual bodies. As much as Wheeler was distancing himself from the mainstream of particle physics, he was still struggling with the "particle problem", that is trying to figure out the spectrum of elementary particles from a deeper level. In the past ten years (Blum, Brill 2020), Wheeler's research had been guided by the idea that everything is made up of particles. However, he had recently changed his perspective, in a sort of gestaltic switch, and now believed that everything is actually made up of fields. This meant that he believed that particles too can be explained and understood through the concept of field. That is the context in which we have to place the notion of geon and identify its role within Wheeler's geometrodynamical program. More precisely, the geon was the central tool in Wheeler's sub-program of "mass without mass", that is explaining the origin of mass without postulating its existence from the beginning as a property. The moonshot was, clearly, to devise a strategy to explain why the allegedly fundamental elementary particles had mass, first of all, and even why certain values of mass. The geon, however, besides being unstable, was many orders of magnitudes off the target. Wheeler could still hope that, after a proper quantization of the theory, everything would almost magically fall into place, but that seemed mainly a mixture of wishful thinking and procrastination. Nonetheless, by 1958, at the 11th Solvay Conference, Wheeler was already lucid enough to consider geons as simple models to help understand what happens during gravitational collapse[90] – and that is their actual relevance in

89Notice that it was "new" concept but, at the same time, was already implicated in the well-established starting point of geometrodynamics. In principle, it was not a novelty, but it concretely became a new tool on its own, in order to manage calculations, devise new situations and problems, and so on.

90In his own words: "New idealized situations – such as deformed geons and patterns of electromagnetic and gravitational fields of spécial symmetry – require investigation before one can easily gain enough insight to see what will happen to pure radiation under asymmetric implosion" (Adams et al., p. 126).

the (pre)history of black hole research.

When talking about Wheeler's "wormholes" at this point, it would be wrong to imagine them as cosmic-sized bridges that are formed by catastrophic astrophysical events. Instead, they should be seen as tiny handles (near the Planck length!) in the structure of space. Their function in Wheeler's geometrodynamics (Misner, Wheeler 1957; Wheeler 1957) was to explain "charge without charge": he aimed to read electromagnetism as a property of geometry. The "entry" of the wormhole acts as an absorber or a "pit" of the field lines that are getting trapped in the throat, while the "exit" would look like a source. Wheeler's wormholes are the result of quantum fluctuations of the geometry of empty space, like ripples: as such, they are short-lived and constantly in the process of being made and unmade. That is strictly related to another of Wheeler's core ideas, quantum foam.[91] These microcharges, via some mechanism possibly similar to that of superconductivity, could perhaps behave coherently to form a much larger "cloud": particles as clouds, then.[92] That was the ultimate ambition but, as in the case of geons, Wheeler made his students and collaborators use wormholes to understand little-explored features of general relativity and collapse. (Beside the two attempts at "mass without mass" and "charge without charge", there was also "spin without spin", which has a more complicated story (Blum, Furlan 2022) and is not directly interesting for our purposes here).

What is important to emphasize, then, is that, after initially being excited about them, Wheeler soon began to use these ideas as toy models to understand how the basic principles of geometrodynamics work. Geons and wormholes, thus, did not represent an irrefutable "deduction" from well-established principles, but rather a conceptual tool to explore and question those same principles. This can provide a new way to think about daring conservatism: instead of simply accepting predefined outcomes based on firm foundations, it created questions that were worth asking about them. An interrogative daring conservatism, then (as befitting a method inspired by Bohr). If something is worth pursuing, it means it is suggesting a certain

91See Appendix B for further remarks about the difference between the way the notion is employed nowadays and Wheeler's. Incidentally, even if "quantum foam" finally appears in the title of his autobiographical book (Wheeler 2000), in his papers he used to speak of "foam-like" structure of space at the scales where quantum effects become relevant (Wheeler 1957, p. 609).

92Here is a difference with Einstein and Rosen's partly similar idea of a bridge, which could possibly be applied to neutrally-charged particles (but it had not its origins in quantum fluctuations, nor was it considered as part of a larger cloud!) (van Dongen 2010, pp. 131-132). Nonetheless, (Einstein, Rosen 1935), besides providing a sort of intuitive blueprint, may have influenced Wheeler's thinking and approach to getting rid of singularities. We shall return to this in a few pages.

direction. However, this only applies in a specific moment and situation: later on, that direction can change, without entirely compromising the value of the work that was done – and that is what happened in the case of geons and wormholes, quite differently from what was planned in the beginning. Against overstuffed accounts that do not compare with actual research situations in their complexity and diachronic development, it is good to keep in mind the possibility of some sort of "heterogenesis of ends".[93]

To summarize, in this early period Wheeler defined his guiding vision, as well as three "axes" or sub-programs to approach it, and some models his students and collaborators were put to work on. In a problem-solving perspective in the short term, "mass without mass" and the other two cannot be considered a success. Similarly, the worth of geons and wormholes, if considered in a naively realistic manner, would be open to discussion, to say the least. However, in the following years they definitely proved to be "valuable science-forming ideas", to echo an effective expression by Maxwell (1965 [1872], vol. 2, p. 301). The results developed by working on geons and wormholes soon found an exaptation, being employed in a quite different way from that originally intended. "Pursuitworthiness" and "heterogenesis of ends" is a conceptual couple whose nexus is strongly suggested by Wheeler's story, highlighting how there can be many different paths or changes in direction, when taking the next step in one's research. Unexpected discoveries and serendipities are by definition unpredictable, but the ground for them can actually be prepared in advance, as Wheeler effectively did.

3. The issue of gravitational collapse

3.1 Preventing collapse

Having now outlined the framework of geometrodynamics and its ambitions, we can better understand the way Wheeler dealt with the new issues that were becoming more and more important to him. One of them, needless to say, was gravitational collapse. Wheeler quickly understood the challenge and significance of studying it.[94] This was soon connected to other research questions – or perhaps better: gravitational collapse became the connection that, in Wheeler's mind, linked the extremely large and the extremely small scales of the universe itself. As a matter of fact, it was not just about the end of

93Clearly, one does not have to take the expression in a Vichian or Hegelian sense: that is just to mean that important exaptations, serendipities and changes of plans *do* occur, cannot in general be avoided and should not be omitted, either.

94Relativity Notebook 1, p. 47.

a star's life (what Oppenheimer and collaborators had started to inquire about in the late 1930s): also the destiny of the universe was at stake. Wheeler believed in a closed universe (Blum, Furlan 2022) and assumed that gravitational collapse awaited everything, leading to a final singularity. The collapse of a star could thus become an anticipation and smaller-scale version of cosmic collapse.

At first, however, Wheeler had troubles with the most daring result by Oppenheimer and Snyder, that is their conclusion about a never-ending collapse. Taking it seriously from a physical point of view would have led to infinite quantities – to a singularity. Wheeler tried to avoid the occurrence of such a problematic outcome by examining and tentatively undermining the process that could supposedly lead to it. That is why he did not just challenge the conclusions by Oppenheimer and Snyder (1939), but also the previous work they were building on, that of Oppenheimer and Volkoff (1939). We will return to this in the following and also in the next chapter: for now, we can just mention that in 1958, in Brussels, at the above-said 11th Solvay conference (for the first time giving the spotlight to cosmology), Wheeler – present Oppenheimer – openly disagreed with his late 1930s work (Adams et al., 1958). Even if, in retrospect, it is easy to dismiss that as a mistake or a lack of boldness (quite ironically for the man who wanted to push general relativity to its limits via daring conservatism!), Wheeler's objections were quite articulated and actually fostered further research. Back then he believed that Oppenheimer and Snyder had not considered enough physical aspects in their basic collapsing dust model. Apart from the very symmetric starting situation, which could be viewed as not very realistic, Wheeler had two main concerns. First, he felt that the idea of energy escaping during collapse by means of radiative processes was being ignored. Second, he believed that the consequences of putting nucleons together under enormous pressures and densities were not being taken into account (and here is why he tried to undermine the whole reasoning by challenging Oppenheimer and Volkoff's paper on neutron stars). Wheeler was assuming that, after a star's thermonuclear cycle (in a case massive enough, of course), there would be a new balance for the collapsing matter. Oppenheimer and Snyder, instead, were suggesting that no balance was ever reached. However, even assuming that their ideas were correct, there was a problem with understanding or making sense of their conclusions: how to think about masses that, via such a never-ending collapse, were cutting themselves away from the rest of the universe, but at the same time could keep their gravitational pull? The whole process was difficult to visualize and Oppenheimer himself, in a letter to Uhlenbeck in February 1939, called his result "very odd" (Oppenheimer 1995, p. 209).

Thanks to the MANIAC computer wanted by von Neumann at

Princeton, Wheeler asked his postdoc Masaki Wakano to perform some calculations and numerically investigate his expectations about a new form of equilibrium for matter (which led to the Harrison-Wakano-Wheeler equation of state, also mentioned in Wheeler's report at the '58 Solvay Conference). This also provides an opportunity to make a couple of further considerations about daring conservatism. One is that Wheeler recognized the importance of computers even in the early stages, not just in the context of military or applied work, but also for fundamental research; we will mention this again in Chapters 3 amd 5. If daring conservatism was meant to explore well-established principles to their limit, computers could act as a sort of accelerator of vision, when it came to numerically probe specific issues. In this sense, the attitude of daring conservatism could interact synergically with early computers, and that is a quite remarkable feature in Wheeler's heuristics.

However, as we have already hinted, the resistance against the results of Oppenheimer and collaborators may also seem a betrayal of daring conservatism, not just because of a lack of boldness, but also due to the postulation of a new phase of equilibrium for "cold matter" (stellar matter at the end of the thermonuclear cycle). Nonetheless, there may be a more interesting angle to consider the whole situation: Wheeler's objections were trying to preserve well-established features of our way of considering matter and, with his equation of state, he was trying to extrapolate the latter to extreme circumstances. Perhaps this was just conservatism, mainly, but rather than portraying Wheeler as betraying his own methodology, we can think of such an episode as a clash of (more or less daring) "conservatisms". We will return to this "impression" in Chapter 3 and discuss it more in depth. Still, the distinction we have introduced between the different levels of Wheeler's overall research enterprise is helpful here: if the daring-conservative squeezing of general relativity, in order to derive everything from geometry, did not seem to be able to justify, at the moment, some features of matter (which is merely derivative, according to the ultimate geometrodynamical ambitions), nonetheless Wheeler was cunning enough to promote the use of ordinary conceptual tools when tackling specific issues. He did not refuse to investigate the problems arising from the combination of nuclear physics and general-relativistic situations just because matter, in the end, was supposed to be derivative – on the contrary, he was the one to put those problems on the table.[95] In this way, Wheeler was able to generate new research questions by

95Cf. Wheeler's comment about disregarding the particle problem in (Wheeler 1964, p. 506): "In a first account of the variation of atmospheric pressure with altitude one disregards the clouds. In the same way in a first account of what goes on in spacetime, it may not be unreasonable to look apart from particle physics. Hence the truncated model, with massless fields but no particles".

bringing his nuclear expertise into general relativity and relying on what it suggested to him. Thus, this early phase of black hole research is very different from a purely geometrical, and somewhat caricatural, attempt at making sense of the Schwarzschild solution and variations: first we have remarked how geons and wormholes, with their specific functions in Wheeler's geometrodynamical vision, were new tools that ended up being exaptated; now we can also underline how his broad nuclear background played a crucial role in shaping his research questions and assumptions.

In any case, there is little doubt that all these tensions were to a large extent triggered by the unwanted occurrence of singularities. As is well-known, in the case of the Schwarzschild solution there is a singularity at the center and one corresponding to the Schwarzschild radius, but the latter is just a fictitious singularity that can be eliminated by changing coordinates. However, back then, that was not clearly understood yet in its physical implications, as we shall better explain in a few paragraphs, and it caused confusion. Nonetheless, today's folklore statements about the central singularity being the crux of the matter (ever since then!) are just a misleading trivialization, as the previous pages already suggest and the next ones clarify.

Wheeler's attitude towards singularities between the late '50s and early '60s had some subtle evolution that we will now try to grasp and document. At the end of the century he would make the *boutade* "Aristotle said that nature abhors a vacuum. I was convinced that nature abhorred a singularity" (Wheeler 2000, p. 229), but that is certainly not the whole story. In a sense, we can identify two poles between which Wheeler seemed to oscillate. On the one side, the quite typical attitude of anathematizing singularities: their infinities are non-physical quantities that signal a shortcoming or merely mathematical artifact of the theory, in need of some fixing. In this respect, Wheeler's position had nothing original – his whole strategy of undermining Oppenheimer and Snyder's analysis of collapse and preventing their conclusion was a sort of conceptual cut-off. Possibly he was also influenced by Einstein's viewpoint that a singularity in a theory brings too much uncertainty and invalidates its laws.[96] On the other side, in the repertoire of the

96"A singularity brings so much arbitrariness into the theory that it actually nullifies its laws" (Einstein, Rosen 1935). This quote also appears at the end of Wheeler's Relativity Notebook 1, where he engages problematically a few points of this paper. Interestingly enough, he does not agree with their strategy of singularity removal, which, in light of his positions during the following years, is at first sight surprising. However, I think that Wheeler's objection was directed at an aspect of the methodology employed by Einstein and Rosen: when gluing together two Schwarzschild solutions into a "bridge", they made a coordinate transformation that moved the singularity at the radius to the origin of the new coordinate system, and then regularized it. In order to do that regularization, however, they proposed to modify and multiply the gravitational field equations with a factor g^2. See also (van Dongen 2010, p. 131).

modern physicist there are also situations in which the appearance of infinities is actually embraced, so to speak, rather than exorcized: the critical points in statistical physics. The co-presence of different behaviors near those points would find a sort of analogue in Wheeler's evocation of quantum foam as a patch near singularities – quantum foam not in the "poorer" meaning it has nowadays (a supposed foam-like granularity of space), but as a cauldron in which different possible (better: virtual)[97] geometries of space, due to quantum fluctuations, are *actively interfering*. No wonder that the creator of the theory of phase transitions, Landau, used to say: "Physics begins where a singularity occurs" (Shirkov 2009). According to Wheeler's expectations, a better understanding of quantum foam – the marriage of quantum mechanics and general relativity – would have indeed opened the doors of a new physics, too.

But let us go back, for now, to Wheeler's first (and initial) attitude. There is another work by Einstein that could resonate well with Wheeler's attempts at preventing the formation of a singularity via gravitational collapse, (Einstein 1939). In that paper Einstein had got the result that the spherical orbits of a system of gravitating masses have as a minimal radius a quantity still larger than the Schwarzschild radius; and he was hoping that something similar would hold also in more general cases. This was mainly done for his own satisfaction, as suggested by Earman and Eisenstaedt (1999), rather than as a contribution to the literature on that topic, in which Einstein was not interested – something similar, in fact, had already been obtained first by Hilbert and then by Hagihara. What was not being considered, however, is a purely radial motion, and that is where Oppenheimer and Snyder's paper comes in. That is what we nonchalantly say in hindsight: however, back then it also added some further paradoxical flavor to the latter's result. Now we can imagine and quite easily concede that the process they were describing and its outcome (the never-ending collapse at the center) were hard to accept and visualize (in the sense of making a sort of mental simulation of what happens), but, actually, even the fictitious singularity at the radius had not been made easier to digest. Further geometric insights were not available yet and, to that, we have to add the paradox of finite vs infinite time: for an observer on the surface of the collapsing star, reaching the Schwarzschild radius required just a relatively small amount of time, of the order of seconds, while for an observer at a distance it would take an infinite amount of time.

That is clearly against the spirit of daring conservatism.

97I am alluding to the Leibnizian (and etymological) meaning of the adjective to say that these are not merely abstract and idle possibilities, but, *qua* possibilities, can have some concrete effect. The most obvious analogy Wheeler had in mind, as we shall discuss in Chapter 4, is with Feynman's sum over histories, but this will become even more evident, during the 1960s, in the arena that Wheeler devised for a quantum version of geometrodynamics, "superspace" (Wheeler 1968c).

Factors such as these, predictably, contributed to Wheeler's decision to reject Oppenheimer and Snyder's work early on.[98] Despite the complexity of these issues, Wheeler's work in 1957 with Tullio Regge attempted to gain a better understanding of the Schwarzschild singularity and its stability through geometrical insights (Regge, Wheeler 1957). In a '56 letter to his young co-author, Wheeler wrote: "I have the feeling that we are unveiling little by little here and there fragments of a wonderfully beautiful and far reaching structure".[99] Evidently, despite his reservations, Wheeler strongly believed that the topic was pursuitworthy. Another paper investigating new aspects of the Schwarzschild singularity, written with a student of his, is (Lindquist, Wheeler 1957) – those, in other words, were the early results that he was harvesting:

> "My paper with Regge was one of ten that I published in 1957, most of them coauthored with students and other younger colleagues on aspects of general relativity and gravitation physics. Teaching the relativity course in 1952-1953 had been my investment. These papers were the payoff – returning the investment many times over, thanks to my numerous students and to the time I found in Leiden for thinking deeply" (Wheeler 2000, pp. 266-267).

This did not just happen in 1957 (except for the quantity): in the next subsection, we will examine a quite impressive series of papers, due to collaborators or even students (and students of former students) that Wheeler was actively involving.

Before moving on, we can briefly summarize some of the previous considerations. Wheeler's doubts and objections were clearly valuable because they brought up the subject of nuclear matter in the context of general relativity. This raised the question of what happened to nuclear matter during the extreme phases of gravitational collapse. In his search for answers, Wheeler began to consider the possibility that the conservation of the baryonic number could actually be violated: we will examine this in the next chapter, but we can anticipate that he even thought about a different way that matter could change into radiation ("delta rays"). He aimed at including this idea in a more detailed physical analysis than what Oppenheimer, Volkoff, and Snyder had suggested in their work. The seeds he had planted, however, were meanwhile growing thanks to his collaborators, and this would convince him to change his mind.

98See also Chapter 5 and Appendix B for Wheeler's struggle in visualization.

99John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 23.

3.2 Lifting the mental block

All the above-said factors gave substance to a "mental block" that, in Thorne's words (Thorne 1994, p. 137; 244), affected Wheeler and other scientists at the time, preventing them from embracing and developing Oppenheimer and Snyder's result and making them instead expect collapse to stop. We are now going to examine how these very same factors were either solved or transformed in the next few years: we will mainly highlight a few important steps that directly show Wheeler's own involvement, as well as the ways through which he was able to involve other people.

First, the "paradox" of finite vs. infinite time and, more in general, the issue of the singularity in correspondence to the Schwarzschild radius was "alleviated" thanks to a series of results that helped better understand the Schwarzschild solution. Nowadays the treatment of the latter is usually presented as a simple topic in all introductory courses on general relativity, together with a discussion on coordinate changes and so on. In this way, however, all the "stratigraphy" of the gradual understanding of those properties is thrown away, each step gets abstracted and isolated from nearby issues it was once interacting with, and commonplace historical statements become *de facto* anti-historical invocations of hyperuranian mathematical problems. A treatment in today's typical framing follows and, then, gets nonchalantly back-projected; if the people of that time thus seem quite dull, "well, that's progress". Instead, we have to keep in mind that a good number of the insights that we take for granted today, as if they had been evident to Schwarzschild himself, are actually the result of a long and quite contrived story, interconnected with a more general debate on singularities, to which an impressive list of names gave their contributions: from Hilbert to Hadamard, from Felix Klein to Weyl, just to name the eminent mathematicians involved in the first few years; and then, of course, Eddington, Lemaître, Richardson, Synge, besides Einstein himself (Earman, Eisenstaedt 1999). The various discoveries and re-discoveries of coordinate systems and singularity treatment are just another example of the confusion by which the historical actors themselves were affected.

David Finkelstein, although he was not Wheeler's student *stricto sensu*, had been influenced by the research agenda set by him, such as spin without spin, and had various interactions with Wheeler's most important collaborator of that period, Misner. It was in '58 that Finkelstein noticed, while working (in dialogue with Misner) on spin-without-spin-inspired ideas (Finkelstein 2013), how in a Schwarzschild scenario time reversal symmetry no longer holds and the surface corresponding to the Schwarzschild radius is not a true singularity, acting instead, in his words, "as a perfect unidirectional membrane: causal influences can cross it but only in one direction" (Finkelstein 1958, p. 965). That is his short paper is titled "Past-Future Asymmetry of the Gravitational

Field of a Point Particle", which is nowadays recognized as providing the decisive interpretation of what later came to be known as the black hole horizon. At the time, Finkelstein, as he later recalled, spoke about such matters also with Martin Kruskal, who in turn knew Wheeler since he was involved in the Matterhorn project (Finkelstein 2013). Kruskal was hesitant to publish his own work on coordinate change, which would appear two years later, in "Maximal Extension of Schwarzschild Metric" (Kruskal 1960). This paper – it turns out – was in part co-written (anonymously) and sent for publication by Wheeler himself, who had realized its importance but left him all the credit. "Spacetime inside and outside the horizon mesh smoothly. I found Kruskal's simple but elegant discovery quite interesting, although I didn't fully comprehend its significance right away" (Wheeler 2000, p. 296).

In '60 there is another paper from one student and one former student of Wheeler's: "Oscillatory Character of Reissner-Nordström Metric for an Ideal Charged Wormhole" (Brill, Graves 1960). The adjective "ideal" is quite a meaningful frame for the way wormholes were by then considered by Wheeler and collaborators, as we have noticed; indeed, a number of those results on wormholes, also in light of the symmetry with respect to their throat, were later employed by cutting them "in half" and considering thus a black hole scenario (in the Reissner-Nordström case, a charged black hole). Already from the abstract we can notice that, at this point, there was awareness of the pseudo-singularities removable through coordinate transformation. (Still, we should also remark that, after all, there was no automatic and universal criterion to determine whether or not a singularity was due to an arbitrary system of coordinates behaving badly). The genesis of this paper involved the undergraduate John Graves playing with coordinate transformations on the blueprint of Kruskal's; after finding something that seemed interesting, he involved Brill,[100] who systematized and added a few pieces, and they discussed it with Wheeler, who offered further insights based on his physical "intuition". In particular, it was shown that, thanks to the electric flux in the wormhole, the throat oscillates instead of pinching off as in the case of a Schwarzschild-like wormhole. However, the intrinsic curvature near the throat becomes infinite, so the singularity issue was still there. The throat being open could also be a problem in terms of causality, such as when we consider two points in regions that are also connected by the wormhole as a "shortcut".[101]

A couple of years later, in '62, a sort of follow-up paper to Brill and Graves was published by Wheeler himself with another student, Robert W. Fuller. Together they tackled similar issues in the case of the Schwarzschild-like wormhole; the title was "Causality and Multiply Connected Space-Time" (Fuller, Wheeler 1962). A couple of aspects are worth highlighting here. One is the strategy now adopted by Wheeler to avoid the central singularity. Since it was shown that even light could remain trapped within the Schwarzschild

100Personal communication.

101See also (Wheeler 1964, pp. 186-187).

radius, Wheeler, rather than trying to pre-emptively halt the process leading to the singularity, hoping that some form of radiative mechanism could do the job, invoked the role of the quantum gravitational Planck-scale fluctuations he had been preaching since the mid-'50s, quantum foam (just "foam" in that paper – p. 922). The singularity was obviously an inadequate representation of what was physically happening, an *asylum ignorantiae* that also marked the limits of the theory; quantum foam could be its patch. In any case, that indicated even more the need for that merging of quantum physics and general relativity, which was Wheeler's ambition and is the still open question of quantum gravity: in other words, he was starting to see the *opportunity* offered by the singularity, in a sense moving away from Einstein's aforementioned attitude about singularities and oscillating towards the other pole. This is an important point: the struggle with gravitational collapse was no longer just a challenging and expected-to-be-fruitful topic – the bulk of work that was being done on that became a sort of leverage to better propagate Wheeler's more general ideas about the features that a future full-fledged theory was supposed (by him, at least) to have. Here appears explicitly what I would call an "epistemology of procrastination", which characterizes so many trendy speculations of today's most ambitious frontiers of theoretical physics. By that I mean the tendency (or the strategy) of evoking a qualitative picture, shown as appealing and promising, and indicating it as the right path for some issue that is presented as very deep, far away not only from the current experimental means, but also from the theoretical ones: we should therefore be on hold, or work along the *suggested* guidelines, for a fully-developed future theory, which in the end will be capable of dealing with the issue quantitatively as well. In Wheeler's case, this heuristic-rhetorical machinery is clearly linked to what we may indicate, with an expression that would horrify any Latinist but that, in this context, effectively conveys the basic idea, as *quantum ex machina.* The geon's orders of magnitude are way off scale? Perhaps, when we will have a fully quantized version, everything will be settled. The microcharges due to wormholes at Planck length have no apparent mechanism of behaving coherently as a cloud-particle? Perhaps that will be explained by some quantum effect similar to superconductivity (Wheeler 1957). The singularity due to collapse is highly problematic? Quantum foam – as an early insight into the expected merging of general relativity and quantum physics – will possibly take care of that.[102]

102We may also notice that this form of procrastination makes leverage on the typical strategy of having a classical theory first, and then quantize it. As we shall discuss in the following chapters, when Wheeler became disillusioned about the promises of geometrodynamics, he would start asking "how come the quantum?" at a fundamental level, that is: "No one see any longer how to defend the view that geometry was created on Day One of creation, and quantized on Day Two. More reasonable today would appear the contrary view, that 'the advent of the quantum principle marked Day One, and out of the quantum principle geometry and particles were both somehow built on Day Two'" (Patton, Wheeler 1975, p. 544). However, we could also remark that, at this stage, there is a tension between the construction

Another curious aspect of this '62 paper is that Niels Bohr himself is mentioned in the acknowledgments. This looks quite bizarre, since there seems to be no story about "black holes" directly involving him.[103] Apparently, according to what is written, during a visit to Bohr in '58 Wheeler expressed his concerns about these matters and Bohr's oracle suggested that he should investigate causality – as he did four years later. Now, we may either surmise that Wheeler used some loosely related conversation as a pretext in order to get Bohr interested (unfortunately, he died a month after the publication); or we could remark that invoking Bohr was a typical strategy for Wheeler, who was always keen on paying tribute to him and, at the same time, grounding his own attempts under his "patronage", as we have commented in the previous chapter.

In any case, with quantum foam postponing for the moment the destiny of the singularity, and with the throat being *de facto* closed even for a photon, causality was secured in the sense that shortcuts in a communication between two points in a multiply-connected spacetime manifold did not seem allowed. In another paper, published during the same month (October '62), Wheeler wrote that "it would seem essential to establish a theory […] which would connect the issues of topology, causality, and singularities" (Wheeler 1962a, p. 887); and, even more interestingly, he refers to the "[c]onjecture that every 'properly closed space' ultimately develops a singularity" and repeats: "Inevitability of singularity in classical solution implies conditions always develop where quantum character of geometry cannot be escaped" (*ibidem*, p. 892). In short, there is a conceptual passage from the inevitability of the singularity to the inevitability of quantum foam (and the role Wheeler envisaged for it). That "conjecture", moreover, obviously rings a bell when thinking about Penrose's famous first result, developed just a couple of years later;[104] and we may add that Wheeler had already heard something similar in the previous decade, from his former student Arthur Komar – for an overview of those early results, I redirect to (Earman 1999). Somehow Wheeler was starting to come to terms with all this in physically relevant (and perhaps unavoidable) terms as well. That is not something to be taken for granted, once again: during that same period Lifshitz and Khalatnikov, for instance, were convinced to have proved that the formation of singularities occurred only under very specific and unrealistic circumstances (Lifshitz, Khalatnikov 1963).

Outside of this specific aspect, the most intriguing point is perhaps, epistemologically, the one about procrastination – how can it rise to

"classical→quantum" and the role played by quantum foam – both as a guiding idea or expectation and as the process out of which something comes out of the quantum vacuum –, since it is treated as a realization already *in actu* of the merging of theories sought by Wheeler.

103Even if in the 1930s he encouraged Chandrasekhar: see e.g. (Thorne 1994).

104See (Furlan 2021) for some comments and archival material about the early interactions between Wheeler and Penrose; we will add something in Chapter 4 and 5 as well.

prominence? In order to establish an "epistemology of procrastination", an effective consolidation of the pursuitworthiness of the issue seems necessary first, so that one has enough credit to be able to keep postponing bigger deliveries. In the next subsection we are going to examine the decisive moment of this story, when progress was made in the understanding of collapse and Wheeler abandoned his previous resistance. We are thus going to see how his "weight" and connections, on a plurality of levels, allowed him to promptly move resources and push the efforts of his group down the path he was starting to see more clearly. Wheeler capitalized on that and kept alive his ultimate vision for quantum geometrodynamics and subsequent – highly speculative – metamorphoses.

4. The turning point

4.1 "The eye-opener"

In one of the '62 papers (Fuller, Wheeler 1962), we have said, there seems to be a detectable hint about a change of strategy in front of singularities: Wheeler would go on to transform the *issue* of the central singularity into an *opportunity* to propagate and push his own ideas and expectations about quantum gravity and future physics. The attitude seems almost ripe to lift the "mental block": in order to understand how this change was brought about, we have to make an attempt at identifying the precise moment of Wheeler's "conversion" and acceptance of black holes (still *ante litteram*, of course). Once we reach this point, however, we are faced with the two existing accounts of how Wheeler got convinced. One is given by Kip Thorne (1994), at that time Wheeler's student and then collaborator, who indicates the turning point in new geometrical insights. The other is in an interview (Miller 2005) with Stirling Colgate, who also worked with Wheeler in the Matterhorn Project, before pioneering the use of computers in astrophysical matters; Colgate implies that the decisive role was played by computers. Let us examine the two versions in more detail, also in light of our previous considerations.

According to Thorne, the decisive factor for Wheeler (and for him as well) was David Beckedorff's Master's thesis, completed under the guidance of Misner (Beckedorff 1962). Thorne called it an "eye-opener", in the literal sense: building upon the new systems of coordinates that had become available, it determined the boundary conditions between external and internal regions in a Schwarzschild scenario, thus providing the first "embedding diagrams" that gave a dynamic idea of what happens in the process of collapse. These were the powerful visual tools that Wheeler needed to form a satisfying mental simulation or picture without which, as he used to say in full

generality about physics,[105] he could not achieve a proper understanding. Beckedorff's thesis can thus be regarded as the culmination of the previous series of results we have examined, from Finkelstein via Kruskal. However, reducing or dismissing the whole process of overcoming prejudice and rejection by just saying that some change of coordinates convinced Wheeler would be clearly over-simplistic. On the one hand, those developments allowed him to digest the issue represented by the rough contrast of finite/infinite time and the fictitious singularity at the Schwarzschild radius. On the other, they did not only offer a visualization tool to imagine what could happen, but rather a different *point of view*, helping Wheeler realize that the exclusive focus on the star getting smaller and smaller was, so to speak, a distraction preventing him (and others) from realizing what goes on in terms of spacetime geometry (Fig. 3). This shift of attention is also the reason why Wheeler later liked to emphasize the aspect of "hole", instead of referring to the star undergoing collapse.[106]

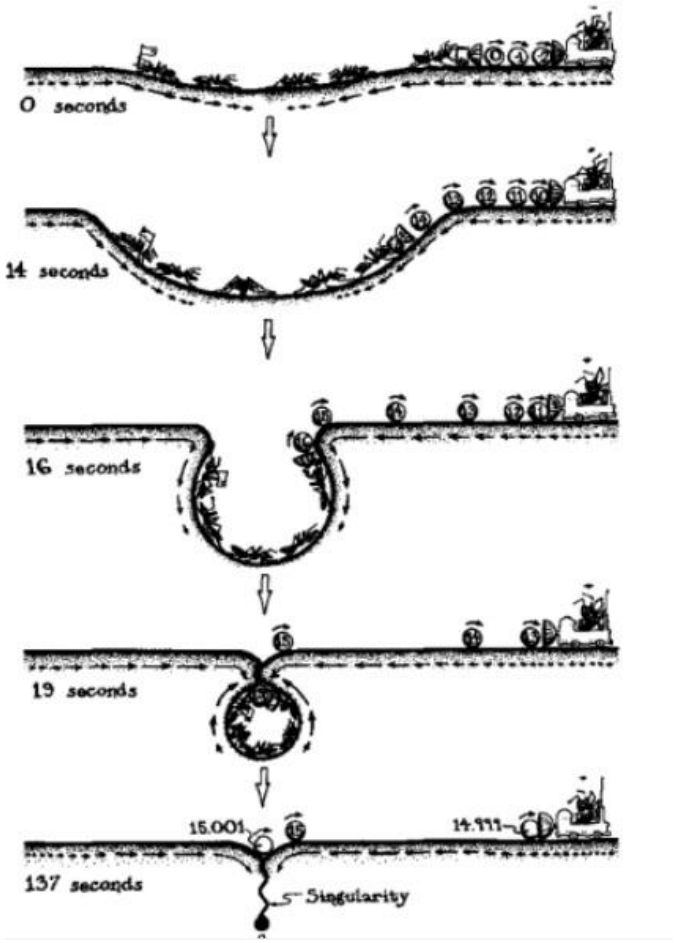

Fig. 3. Embedding diagrams (section of). Credit: (Thorne 1994, p. 247).

105"If I can't make a picture, I don't understand" (Wheeler 1994a). See Chapter 5 and Appendix B.

106See Appendix B for further remarks on that.

For someone unconvinced by Oppenheimer and Snyder's results, or better by their physical relevance, however, these mathematical developments could still not be enough, *per se*: after all, "Wheeler's first moral principle" was "Never make a calculation until you know the answer" (Taylor, Wheeler 1992, p. 20). As a matter of fact, at the beginning of Beckedorff's thesis, Wheeler is explicitly engaged as *the* objector and his expectations of finding some new phase of stability for "cold matter" are mentioned. Oppenheimer and Snyder had neglected so many physical processes that, Wheeler argued, it was no wonder that they ended up with nothing to prevent a paradoxical never-ending collapse. While Wheeler was asserting that the conclusion of no equilibrium being reached was a *petitio principii*, the same objection was leveled against him by Beckedorff and Misner: the assumption that an equilibrium phase had to be found, with a new state of matter, was also debatable. This is, we may say, that kind of tension between the equilibrium of cold matter and daring conservatism that we previously commented upon from a different angle. While Beckedorff and Misner did not expand much on their remark, it is worth adding at this point that another Master's thesis in that period, by Allen Mills (1962), convinced Wheeler that, in his own words, "[a]ll radiation of all kinds […] can be fully trapped around a sufficiently concentrated mass" (Wheeler 2000, p. 295). That delivered a lethal blow to his early strategy of singularity avoidance, abandoned in the '62 paper with Fuller. It is certainly remarkable how many students (and students of his students) Wheeler was able to actively involve in his quest.

Let us listen now to the other account. According to Colgate, the turning point was represented by the results offered by computers, and he even said that he was there when Wheeler somehow got "converted". The suggested timing seems, again, around '62. Now, the two accounts are not necessarily in contradiction: they are surely both reliable in pointing out crucial factors in the development of Wheeler's positions; the challenge is to combine them coherently and chronologically. One must, first of all, remark that the two sources are not on an equal footing: while Thorne's account is based on a more comprehensive personal involvement with those issues, as well as on conversations and interviews (and he does not neglect the role of Colgate himself), Colgate's account is definitely more unilateral and fluctuating, based exclusively on personal memories – that is what often happens in interviews made many years after the facts, as we have already commented in the case of the *Sources for History of Quantum Physics*. Another problem is that, due to military secrecy, a relevant part of Colgate's work is still obscure, and he has definitely received less historical attention than he deserves. Luckily, there is a short recollection by Richard White, Colgate's collaborator at the time, who adds some details that allow us to reach a slightly different interpretation of Colgate's recollections (White [undated]). Let us see how.

In '60 Colgate, in relation to his interest in cosmic rays, was already

working on supernovae;[107] soon White joined his efforts, thanks to his expertise in computer coding. Livermore was their base, where there was also Teller, Wheeler's friend – but they were quite far away from Princeton. As Wheeler himself would write in '68, "at the Lawrence Radiation Laboratory of the University of California at Livermore, California, there stands an impressive electronic computer. It predicts the performance of fission and fusion bombs far more complex than the Alamogordo device" (Wheeler 1968b, p. 252). If one pays attention to Wheeler and Fuller's '62 paper, it is possible to notice in fact that "Part of this work was done at the University of California, Berkeley, California while the author (JAW) was on leave of absence from Princeton University" (Fuller, Wheeler 1962, p. 919). That puts our actors together in the right geographical area. While it is not entirely clear, at least at the moment (while waiting for other sources), what Colgate and White's early attempts consisted of, we can be sure that they did not involve general relativistic effects at all. As White himself says (White [undated]), it was only in '63 that Wheeler, with quite a long trip, brought them some experts from his circle, in order to implement general relativity as well; and only in '65 the same White, with Michael May, had some results ready, after tackling directly the issue of gravitational collapse (May, White 1966). All this is confirmed not only by checking Colgate and White's publications from those years, but even by a letter, dated November '64, in which Misner suggests White some basic references to learn the Schwarzschild metric.[108] Then, even giving credit to Colgate's recollections, what "convinced" Wheeler around '62 was *not* some general relativistic calculation. At this point, we could decide to postpone the year that, perhaps incorrectly, he was referring to, but then the role of calculators would have been (at least for Wheeler's path) limited to mere corroboration. Alternatively, considering that in '63 Wheeler decided to deploy his available resources and interact more with the West Coast,[109] it is also reasonable, if not unavoidable, to assume that he saw something worth investigating in the previous year.

Even without general relativity, Colgate and White had found in their computer work on supernovae that, following Fowler and Hoyle's assumptions about certain stars at the end of their thermonuclear evolution (White [undated]), the different kinds of pressures expected to counterbalance the gravitational one were insufficient to prevent collapse. Now, it is worth remembering that Wheeler too came from a background similar to e.g. Fowler, a nuclear one *lato sensu*,[110] and he too was expecting physical mechanisms – presumably neglected by Oppenheimer and Snyder – that were capable of

107For a broader context, see (Bonolis, Furlan 2024). We will say something more also in Chapter 3.

108Misner to White, 6 November 1964, in John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 18.

109Cf. also (Wheeler 1968b).

110We will return to this in the next chapter.

stopping the collapse. It is not at all far-fetched to assume that, seeing those results by Colgate and White, Wheeler also abandoned part of his resistance on that, even exclaiming at some point, according to Colgate (Miller 2005, p. 211): "The big deal, Stirling, is that it makes a reality of these things!". In any case, after that moment Wheeler decided that, at the very least, a full general relativistic model was worth investigating thanks to the calculators – hence the importance of bringing his team together from coast to coast. The pursuitworthiness of these matters, we could say, was getting more and more substantial even in organizational terms, and this definitely seems a *conditio sine qua non* for an "epistemology of procrastination" to partially step in.

Even if we were to fully listen to Colgate's account, we may have doubts that Wheeler was entirely convinced about "black holes" simply by a computer result – it would be better to say that he promptly integrated that new output in the mental picture that he was composing. This is quite different from the epistemological status quite often granted nowadays to the role of computer calculations and simulations: for gravitational collapse, the role was surely not played by analogue "experiments *in silico"* or "one-shot" simulations. Instead of a model offering a ready-made way of putting together a pictorial narrative of what is going on, in this case there were numerical results obtained in some outdated (gravitationally speaking, even Newtonian) theoretical scheme of calculation, which nevertheless, also thanks to Wheeler's expertise and acumen, became relevant in informing and constraining his mental picture of the essential processes and the guiding vision he was offering to others. It is, in other words, a kind of pursuitworthiness in which elements are gradually integrated over and over and weighted again: rather than a one-directional march of a one-shot calculation, here what gets displayed is a flexibility which *does* have an open-endedness of some specific elements, but is also globally accompanied by a powerful guiding vision. When Wheeler started investing more and more in this matter, he had his own idiosyncrasies, reservations, doubts, positions: the way a series of factors converged in the same period to change his mind illustrate well his *modus operandi* as a "seeker" and a group leader, but also the openness and plurality of directions which the notion of pursuitworthiness should be able to contemplate, as suggested above.

It seems reasonable to conclude, while waiting for further archival documents,[111] that, next to the work by Allen Mills, what Wheeler saw in Colgate and White's early research undermined his matter-related objections to Oppenheimer and Snyder, while Beckedorff provided a satisfying tool for visualization. The very existence of two different accounts could be seen as a consequence of the various lines of research that Wheeler was considering at the same time pursuitworthy. Then, even if it is not entirely possible to pinpoint a day of "conversion" on the road to Damascus, we may nonetheless

111Either thanks to further exploration of Wheeler's archives or, possibly, to the surfacing of new (de-classified?) material concerning Colgate.

state with confidence that, by ‘62, there were the elements to overcome the rejection of Oppenheimer and Snyder's result.

4.2 No way back

The moment Wheeler really faced the conceptual inevitability of the yet-to-be-named “black hole” was, at least in published material, his paper (but it would be better call it a book) “Geometrodynamics and the Issue of the Final State” (Wheeler 1964). If we consider that it was actually born out of a series of lectures given at the summer school in Les Houches in July '63, and certainly prepared quite in advance, we even have a nice continuity in our coverage of the different phases of Wheeler's thought. This paper is indeed a large synthesis of his views and of the work of his collaborators: while thanking them collectively in the acknowledgment at the end of the paper, the only one mentioned explicitly was his new student “Mr. Kip Thorne”, and that is definitely meaningful also for the reliability of the account we have endorsed. The *incipit* is very telling as well: “If Einstein's general relativity has a close connection with the inner structure of physics – and there is no indication that it does not – then there is a good reason to spell out and understand its consequences” (Wheeler 1964): a basic enunciation of daring conservatism, once again. The title itself is quite resonant with the that of Beckedorff’s thesis, i.e. “Terminal Configurations of Stellar Evolution” (Beckedorff 1962). Wheeler’s is obviously broader, since by then he had also linked together the issue of the final state of a star to that of the initial and final phases of the universe. In the following years Wheeler’s writings, in fact, frequently mention the idea that black holes allow us to study the destiny of the universe “in miniature” (e.g., Wheeler 1968b), and their prediction as a consequence of gravitational collapse is presented as the fourth test of general relativity.

After Les Houches, later that year, in December ‘63, the epoch-making First Texas Symposium, usually understood (e.g., Thorne 1994; Bonolis, Furlan 2024) to represent the birth of relativistic astrophysics, took place. The topic, “Quasi-stellar sources and gravitational collapse”, marks the moment in which the predictions of general relativity about the extreme consequences of gravitational collapse (even if from the side of quasars – a partly different story from ours) start to be connected, for a larger community, to the actual work of astrophysicists. In ‘65, Penrose would publish his first theorem on the inevitability of singularities (Penrose 1965), given quite general assumptions (a result made stronger at the end of the decade thanks to the work of Hawking, too); and, in that same year (but published at the beginning of '66), after a few months, the first simulation of a collapsing star with a relativistic treatment was obtained by Michael May and the already mentioned Richard White (May, White 1966), with some help from Wheeler’s circle. Black holes

were at that point just awaiting their name, at the end of the following year (Bartusiak 2015; Furlan 2021).[112]

We have thus seen how Wheeler fully embraced black holes and ultimately established them, daring-conservatively, as the newest and most spectacular prediction of general relativity. I have attempted to preserve the historical complexity of Wheeler's heuristics and to give also an idea of the interplay with other factors (institutional, military, etc.), which no doubt would deserve their own study. It should be quite evident, by now, the dramatic difference, especially in this case, between an actual historical analysis and a pseudo-historical narration on the blueprint of something like "The problem was to make sense of some solution of general relativity; people took a while to get there – here a few names and dates – but, finally, what we now know was achieved". Besides this historical lesson, as a conclusion of the chapter I would like to offer a few suggestions about the current situation in some highly speculative areas of physics Directing one of the "hubs" of the Renaissance of General Relativity, Wheeler contributed dramatically to materialize and substantialize, also in institutional terms, the pursuitworthiness of "Einstein's" vision and its fusion with quantum physics. While assessing, through a rhetorical style entirely *sui generis*, the worthwhileness of that grand vision and project, he was also able, depending on the situation, to quickly transfer that pathos and the promises of a bright future to specific topics and issues, such as gravitational collapse, and capitalize on new progress made in those directions. That, in turn, could be used to keep alive his more visionary and ambitious quest. As a matter of fact, Wheeler, after accepting the physicality of black holes, was not satisfied with studying them as an object of the newly-born relativistic astrophysics: while of course keeping up to date, he largely left this task to his collaborators. To try and devise the black hole's ultimate conceptual implications for fundamental physics and for spacetime itself was, instead, the mission he assigned himself, as we shall discuss in the next chapter, and this, paradoxically, would quite soon lead him to abandon his own geometrodynamical program (or better: to go beyond it). Wheeler never rejected his previous thoughts or intuitions and kept returning on them: at the very least as valuable "science-forming ideas", we may say, they *had been* worth the pursuit, as we have already seen in this part of the story and as we will be later saying about the whole parable of geometrodynamics. Even if there is no formula or theorem bearing Wheeler's name in the investigation we have just followed, he certainly had his merits, which can be perhaps synthesized in the picture of him taking by the "throat" the issue of gravitational collapse and thus, in his own peculiar way and with his own

112Even if their "baptism" at the end of '67 is a story later repeated by Wheeler himself (Wheeler 2000, p. 297) and by many others, his notebooks seem to suggest a different one: in Relativity Notebook 14, e.g. on p. 204 and p. 207, three months before the usual date, Wheeler is already using nonchalantly the phrase "black hole" for discussion with Robert Dicke's group.

tools, grabbing the research opportunity as it presented itself, by the neck of the bottle (to echo Bacon's epigraph).[113] When he later went on with his speculative projects or embarked on new ones, he could count on the "pursuitworthiness credit", so to speak, that he had previously achieved in his career, in general, and, more specifically, thanks to specific issues in these developing areas of research. He would thus invest or transfer such credit, at least in some measure, to his new visionary projects, and involve new people as well. As stated in an interview at the end of the '70s,

> "One of the conditions, I think, for advance in this field, as in any field, is believing that advance is possible. What I hope I'm creating is a sense of faith that it can be done. Faith is the number one element. It isn't something that spreads itself uniformly. Faith is concentrated in a few people at particular times and places. If you can involve young people. in an atmosphere of hope and faith, then I think they'll figure out how to get the answer. Faith and hope are absolutely central to everything one does. You need people who have imagination, daring and the ability to get somewhere. That, to me, is the way research works" (Wheeler 1979f).

As we have seen in Chapter 1, that is the same faith Wheeler claimed to have learned from Einstein (the interview just quoted, after all, dates back to the latter's centenary); but Wheeler's quest for black holes marked also a subtle line for that balance between theoretical speculation and experimental tests. The fundamental questions that he was framing in the background were soon going to break that balance, as happened to the plethora of more recent quantum gravity approaches in desperate need of empirical injections. These approaches, as is well-known, have been pushing in (or claiming the pursuitworthiness of) different directions. Wheeler's storyline across these years also saw, for many aspects, the dawning of such a situation, in which the claim of something being pursuitworthy seems capable of lasting for a dilated duration without empirical interplay. We can thus get at least some insights on the uses and risks of a notion like pursuitworthiness, as well as on its possible responsibility (underscored in other contexts by Lichtenstein 2021) in generating a scenario of non-dialogical disagreement among different approaches, as epitomized today by various quantum gravity "tribes" in conflict.[114] Wheeler's case, as seen in the heuristic path here examined, can work as a *pharmakon*, in its double meaning. As a medicine, or at least as a

113The "throat", of course, first referred to the wormhole tunnel staying opened or getting pinched-off, as discussed in the aforementioned papers by Brill and Graves (1960) and by Wheeler himself with Fuller (1962). Incidentally, if we were to further remark on some sort of pictorial resonance with the Baconian epigraph and its mention of "hair", we could add that at the beginning of the '70s, to address a series of results with a compact phrase (Thorne 1994; Blum, Furlan 2022), Wheeler coined the famous expression "a black hole has no hair".

114See also the Conclusions.

resource, when it is considered with a proper historical and critical awareness, as well as with Wheeler's interrogative attitude. As a poison, if that example is just mimicked or employed almost as a set of *idées reçues* transmitted by a sort of tradition, or as a repertoire of strategies to institutionally establish a kind of pursuitworthiness which, shielded by a constant procrastination, becomes almost an end in itself. This ambiguity is another reason to pay close attention to serious historical reconstructions.

3. Beyond the Last Star

In the previous chapter we have sketched the story of how Wheeler came to embrace the physical relevance of the most extreme phases of gravitational collapse. In this chapter we are going to explain how he tried to push those results to their conceptual limits, ultimately challenging the role of notions such as space, time, and physical law. Since the relevant documents have been discussed in (Blum, Furlan 2022), there is little point in repeating here that analysis: I am going to extract a few highlights and integrate them with a new angle, inspired by more recent archival research.

Each of your gifts leads to deep thoughts.
– Zel'dovich to Wheeler, 1970 Christmas card

1. Topological worries

We have followed Wheeler's trajectory from the early phases of geometrodynamics to the consecration of the black hole as its most engrossing issue; or, in other words, as the most spectacular, and possibly rich in consequences, fruit of the daring-conservative exploration of general relativity. As such, it was indeed the central topic in the decades of Wheeler's career that we are examining. Historiographically, we are starting to cover a huge lacuna in the (pre)history of black hole research and to properly frame, also conceptually, its guiding questions and ideas, or at least those of one of the main groups that were working on it. If 1967 marks the moment of Wheeler's public adoption of "black hole" and the beginning of his enthusiastic popularization of the latter (at various levels of audience),[115] and if in that same year he also delivered the lectures that are the *summa* of his attempts at quantum geometrodynamics (Wheeler 1968c), from his private notes we see instead a very different face. "Why is everyone so silent? Why does it have to be me who says this? Story *crying* to be told. Why so long. Silent, on a peak in Darien – the only charitable explanation. *Have* to touch on this question".[116] Wheeler's *Unruhe* is not just a manifestation of his restless spirit of inquiry – yes, he wanted to explore as soon as possible the long-ranging conceptual implications of gravitational collapse, or what black holes could tell us about cosmic order, but he was also starting to perceive some cracks in his geometrodynamical vision. The two main difficulties, as a matter

115It is worth noting that the famous paper "Introducing the Black Hole" (Ruffini, Wheeler 1971a) was published in a "semi-popular" journal such as *Physics Today*.

116Relativity Notebook 14, p. 140. The "peak in Darien" is a reference to John Keats, as we shall explain in Chapter 6.

of fact, are stated in (Wheeler 1968c, p. 281; 284), but, before getting there, we have to quickly recapitulate the technical notions Wheeler was trying to use to express his guiding view. Here, in the first two sections, we are just going to mention the salient traits: I redirect to (Blum, Furlan 2022) for a more detailed examination of sources and related conceptual passages.

Wheeler's attention had been caught by gravitational collapse, but we should not forget that, already in the mid-'50s, he was clearly aspiring to a quantization of general relativity, possibly on the blueprint of Feynman's sum over histories: that was indeed the topic he quite optimistically assigned to Misner for his Ph.D. dissertation. His already mentioned way of considering quantum foam as a form of resonance or interference between different possible (or virtual) geometries of space is obviously related to that hope. The first attacks did not work, but Wheeler persisted and tried to formalize his idea by introducing the notion of "superspace" (which, of course, has nothing to do with the homonymous concept related to supersymmetry). Roughly speaking, it is the arena he devised for a quantum version of general relativity: a space in which "every"[117] point represents a 3-geometry of the universe. The geometro-*dynamical* evolution of the universe would thus be represented by a trajectory in this space. Since, however, superspace is supposed to encapsulate a quantum character, one cannot precisely speak of points and trajectories in a classical sense, with infinite precision. The story of the universe may seem to be *one* story as an approximation during its central phases, but, when it gets close to the initial and final singularities (the Big Bang and the Big Crunch),[118] the "thickness" of the trajectory increases, interference with other possible geometries takes place, and the notions of space and time result not properly defined, inadequate. The black hole was a smaller-scale version of, and thus a special window on, that process. This is where Wheeler's vision slammed against the wall of topology. In this superspace,

> "DeWitt constructed a Schrödinger-type equation for quantum gravity (DeWitt 1967), an equation that would become known, quite ironically, as the Wheeler-DeWitt equation. This was of course hardly a complete theory of quantum gravity, as many essential mathematical questions regarding this equation were (and are) still open. Even so, it clearly revealed that Wheeler's expectations would not be met in this approach. The Wheeler-DeWitt equation described only changes in the metric structure of space, not in its topology; and the dimensionality of

117The identification between 3-geometries and points of superspace is actually more refined, but it is not too relevant here.

118As we have already remarked, Wheeler was convinced that the universe is closed and destined to face the Big Crunch due to gravitational collapse.

> spacetime, rather than appearing as a dynamical quantity, appeared to be hardwired into the equation. Of course this was to be expected from a theory that arises from a direct quantization of general relativity; Wheeler liked to emphasize that the Wheeler-DeWitt equation can be derived directly from the Hamilton-Jacobi formulation of general relativity, just like the Schrödinger equation can be derived directly from the Hamilton-Jacobi formulation of classical mechanics. But the absence of a dynamical topology (and dimensionality) flew in the face of Wheeler's expectations for quantum geometrodynamics" (Blum, Furlan 2022, p. 296).

Let us explain better the role of topology in Wheeler's scheme, since, regardless of the difficulties just mentioned, the unwritten story of how topology entered into the toolbox of theoretical physics would definitely have to consider his efforts and speculations. As early as the mid-'50s he was conjecturing some connection between the Betti number of a manifold and fundamental properties of physics (intuitively, because the fluctuations of quantum foam – the making and unmaking of wormholes – change the number of "handles" of the space manifold);[119] he was also wondering whether one should say that everything is geometry or, even at a deeper level, everything is topology;[120] he was relying on Misner, who earlier had, quite atypically, followed a course in topology, to keep up to date and also try to establish contacts with distinguished topologists at Princeton, such as John Milnor; and the contrived attempts at "spin without spin" seemed to touch upon topological issues, too (and topology-change). Indeed, as Hermann Weyl, shortly before passing away, wrote in the preface to the third edition of his *The Concept of a Riemann Surface* (first published in 1913): "In the more than forty years which have passed since the appearance of this book the face of mathematics has changed noticeably. Above all, the young shoot 'analysis situs' has become the tree topology, affording shade to large parts of our science" (Weyl 1955, p. VII) – and by then Wheeler was trying to make use of it to turn the tree of physics upside down. The appearance of embedding diagrams, then, seemed to suggest Wheeler a change in topology in the very extreme phases of gravitational collapse.[121] By 1967, moreover, his student

119Relativity Notebook 3, p. 63. In one of Wheeler's "Reflections on Plan of Physics" we can also read, in the same notebook, p. 152: "Believe it important to be able to pass from one topology to another".

120"Makes one think that deeper meaning of physics is topological" (Relativity Notebook 4, p. 132).

121"In classical geometrodynamics space does not change its topology. Space may be "preparing" to change its topology, but it cannot actually make the change within the context of classical theory. It can at most signal its "intention" to change topology by developing

Robert Geroch was obtaining relevant results about the (im)possibility of topology-change in general relativity under quite general circumstances (Geroch 1967). In short, the situation was as follows: Wheeler needed topology-change to express his fundamental idea of quantum foam, and more specific (relatively speaking!) central problems such as the issue of gravitational collapse and the hope of constructing particles out of geometry seemed to require it (Wheeler 1968c, p. 281; 284). However, progress in that direction was lacking and, on the contrary, results such as Geroch's seemed to suggest that the mathematical machinery was not (classically) suitable. Even if there was nothing as definitive as a general no-go theorem, stagnation led Wheeler to stop invoking the *quantum ex machina* and make instead a quite unexpected move at the beginning of the 1970s, as encapsulated in the "parable of the two lawyers" in *Gravitation,* which has remained cryptic and unexplained for almost half a century (Blum, Furlan 2022, pp. 297-298).

> "There are reputed to be two kinds of lawyers. One tells the client what not to do. the other listens to what the client has to do and tells him how to do it. From the first lawyer, classical differential geometry, the client goes away disappointed, still searching for a natural way to describe quantum fluctuations in the connectivity of space. Only in this way can he hope to describe electric charge as lines of electric force trapped in the topology of space. Only in this way does he expect to be able to understand and analyze the final stages of gravitational collapse. Pondering his problems, he comes to the office of a second lawyer with the name "Pregeometry" on the door. Full of hope, he knocks and enters. What is pregeometry to be and say? Born of a combination of hope and need, of philosophy and physics, and mathematics and logic, pregeometry will tell a story unfinished at this writing, but full of incidents of evolution so far as it goes" (Misner et al. 1973, p. 1203).

The first lawyer represents the efforts in the superspace of quantum geometrodynamics or, speaking in a less Wheelerian way, quantum gravity *à la* DeWitt. The other lawyer points instead in the direction Wheeler would pursue from that moment on, and which would ultimately lead to his "it from bit" phase in the 1980s, after a decade of new speculations and attempts.

> "Wheeler – faced with the limits of classical differential geometry and a quantum theory of gravity that was not able to overcome these limits – did *not* give up on his program, but instead turned to a different

somewhere a curvature that increases without limit ("gravitational collapse")" (Wheeler 1968c, pp. 279-280)

> "lawyer" who would tell him "how to do it". [...] He held on to the tenets of his program, in particular the concept of microscopic foam-like fluctuations of topology, but conceded that these were not to be had in the framework of quantum gravity" (Blum, Furlan 2022, p. 298).

We should notice that, as much as we have seen the seeds of an "epistemology of procrastination" in earlier years of this research, such a radical move shows very well how Wheeler's research was genuine and restless, and how he was not interested in exploiting the still incomplete technical attempts to make an indefinite living, so to speak. Perhaps some of his more or less alleged continuators today should keep it in mind as a lesson, but we will return to that in the Conclusions. Before closing his geometrodynamics worksite, however, Wheeler had still something to daring-conservatively squeeze out of general relativity, thanks to the the black hole: that would offer him important hints for his "pregeometry" quest, too.

2. Laws transcended

A simple way to sketch a crucial strand in the activities of Wheeler's circle between the end of the '60s and the beginning of the '70s would be the following.[122] After fully embracing black holes, Wheeler could not help wondering about the destiny of in-falling matter. If we keep in mind his geometrodynamical vision, it was natural to inquire what happened in the extreme conditions of those cosmic forges, where geometry and particles could perhaps fade into each other. Indeed, as we will soon say, that was a question he had been asking for more than a decade and, by the late '60s, there were new powerful insights, both mathematical and physical. The conclusion that Wheeler reached was radical:

> "Gravitational collapse deprives baryon number and lepton number of all significance. "Baryon number is conserved." "Lepton number is conserved." Of all principles of physics these familiar conservation laws belong among the most firmly established. Yet with gravitational collapse the content of these conservation laws also collapses. The established is disestablished" (Wheeler 1971b, pp. 192-194).

This was not just "intuitively" related to the indistinguishability of leptonic and baryonic forms of matter once they cross the black hole horizon: in both cases, Wheeler and his students or collaborators did actually dedicate some

122For more details, including archival material, I redirect again to (Blum, Furlan 2022).

analytical study to the topic (Wheeler 1971c; Bekenstein 1972). If the electric charge of a black hole and its increase could be in principle detected at large distances via its electrostatic field, the range of strong and weak interactions, which distinguish between leptons and baryons, is too short to cross the horizon.

> "It is true that no attempt to observe a change in baryon number has ever succeeded. Nor has anyone ever been able to give a convincing reason to expect a direct and spontaneous violation of the principle of conservation of baryon number. In gravitational collapse, however, that principle is not directly violated; it is transcended. It is transcended because in collapse one loses the possibility of measuring baryon number, and therefore this quantity can not be well defined for a collapsed object" (Ruffini, Wheeler 1971a, p. 36).

In such situations, then, the validity of these laws of conservation could not be ascertained even in principle. From this, Wheeler extrapolated the lesson that black holes require us not only to drastically revise our notions of space and time, but also that of physical law. Strictly speaking, it is obviously a *non sequitur*, even assuming that we accept that the conservation of leptonic and baryonic numbers is "transcended"; at this point, however, we can easily recognize that this is actually a daring-conservative extrapolation, which is not without an implicit question mark. What seemed to have not a solid physical ground any longer was the picture of a cosmic order governed by laws given from everlasting to everlasting (Wheeler 1973). Daring conservatism, pushing lawfulness to the extremes, ended up questioning the status itself of physical laws: thus, Wheeler did not just turn the "tree of physics" upside down – he uprooted it. "The golden trail of science is surely not to end in nothingness. There may be no such thing as the 'glittering central mechanism of the universe' to be seen behind a glass wall at the end of the trail. Not machinery but magic may be the better description of the treasure that is waiting" (Wheeler 1973, p. 203). If on the one hand the crisis of geometrodynamics led Wheeler to think that he needed some "pregeometry", on the other the lesson of the black hole convinced him that the idea of a natural order or mechanism, given once and for all and independent from the observer, was to be abandoned. How he tried to combine these two insights is the object of the second group of chapters.

Daring conservatism, as applied to the principles of general relativity, petered out. However, the shortcomings of the geometrodynamical view were not a mere inadequacy in which we happened to surprise the theory, so to speak, or to catch it in error from the outside: it is the theory itself that gave us

a last spectacular success – the black hole – and, at the same time, pointed out where something more was required. Geometrodynamics and its results were not to be disavowed: they were to be overcome in depth. The question that the "pilgrim" Wheeler had asked Max Born in – not by chance – 1967, which one is deeper between the quantum principle and the relativity principle, now had an answer, that soon became a new question: "How come the quantum?". At this point we cannot find surprising that Wheeler went back to meditate upon Bohr's teachings; but the door to lawlessness had been opened.

3. Again on the "clash of conservatisms"

Before closing this part of Wheeler's story and moving on, there are still a few considerations worth making. We have already mentioned that in 1972 – a period of crucial importance for the destiny of geometrodynamics, as we have just seen – Misner, while addressing the Philosophy of Science Association (Misner 1974), distinguished between a "mathematical" geometrodynamics, a "physical", and a "visionary" one. He had contributed to the former two – that is, considering a general relativistic universe made out of fields as if it were a mathematical model, and evaluating the possible physical relevance of the results thus gained –, but he ascribed the third (quite distant from his working style!) entirely to Wheeler. This, in a sense, was already mirrored by the fact that the 1950s compendium of (classical) geometrodynamics (Misner, Wheeler 1957) was followed by (literally: same journal, same issue, consecutive pages), but also separated from, an even more "visionary" and programmatic sketch towards a quantum geometrodynamics (Wheeler 1957). Wheeler's ambition of deriving everything out of geometry was, and remained, a long shot, as he himself was well aware. Nonetheless, as we have noticed more than once, that did not prevent him from investigating matter and its properties in general relativistic situations, instead of disdaining it as something merely derivative: Wheeler, on the contrary, brought his broad nuclear physicist's mindset in the new field and generated new problems to work on, since he expected extreme situations such as gravitational collapse to be a unique window on the ultimate nature of matter and the deep relationship between the marble of geometry and the timber of particles.

Linked to all that, in the previous chapter we have appreciated how daring conservatism, far from being a rigidly deductive method, revealed in practice its flexibility and fruitfulness, but also its ambiguity when it came to Wheeler's introduction of a new phase of equilibrium for cold matter. Part of this ambiguity can arguably be related to the fact that, if, in a "visionary" mode, daring conservatism could hope to squeeze everything from the

Einstein-Maxwell Lagrangian, in more concrete research terms Wheeler was also making leverage on the above-mentioned coupling of matter and geometry. Daring conservatism was thus not a single linear chain of reasoning, but, for the moment at least, had two orders of considerations that Wheeler was trying to make flow together. That has not prevented us from identifying quite precisely the trajectory of this heuristic methodology and its overall meaning, but, since we are now "complexifying" it a bit, we could still take a closer look at the "impression" of a clash of conservatisms, as suggested in the previous chapter. At a psychological level, so to speak, it seems plausible to say that a daring-conservative preservation of some features of matter could obstruct the most radical implications of geometry: a new equilibrium situation for cold matter would make the final phases of collapse more palatable and visualizable, at least according to Wheeler's taste. In that case, he did not make the best choice at first; ultimately, however, pushing his geometrodynamical insights to their limits, he would sacrifice something as fundamental as the law of conservation of baryonic and leptonic number. With this in mind, we can go back to the "delta rays" story that we have mentioned in Chapter 2 and better contextualize it. We shall thus realize that the "clash of conservatisms" is indeed an impression from afar (relatively speaking), but also that daring conservatism was even more entrenched in Wheeler's way of thinking about different issues.

Already in 1956, while trying to undermine Oppenheimer and Volkoff's (even before Oppenheimer and Snyder's) '39 paper, Wheeler annotated in his notebook that he wanted to analyze it by "simply recognizing the 'law' of heavy particle conservation".[123] Daring conservatism as applied to the baryonic number, we may say, even if those scare quotes around "law" suggest that Wheeler was not entirely convinced about its fundamental character and was thus moving in a tentative way.

> "What were now the implications of considering the law of baryon number conservation for neutron cores? It offered an alternate reading of the Oppenheimer-Volkoff limit. Oppenheimer had assumed that the neutron core would become unstable if mass was added beyond the limit. This was illustrated by looking at the free energy as a function of density for different values of the mass: equilibrium was attained for the density minimizing the free energy, but for masses greater than the limiting value the free energy curve did not have any minima" (Blum, Furlan 2022, p. 287).

Wheeler was instead thinking that

123Relativity Notebook 4, p. 36.

> "mass was a bad measure of the fixed amount of matter contained in a collapsing star. After all, mass was already in special relativity something that could be transformed into energy and thus radiated away. A better gauge of the amount of matter was baryon number. But if one consequently imagined making a star bigger not by increasing its mass, but by increasing the number of baryons there was a whole different way to read the Oppenheimer-Volkoff limit: not as a maximal mass for stability, but as a maximal mass, period. What this implied was that if one had reached the maximal mass and then added another nucleon, the mass would no longer increase; instead it would presumably decrease (the mass of the nucleon plus the mass lost by the star being radiated away), ultimately reaching some constant mass value" (Blum, Furlan 2022, pp. 287-288).

What if this constant mass value were zero and it could be reached with a finite number of nucleons?

> "Adding further nucleons to such an object would make no difference to the mass ("all the mass energy will be radiated") and no appreciable difference at all, except to change the baryon number. And while this would not change any of the immediate properties of the object itself, it might eventually make "a difference": Wheeler imagined "a special one of the gods who will keep track of the number of nucleons in the thing – no one else will care." When the "limiting object" then encountered a limiting "anti-object" (with a large, supercritical negative baryon number), the two would annihilate and result in an object with a possibly subcritical and thus observable baryon number: if, e.g., the number of baryons in the first object minus the number of anti-baryons in the second were 1, the result of their annihilation would be a neutron or a hydrogen atom with baryon number 1. Wheeler imagined that "the special god would smile and say 'Look, see!'" – vindicated, one might say, in his daring-conservative belief in the law of baryon number conservation (Blum, Furlan 2022, p. 288).

The question was if such a super-condensed state of matter could actually exist. "'*Either* there exists a super condensed phase *or* law of conservation of nucleons fails – and we don't see former' – This would be my first go around at seeking a conclusion".[124] He reached this temporary position via another

124Relativity Notebook 4, p. 40.

Gedankenexperiment:[125]

> "When one has nearly the peak mass for stability against collapse, one has a very interesting situation – add one nucleon; mass of star increases by a negligible fraction of mass of one nucleon; hence bulk of mass is given off as heat. When beyond this point, get off more energy than MC^2; hence could have 2 such stars, one the anti of the other and make a profit producing nucleons out of vac[uum]. Expect star will take profit".[126]

Wheeler was thus ready to give up the law of conservation of the baryonic number that he had at first "taken seriously":[127] here, on a smaller scale, we can see how he reached via daring conservatism a sort of *reductio ad absurdum* and he thus dismissed the fundamental status of the initial tenet. That is also a form of interrogative daring conservatism, in a sense, although obviously less ambitious than its application to "Einstein's" vision. It is important to realize that the "Either... or" conclusion originated from what Wheeler considered a mistake in Oppenheimer and Volkoff's treatment, and *not directly* from his rejection of Oppenheimer and Snyder's way of "taking seriously" the indications of the formalism of general relativity. It remains true, however, that "Wheeler had assumed that the process that violated baryon number would simultaneously prevent the collapsing star from shrinking below its Schwarzschild radius" (Blum, Furlan 2022, p. 289). As Einstein too had written in the '39 paper we mentioned in the previous chapter, "matter cannot be concentrated arbitrarily" (Einstein 1939, p. 936): thus, the Schwarzschild radius was not meant to physically exist as such. Wheeler's early speculations about cold matter and its equilibrium have to be placed in this context. That is the actual background of the seeming "clash of conservatisms", which thus appears less direct.

By the early '60s, however, as we have seen, Wheeler was considering the Schwarzschild radius differently – and this is where "delta rays" came in.[128] The in-falling nucleons were now supposed to get "crushed out of existence": they were imagined to disintegrate, as if that were a new type of

125While this analysis is done in Wheeler's notebooks, there is an echo of that in the '58 Solvay conference as well (Adams et al. 1958). In Chapter 5 we will make some further consideration about the curious shape taken by the argument in-there.

126Relativity Notebook 4, p. 36.

127See Appendix A for another case in which daring conservatism and "taking seriously" are equated.

128(Blum, Furlan 2022, p. 290). Special thanks also to the notes taken by Dieter Brill of a talk given by Wheeler at the First Texas Symposium on Relativistic Astrophysics, 16-18 December 1963.

radioactivity that would emit “delta” radiation. These rays would keep track of the baryonic number and now ensure somehow its conservation. As already said, these speculations were short-lived, but, besides Brill's notes, there is some vague allusion to them at the end of (Harrison et al. 1965) and in a later remark made *en passant* by Thorne (2019, p. 15). Thorne said that he “discouraged” Wheeler from pursuing those ideas (even if he does not call them “delta rays”), but, in retrospect, had also some regret because his mentor, had he refined them, might have anticipated Hawking radiation. Of course, in Wheeler's mind surprising transformations could take place, but that is perhaps debatable, although not so far-fetched.

Once Wheeler fully embraced black holes, the scenario for his recurring question on the relation between the extreme phases of gravitational collapse and matter changed once again, and so did the specifics of putting that question at work, as we have already sketched in the previous section. Clearly, he was not just interested in what happens to baryons and leptons *per se*. In '68, in one of the self-reflective moments of the notebooks, he wrote: “the great question is, do black holes and elementary particles belong to the same breed of cats. A black hole has mass, angular momentum, charge, magnetic moment – but so far as I know, nothing else. Baryon number, neutrinoicity, strangeness – all these as far as I can see, go out in the collapse”.[129] Shortly after that, he updated his *Gedankenexperiment* of twelve years earlier: “If a black hole 'made of' neutrinos collides with one 'made of' antineutrinos, is the outcome different from the collision of the black hole 'made of' neutrinos and one of the same macroscopic quantities made of [neutrinos], or photons, or ordinary matter, or some mixture thereof?”[130]

> “He was beginning to suspect that even if matter went into the black hole unharmed (i.e., without losing its identity through something like delta radiation, or as he put it in his notebook “all down, none out”), the special god would no longer be vindicated in keeping track of how many baryons or neutrinos went in; baryon number as a property of matter would simply vanish in collapse since it was not a possible property of black holes” (Blum, Furlan 2022, p. 291).

At this point, we are back to the investigations that would lead him to the “transcendence” of laws. It is now clear that, even with respect to the violation of the baryonic number, Wheeler's ideas and expectations changed more than once. It is also evident, however, that his attempts at coupling the geometry of general relativity and the properties of matter represent a *fil rouge* that

129Relativity Notebook 15, p. 60.

130Relativity Notebook 15, p. 61.

accompanied him during the two decades of geometrodynamics, and arguably even longer than that: as we shall discuss in Chapter 7, it is within this order of ideas that Wheeler inspired his student Bekenstein[131] and got in turn some "hints" about his later "everything is information".

While Wheeler's moonshot throughout the '50s and '60s was indeed to derive matter from geometry, he was also wise and cunning enough to keep the two strands with relative strands and, as we have seen, assign more concrete research issues to students and collaborators, and then coordinate them within the framework of his own vision. That is made evident, after all, by the list of works that first led him to abandon his reservations on collapse and then to better explore those exotic scenarios. Daring conservatism, in all this, revealed its many facets. Still, the fact that, the "visionary" and hoped-for explanation of matter notwithstanding, particle properties were instead used as tools to get new insights is also related to Wheeler's peculiar trajectory across physics and his previous expertise: but was he the only nuclear physicist, in a broad sense, that, around those years, turned his attention to general relativity and the cosmos?

4. The violent universe

If Wheeler's path is admittedly idiosyncratic, the methodology he crafted on his own may seem even more so. If we scratch beneath its peculiar surface, however, we can actually frame it within – and, in turn, use it to shed light on – the attitude and the contributions that, between the '50s and the '60s, characterized a number of versatile physicists who, like him, had a broad nuclear background and brought their expertise to the service of the newly emerging astronomies (radio, gamma, X-ray), relativistic astrophysics, and cosmology. A particularly meaningful parallelism is that with Yakov B. Zel'dovich, Wheeler's Soviet counterpart in more than one way. Even if Wheeler's turn to general relativity and related issues dates back to the early '50s, while Zel'dovich's almost a decade after, the affinities between the two of them are quite striking, and the scientific developments that were becoming more and more intertwined with Cold War technology would contribute to put

131"I can recall confessing to Bekenstein how bad my conscience has always been in putting a hot teacup next to a cold one. Although energy is conserved in the exchange of heat between the two, that process increases the entropy of the world in an irreversible way that echoes unforgivingly down the corridors of time, forever. "But," I said to Jacob, "if a black-hole comes by, why can't I drop both teacups in and hide the evidence of my crime?" Bekenstein, however, is a man of great integrity. This proposed escape did not appeal to him. He came back a few months later with the conclusion that the black hole itself has entropy" (Wheeler 1994d, pp. 285-286).

them on parallel tracks already in the mid-'60s (Bonolis, Furlan 2024; Furlan, Bonolis 2024). They both had a broad nuclear expertise, since they were distinguished theoreticians but also at the head of the H-bomb projects of their respective countries. They both were quick to realize the possibility of exaptating the computer tools and the understanding of physical processes gained to develop thermonuclear weapons and applying them to astrophysical issues. "Work in the theory of explosions prepared us psychologically for research on explosions of stars and the very greatest explosion – the Universe as a whole".[132] They would lead two of the major research groups in relativistic astrophysics; both of them would associate their name with black holes; and they shared a common attitude towards general relativity and its principles. At a summer school in Tartu, in July 1962 (Furlan 2023), Zel'dovich, while offering an overview of astrophysical problems in the light of fundamental physics, briefly commented on the formalism of general relativity, refusing for the moment any modification and clearly saying that the task at hand was to fully explore its implications: "The problem of the theory of gravitation is to make the correct application of the theory to such complicated problems as stars and the universe as a whole" (Zel'dovich 1963, p. 948). The name of "daring conservatism" would have not sounded so well in the Soviet Union, but this is as close as one can get – and not only in relation to the exploration of Einstein's legacy. Even before that, identifying general principles to make leverage on was central to Zel'dovich's style: it is no coincidence that, among his contributions, we can find the formulation of the law of "nuclear" (or, according to current terminology, baryonic) charge conservation, which, in the midst of the "particle zoo" confusion, he tried to extend to the newly found unstable species found in cosmic rays (the so-called "strange particles") (Zel'dovich 1952); likewise, in 1953 he formulated the law of conservation of "neutrino" (leptonic, in modern terms) charge (Zel'dovich 1953).

Wheeler and Zel'dovich first met in person in 1968, in Tbilisi, in occasion of the 5th International Conference on Gravity and the Theory of Relativity,[133] but as early as 1963, in his Les Houches lectures, Wheeler (1964, p. 325) shows that he was aware of Zel'dovich's work on gravitational collapse (Zel'dovich 1962). From the commentary of the editors of Zel'dovich's *Selected Works*, it seems that Zel'dovich too, like Wheeler, linked this topic to more general reflections about the nature of matter: "Ya.B. showed in 1962 that even a small mass can collapse if its density is

132This is Zel'dovich in an autobiographical note – see Zel'dovich (1993b, p. 640) – but something very similar could be said of Wheeler, too (cf. Chapter 5 for his own words).

133John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, boxes 33 & 70.

sufficiently high. From this followed a paradoxical conclusion, that the equilibrium of any mass is always metastable with respect to gravitational collapse" (Zel'dovich, 1993a, p. 38). During that same decade, their respective young collaborators, Kip S. Thorne and Igor D. Novikov, managed to visit their counterpart's group and intertwined a friendship that is also witnessed by their later books, aimed at larger audiences.[134] Zel'dovich and Wheeler too, besides the mutual professional admiration, established a warm relationship, as can be seen from their correspondence. That the previous leaders of the military projects to create H-bombs could begin to interact already during the 1960s (Cold War and their previous roles notwithstanding), and even have some personal exchanges, is an interesting story also from a human point of view. The blossoming of relativistic astrophysics was thus, in a sense, fertilized by the most destructive weapon of the Cold War and the Iron Curtain did not prove an insurmountable obstacle in communication between scientists.

Did we just happen to find a subject for some Plutarchean *Parallel Lives*, or is there more to it? It is now time to speak of the discovery and implications of the "violent universe". This phrase, now rather rare among historians and even more so among philosophers of science, is still used in some circles of astrophysicists and, significantly, dates back to the very 1960s: at the end of that decade, Carl Sagan would make his debut in a television documentary with the title *The Violent Universe* (1969). If the optical contemplation of the sky had been suggesting the silence and the emptiness of cosmic spaces, the opening of new channels – the new astronomies that were being born (radio, X-ray, gamma, neutrino) – were gradually unveiling how catastrophic phenomena, involving unprecedented magnitudes, are inhabiting outer space. It is important to realize that the impact of these new channels cannot be reduced to some additional "filter" to look at the sky (Bonolis, Furlan 2024). The resulting picture of the universe, with large-scale phenomena of energies far beyond our Earth-shaped imagination, was dramatically different from the merely optical one. In this context, it is interesting to emphasize how, both east and west of the Iron Curtain, pioneering contributions were made by physicists who had a nuclear background *lato sensu*, that is in nuclear as well as subnuclear properties of matter, its interactions with radiation, and so on. Wheeler and Zel'dovich clearly fall under this profile, but we could also mention Fowler, Hoyle,

134(Thorne 1994; Novikov 1998). Perhaps more importantly, already during the 1960s they contributed to the translated versions of the technical work they had done with their group leaders: "Kip edited the translations of the astrophysics books written by Zeldovich and myself, while I edited the translations of his books published in Russia" (Novikov 1998, p. 107). Nowadays, of course, it is quite easy to neglect the issue of translation in these fields, or take it for granted.

Ginzburg, Pontecorvo, and others – or, even before them, Fermi himself, when he was thinking of the mechanisms of acceleration that today bear his name. Even if we would not be able to find as many striking parallelism as those between Wheeler and Zel'dovich, the key point is the following: this kind of physicists, in front of the novelties of those years about the cosmos, were trying to make leverage on their "fundamental" expertise, on well-established principles of physics, and, before invoking the need for new physics for remote new phenomena or postulating new types of entities, construct as much as they could with the conceptual tools they had. The resonances with daring conservatism are obvious. Quasars, pulsars, black holes were new exotic species of the "violent universe", but they were not free novelties. A deeply interconnected theoretical framework – although, at the time, largely heuristic – had prepared the ground for the understanding of the non-thermal universe.

If we have this larger framework in mind, the fact that Wheeler's change of mind about the yet-unnamed black holes happened in the early '60s does not seem coincidental, either. Fowler and Hoyle (1963) proposed the idea that extremely strong radio emission could be due to "star-like objects" in the centers of galaxies, but nuclear energy, the basis of a star's evolution, could not be responsible for that – instead, the release of gravitational energy, in a process of compression of enormous masses to lengths comparable to their Schwarzschild radius, could be the key factor. Shklovsky (1962), in the Soviet Union, had independently reached similar ideas at that time. Quasi-stellar radio sources (quasars) would be announced early in 1963 and general relativity finally seemed to make contact with observational astrophysics: this was one of the triggers that led to the First Texas Symposium later that year (with the title *Quasi-Stellar Sources and Gravitational Collapse*) and the birth of "relativistic astrophysics" (Robinson et al. 1965). Times were ripe, and Wheeler and his group were ready not to lose the opportunity – but the idiosyncratic methodology that had led them there was not so unique or outlandish, after all.

5. The fog of war

After the temporary inaccessibility of Wheeler's archives during the recent pandemic, it has become possible to consult his collections again: the result is that there are a few additions and clarifications to be made about the reconstruction of Chapter 2, which was made with the material that was available during the closure. Stirling Colgate's role (and thus also his account, or better what Miller (2005) reports)[135] is still not entirely clear: most probably

135I have contacted Miller, but he claims to have destroyed the interview from which he

due to military secrecy, there seems to be hardly any trace of him in Wheeler's archives. For sure, in Wheeler's notes of the early '60s (Relativity Notebooks 9-11) it is possible to see numerical results presumably due to calculators, and there is no doubt about the interactions with Colgate and his collaborators, but the story of Wheeler being *first* convinced by similar outputs does not match the actual documents – not just due to the (temporary?) absence of those that could support this account, but also because of the conceptual struggles Wheeler was still facing after the alleged '62 turning point. Speaking of which, it turns out that Thorne's account is not entirely accurate from a chronological viewpoint, either. Clearly, when writing the book (Thorne 1994), he discussed matters with Wheeler, getting his approval, and in general he made a thorough and reliable work, so that, conceptually, we have no reason to doubt it. However, perhaps because Thorne's own experience was also intermingled in his version of the story, a few elements from Wheeler's notebooks would seem a bit out of place if we stick to that account. Wheeler's process of conversion looks much more foggy and gradual than suggested by the "convergence" of results we have outlined in the previous chapter, trying to put the two accounts on an equal footing. There were also chronological "coincidences" (the theses of Beckedorff and Mills, Thorne's arrival, Wheeler's '62 stay on the West Coast, etc.) that seemed to settle the issue around '62, as we have discussed. The story told by the notebooks is a bit less spectacular and, we may even say, less clear. The title of this section alludes to that, by borrowing the famous metaphor usually attributed to von Clausewitz about the uncertainty and actual confusion on the battlefield – but, since Colgate's role is difficult to assess with precision due to military secrecy, it can also be referred to that. Nonetheless, all the considerations we have made about Wheeler's merits, heuristics, promotion of research against his own tenets, and style of leadership are not touched by these corrections.

From the beginning of '63 on, something quite unusual happened: Wheeler started to fill almost half of Relativity Notebook 10 while remaining remarkably focused on one topic. What was engrossing him so much was Alastair Cameron's paper about neutron stars (Cameron 1959). This does not just mean that Wheeler was updating himself about relevant astrophysical matters: Cameron knew the work of Wheeler's group presented at the Solvay conference (Adams et al. 1958) and was pioneering the application of computer simulations to astrophysical topics. The paper dealt in fact with his computer simulations of several neutron star models. In examining the physics of supernovae explosions and of the formation of chemical elements, he had been able to conclude that "neutron stars are probable products of the supernova process" (Cameron 1959, p. 884), at a time when neutron stars were

quoted...

little more than theoretical entities. In discussing the extreme densities inside of them, he remarked that, beyond a certain energy threshold, neutrons could be transformed into protons, mesons, and even hyperons. Finally, he also suggested that neutron stars, far from being completely inert once formed after the supernova outburst, might instead show some "low-level activity" that might be "the source of the periodic disturbances in the Crab Nebula" (Cameron 1959, p. 994). What is more, Cameron knew Colgate and held him in high esteem: "Stirling is your ideal theoretical astrophysicist, your ideal plasma physicist, your ideal hydrodynamics physicist, all of those put together, and I mean it represents just a marriage of what you need to do on the weapons side and what you can apply using just basic physics principles on a whole bunch of other subjects" (Cameron 2003). The resonances with Wheeler's interests and tools at the intersections of subdisciplines are simply obvious, so it is not surprising that he read the paper very attentively; and, of course, this is arguably a point in favor of the overall reliability of Colgate's account, chronological details aside.

Wheeler was so taken, however, because, in the midst of all this, he thought at some point to have found a new state of equilibrium for cold matter (again his "old" idea, therefore): accordingly, he gave those pages the evocative title of "The Last Star" (Relativity Notebook 10, p. 122). In the following notebook, we notice that Thorne himself really started to make a significant appearance only around the summer of '63 (just to shift the chronology a bit, even if he is already mentioned in Relativity Notebook 10, p. 14). But, then, what about the Les Houches lectures during that same summer, in which Wheeler thanked him for his assistance and referenced Zel'dovich's early paper on the gravitational collapse of *any* body compressed beyond its Schwarzschild radius (Zel'dovich 1962)? That is also a later addition, shortly before the lectures were printed the following year (Wheeler 1964): as a matter of fact, it was Misner who, in fall '63 (Relativity Notebook 11, p. 126), pointed out Zel'dovich's work to Wheeler, who then began to read it attentively. Misner's receptiveness and his role in "correcting" Wheeler should thus give him more credit in this story. Perhaps even more importantly, it is only in '64 that Wheeler found the time to read Beckedorff's thesis (Relativity Notebook 12, pp. 189-ff.): his attention is clearly caught by the construction of the embedding diagrams, so we can trust Thorne's "eye opener", although delayed. Not even that, however, allows us to really pinpoint a drastic moment of conversion in the notebooks.

Even before Wheeler read Beckedorff, the First Texas Symposium, in December '63, took place, as we have already recalled, and by that time the (astro)physical relevance of general relativistic gravitational collapse had been established. At the event, Wheeler actually gave a talk, which, however, he did

not publish in the acts (Robinson et al. 1965). This may seem symptomatic: thanks to the notes of Dieter Brill, we already know that Wheeler spoke of "delta rays", but the idea was soon after abandoned and Wheeler, since his thought was very much in flux and undergoing a change, withdrew the paper from the proceedings' plans. If we go through his notebooks, we can notice how the first half of '64 is dedicated to prepare and revise the Les Houches lectures (with the help of Thorne, as indicated in the acknowledgments) and the "Dallas paper", which however did not see the light. We are thus in the middle of '64 without a clear "Eureka!" moment,[136] even if, in that year, there are publications such as (Wheeler 1964) that no longer showcase his most blatantly "wrong" idiosyncrasies or forms of resistance against collapse. Clearly, although he had understood the role of the Schwarzschild radius and had imagined quantum foam as a patch for the central singularity, he was still struggling with a detailed *mental* simulation of the whole process and its implications (and he was certainly not alone in that). While further close reading will certainly unveil other aspects, for now we can stick to our reconstruction of the parable of daring conservatism and geometrodynamics, now also contextualized in a broader framework. In turn, as promised in the Introduction, by following Wheeler's "worldline" we have indeed got new insights on that larger context as well.

136It is meaningful that the same conclusion was reached in (Blum, Brill 2020) while trying to pinpoint a precise moment of Wheeler's "conversion" in the early '50s.

And as imagination bodies forth
The form of things unknown, the poet's pen
Turns them to shapes, and gives to airy nothing
A local habitation and a name.

SHAKESPEARE

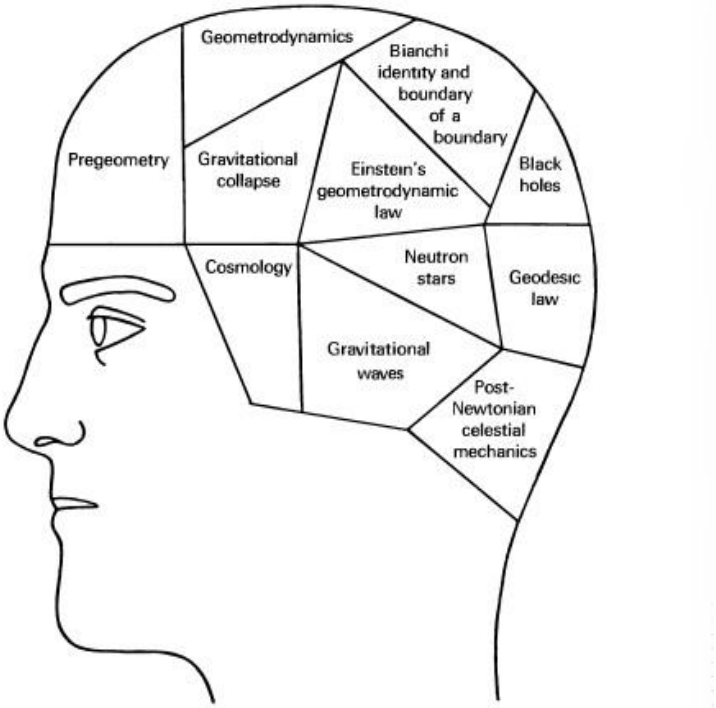

Fig. 4. “Phrenological” diagram from (Misner et al. 1973, p. 1219): what is needed in one's head to explore “Einstein's vision” and its legacy.

Appendix A. Daring-Conservative Regrets: Katharine Way, Wheeler, and the Dawn of the Nuclear Age

This chapter is called "appendix", in part because it consists of the autonomous text of a talk not published yet (and thus it is a bit redundant with respect to what we have already said), but it is fair to say that it deals with an appendix to the parable of daring conservatism, rather than being a mere appendix to the other chapters, as if they were not on equal footing. Wheeler, besides being in his own right a key figure in 20th-century physics, was also an exceptional witness and teacher. Little known is the fact that his very first Ph.D. student was a woman, Katharine Way (1903-1995), who played an important role in the postwar organization and dissemination of nuclear data. Towards the end of the century, Wheeler made quite a surprising claim: that Way's work while she was his student came very close to anticipate the discovery of nuclear fission. Besides gathering the few pieces of information about Way's early work, this paper will provide a proper contextualization and evaluation of Wheeler's words, by analyzing his peculiar communicative style that often mixed in subtle ways history, his personal experience, and theoretical insights or guiding ideas. It will thus emerge how figures such as Marie Curie, Lise Meitner, Maria Goeppert-Mayer, and Katharine Way herself represent a fil rouge in Wheeler's story of the exploration of the nuclear realm during the 1930s, providing an original viewpoint that, however, has also to be properly taken into account when evaluating the claim about his former student's work.

One keeps forgetting to go right down to the bottom.
One does not put the question marks deep enough down.
– Wittgenstein, *Vermischte Bemerkungen* (1980, p. 62e)

1. Introduction

"Had we followed her lead, we might have thought of fission" (Wheeler 2000, p. 23). This is none other than John Wheeler speaking in his autobiographical recollections about the work of his very first Ph.D. student, Katharine Way (1903-1995), in the second half of the 1930s. Wheeler's vast corpus of published and unpublished writings is a precious but little explored source: if many have heard something about his work, or at least his popularization of black holes, much less known is his exceptional role as a witness who, with his long life and career, spanned almost a century. Also: many know about his many distinguished students, but what about women that studied with him? Katharine Way is certainly not so famous today; and yet, she did enjoy a quite distinguished career in nuclear physics and, as Wheeler seems to hint at, she reached the theoretical "quasi-discovery" of such a decisive phenomenon as

fission. In the first part of this paper we will better look into Way's early work and begin to contextualize Wheeler's claim; the second part, instead, will provide a critical reading of it, since Wheeler's texts have typically a number of layers that can easily mislead the reader. By examining his peculiar way of intertwining history, his personal experience, and theoretical insights or guiding ideas, as well as his narrative building, we will take a look at his view of the history and prehistory of nuclear fission and, as a sort of *fil rouge*, the role played by various women in it. In the light of such considerations, we will then be in a much better position to evaluate his claim about Way as well.

2. Katharine Way: on the verge of nuclear fission?

An important obstacle to investigating Way's life and work is the paucity of archival sources, as is unfortunately often the case when trying to reconstruct the stories and contributions of women scientists. The libraries of Duke University, where she spent a good part of her career after the Second World War, hold but a couple of slim folders, containing newspaper clippings that are not particularly relevant for the purpose of this appendix.[137] Wheeler's archives and recollections are then key sources, despite their historiographical problems. Although Wheeler and Way stayed in touch for almost six decades, Wheeler's archives contain only a few letters between the two, which they exchanged mainly on the occasion of academic celebrations. As we will see below (and as we have discussed in Chapter 1), Wheeler's recollections can also be challenging to interpret. Before diving into this particular difficulty, however, some biographical context about Way is warranted. Previous authors have already gathered relevant biographical data about her (Martin et al. 1996; Howes, Herzenberg 1999; Ware, Braukman 2004). Here, we also assemble deeper insights into her early work on nuclear models, which are largely missing from the secondary literature.[138]

Katharine ("Kay") Jones Way was born in Sewickley, Pennsylvania, in 1903,[139] the second of three children from a relatively wealthy family that

137In these two thin folders of "biographical information" about her in the collections of Rubenstein Library, Duke University (Biographical Reference Collection, box 26; New Service Biographical Files, box 107) we can nonetheless read, for instance, that she actively supported "triangle women", meaning by that women working in the "Research Triangle" whose vertices are Durham (home of Duke University), Raleigh (home of North Carolina State University) and Chapel Hill (home of the University of North Carolina at Chapel Hill).

138The lack of archival sources is only a partial excuse for that, since her published work can be quite easily consulted.

139Second- or third-hand sources erroneously report 1902. Wheeler, born in July 1911, explicitly states that she was eight years his senior and that her 90th birthday was in 1993.

could afford to send her to private boarding schools first in Plainfield (New Jersey) and then in Greenwich (Connecticut). Her early life was marked by the loss of her mother, when she was twelve. Shortly thereafter, her father, a lawyer, got remarried (Ware, Braukman 2004, p. 670) to a practicing otolaryngologist, who acted as a role model of a working woman for Way. Given this family and educational background, and if we were to focus exclusively on Way's birth year, she would appear to belong to what John Slater (1900-1976) once called the lucky generation of physicists, in analogy with Malcolm Cowley's similar label for dos Passos, Faulkner, Fitzgerald, and Hemingway in literature (Schweber 1990). For Slater, that generation referred to physicists born to see in their prime, or even contribute to, the advent of quantum mechanics, typically through some *Lehrjahre* in Europe. While Robert Oppenheimer, born in 1904, felt he had already arrived a bit too late to take the main stage (Schweber 2008, p. xi), Way's one-year chronological edge was not what it seemed. Her college education was indeed troubled for reasons that remain unclear, but which include illness and a change of curricular interests. Way first enrolled at Vassar College (New York) in 1920, but she had to interrupt her studies only two years later because of suspected tuberculosis (Ware, Braukman 2004, p. 670). Following a two-year convalescence, she joined Barnard College, in New York City, for a couple of semesters (1924-1925). However, still uncertain about choosing one field over another, she interrupted her studies once again. Only in 1929 did she begin to devote herself to mathematics at Columbia University, notably attending the lectures of Edward Kasner (relatively well-known today for introducing the term "googol").[140] She attended classes until 1934, in the meanwhile completing her BSc in 1932 (Ware, Braukman 2004, p. 670).

It was during this time at Columbia that Way became intrigued by physics after reading – perhaps rather unusually for a future professional physicist – Bertrand Russell's *The ABC of Atoms* (Howes, Herzenberg 1999, p. 42). Meeting Wheeler would do the rest: Way herself would later recall when she "was first seeing the world of physics through [Wheeler's] eyes".[141] It is not clear how they first met or why she moved for graduate work to the University of North Carolina at Chapel Hill.[142] What is certain is that, once

This is further confirmed by a copy of her curriculum vitae preserved in Wheeler's archives (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68). That discrepancy nevertheless illustrates the general neglect surrounding even the few straightforward pieces of information about Way's life.

140Kasner and Way, together with Erna Jonas and George Comenetz, also wrote a paper on centroidal polygons and groups (Kasner et al. 1934). That was Way's first paper.

141Way to Wheeler, April 27, 1983. (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68).

142Neither her obituary (Martin et al. 1996), nor the other referenced sources, nor her 1978

Wheeler came back from Copenhagen in 1935, Way became the first graduate student of the young professor (eight years younger than her). Her dissertation was dedicated to the *Photoelectric Cross Section of the Deuteron*,[143] which followed from her paper with the same title (Way 1937). Even though she had fulfilled the PhD requirements by 1938, she held on to her graduate student status (Howes, Herzenberg 1999, pp. 42-43), given the persistent unemployment after the Great Depression. During that time, she also kept working on nuclear physics. Upon finally receiving a research fellowship at Bryn Mawr College, she officially put an end to her PhD and moved to the famous women's college for a year. She then obtained a teaching position at the University of Tennessee, where she stayed until 1942.

During the war, after hearing rumors about a nuclear project in Chicago, Way asked Wheeler if there was something she could do (Howes, Herzenberg 1999, p. 42). She hence became part of the Manhattan Project as a member of the Metallurgic Lab, where Wheeler also worked (Wheeler 2000, p. 150). There, she initially analyzed, together with Alvin Weinberg, the data from Fermi's first atomic piles to evaluate whether the flux of neutrons was sufficient to allow a self-sustaining chain reaction, and then, with Eugene Wigner, she developed the *Way-Wigner* estimate of the fission product decay (Way, Wigner 1948).

Her involvement with war-time research left her with ethical concerns. In the summer 1945 she signed the Szilard petition opposing the use of atomic bombs against Japan. Right after the war, while pursuing nuclear research at Oak Ridge National Laboratory, she became publishing director for the Federation of the American Atomic Scientists, and, together with Dexter Masters,[144] she co-edited the New York Times bestseller *One World or None: A Report to the Public on the Full Meaning of the Atomic Bomb*, in which Albert Einstein, Niels Bohr, Oppenheimer, Wigner, Arthur Compton, Leo Szilard and others expressed concerns and offered to a larger public a problematization of the perspectives opened by the Nuclear Age (Masters, Way 1946).[145] On the surface, Masters and Way were "invisible" editors, as

curriculum vitae kept in Wheeler's archives (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68), provide any information about Way obtaining a MSc. Ware and Braukman (2004, p. 670) simply state that, after 1934, she "continued her education at the University of North Carolina".

143A copy – with the title indicated and dated 1938 – is preserved at the University of North Carolina (Wilson Library, North Carolina Collection, C378 UO2 1938 WAY).

144Nephew of Edgar Lee Masters, Dexter Wright Masters (1909-1989) was actually a writer who, during the war, had served on the communication staff of the US Air Force and edited classified publications for research labs. Later he would also write a novel, *The Accident,* about the final days of a physicist – inspired by the case of Louis Slotin – dying from radiation sickness (Masters 1955).

145See also Appendix B here.

the book contains no preface or comment signed by them. However, given Way's role as publishing director of the Federation and her endorsement of the Szilard petition, it seems safe to assume that she likely shared her views in the last section of the book, "Survival Is at Stake" (Masters, Way 1946, pp. 215-220), signed by "The Federation of American (Atomic) Scientists":

> "American scientists, acutely aware of their responsibilities for making known the full implications of their scientific developments, have been mobilizing ever since the end of the war. In October scientists from the atomic project joined forces, and in December the Federation of American Scientists, open to all scientists and engineers, was formed. Member associations across the country are encouraging qualified scientific and political discussion such as that presented in this book" (Masters, Way 1946, p. 215).

In the years that followed, according to Wheeler (2000, p. 150), "[s]he made the decision not to teach, electing instead to pursue research". In 1947, she started working at the National Bureau of Standards in Washington but, more generally, in the years after the war and for the rest of her career Way's main activity consisted of organizing the Nuclear Data Project, which systematically gathered data about atomic and nuclear properties, evaluated and disseminated them. In 1964 she established a first journal of the project, *Nuclear Data Sheets,* which was followed in 1965 by another, *Atomic Data and Nuclear Data Tables,* to which Way's name is indissolubly associated as editor. That association, in particular, led Wheeler to call her "dear to the community of nuclear physicists for her own work in the field as well as for her contribution to theirs" (Wheeler 1979, p. 254). From 1968 to the end of her career she was at Duke University.

Way's scientific *magnum opus* consists of the edition of journals and volumes of nuclear data. As colleagues wrote in her obituary, "by her insistence on the critical evaluation of all published basic data and her ability to combine these data into as logical and self-consistent a set of nuclear structure properties as possible, Kay influenced an entire generation of evaluation experts and the presentation of data in physics literature" (Martin et al. 1996). If we open the two volumes she edited in 1973, *Atomic Data and Nuclear Reprints* (Way 1973), in the short and sober preface we can read words that, in this case, were certainly written by her:

> "Since 1968 the journal Nuclear Data Tables has published four works on internal conversion which, taken together, present a complete set of values for the internal conversion coefficients. The collection of these

> four papers into a single volume with an additional table, Appendix B (to help find L-subshell ratios), provides a compact tool for the analysis of nuclear radiations. Such a tool is needed not only by nuclear spectroscopists in constructing decay schemes but also by health physicists in estimating dosages, nuclear engineers in calculating shielding requirements, and theorists in checking internal conversion theory itself" (Way 1973, p. ix).[146]

This work, as is easy to guess, became an important reference for the experimental, theoretical, engineering, and even biomedical communities, as well as an opportunity to establish common standards among them. As Way writes without any flamboyance: "It is hoped that the present volume will make easier the comparison of experimental and theoretical values and thus lead to a deeper understanding of the conversion process" (Way 1973, p. x). A similar role in enabling the coordination and cooperation of different communities was also played by her in organizing the consortium of universities doing research at the Oak Ridge facilities (Martin et al. 1996).

After decades of this kind of service, Way mentioned in a letter to Wheeler (dated September 2, 1980)[147] that she was "planning to give up the journal [*Atomic Data and Nuclear Data Tables*] soon and work on a book on the ageing process". The last phase of her life was indeed characterized by an interest in health care for the elderly (Ware, Braukman 2004 p. 671). Only a couple of years later, she retired from that role, but not before sending around a little memoir titled "History of a Compilation Journal".[148]

From a brief exchange between Way and Wheeler at the end of April and beginning of May 1983,[149] we can surmise that she had a joyful retirement party at which she was presented with old pictures, notes, her thesis cover and other mementos. (Wheeler too took part in the event and was responsible for many of these gifts.) It is not known what became of these materials, but from

146In an unassuming tone, she goes on to explain in very simple terms what these efforts are about: "In a nuclear transition the energy released can be emitted as a photon, with $E = h\nu$, or can be transferred to an atomic electron which is ejected with an energy equal to $h\nu - Bi$ where Bi is the binding energy of the electron in the *ith* shell. The internal conversion coefficient is defined as the ratio of the probability of electron emission to the probability of gamma emission. This ratio depends, of course, on the shell from which the electron is ejected. Partial coefficients must be computed for each shell, and subshell, and summed to obtain the total conversion coefficient. Fortunately the partial values decrease rapidly with increase in the principal quantum number so usually only the inner shells, K, L, and M, need be considered" (Way 1973, p. ix).

147John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68.

148Letter to Wheeler dated 12 November 1982, John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68.

149John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68.

Way's April 27 letter we do know that she felt she owed a debt of gratitude to Wheeler and the other participants, "one which I can repay only by trying to pass on the kindness and goodwill you showed to me. You gave me a wonderful shot of self-esteem to carry me forward into a less exhilarating future. I'll do my best to make good use of it". Nonetheless, in her words we can sense a shadow, so to speak – that of farewell to scientific activities and, perhaps, the loneliness of old age. (She never married.)

Way passed away in Chapel Hill in December 1995. Wheeler, in his autobiographical book published a few years later, recalls how, in 1993, when she turned ninety, "I visited her in her Chapel Hill retirement community, Carolina Meadows, where I found her as lively and opinionated as ever" (Wheeler 2000, p. 150).[150]

Having caught a glimpse of the relationship between Way and Wheeler from the latter's viewpoint, we may also quote here some delightful rhymes that she wrote in 1977, after the 65-year old Wheeler retired from Princeton and moved to Texas:[151]

"Dear John,

Here's some of what I learned from you
On how to work, what to do.
Before you start, make due reflections
On all exceptions, all corrections;
Never think a small chance nil

150It is unclear whether "opinionated" referred to some specific set of ideas or it was just a way to characterize her as a person of firm opinions (in the same page he called her "not reluctant to express her definite opinions on people and events"). At first sight, a possible hint could be found in a letter to Wheeler dated April 27, 1983 (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68), in which she writes that her happy days in physics "were almost brought to a close in the McCarthy days from which I was rescued by that blessed chicken farmer", but her troubles do not seem to have had a political or ideological origin. A little research could in fact clarify that what she was referring to is probably linked to the aftermaths of an episode that we find some traces of in (Libby 1979): in Chicago, as a friendly gesture, she had let a visitor from the Canadian Atomic Energy Program stay in her apartment, since she was out of town. This visitor happened to be later convicted of treason in Canada and, consequently, Way too had a series of security-clearance difficulties. This is the context in which we need to put the remark by (Ware, Braukman 2004, p. 30) that, during the McCarthy era, "[p]hysicist Katharine Way spoke out against the unfounded accusations sabotaging careers in her field, charges often rooted in the secret wartime conditions necessary to develop the atomic bomb", although we may wonder whether she "spoke out" before, during or after the above mentioned episode.

151The poem is part of an anthology of personal recollections, *A Family Gathering*, offered by many of Wheeler's former students and collaborators. Its index can be found in John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 43.

For what can happen surely will.
Then calculate with all your might
Make it right, make it tight.
Check by day, recheck by night
Phys. Rev. at last will show delight.

Now a toast to you and Janette
You've made this earth a better planette".

Her affection is also displayed in her letter thanking Wheeler for his contribution to her own retirement party in 1983, recalling the "happy days [...] when I was first seeing the world of physics through your eyes".[152]

Wheeler, in turn, showed how highly he valued her role in the nuclear physics community when he, in 1978, together with Gertrude Scharff Goldhaber, Eugene Wigner, Alvin Weinberg and others, nominated her for the Tom W. Bonner Prize in Nuclear Physics from the American Physical Society (which, despite the strong supporting party, was not awarded to her, neither that year nor later). Wheeler's letter, as generous as it is insightful, contains some telling statements:

> "I do not have to say anything about her unique contribution that is certainly worth the work of at least 20 people in analyzing nuclear data from a discriminating point of view so that it makes the lives of all of us so much more productive than would otherwise be the case.
>
> It has been said that she is responsible for the best storage and retrieval system in the whole of physics; and I agree completely. What I would want to add is something much closer to my own experience because after all she was the first graduate student I ever had and am very much aware of her contributions in exploring in the 1936-1938 period new pathways in nuclear physics, including her publications on the relevance on velocity-dependent forces in nuclear magnetic moments. In this connection, she analyzed the combined effect of rotation and high nuclear charge on the shape and magnetic moment of a rotating nucleus. She discovered that a heavy nucleus had no stable configuration if it rotated too fast, precursor – if we had only known it – of nuclear fission.
>
> In wartime days I was close to her work for the metallurgical product of the Manhattan Project and can testify that her calculations of heating effects of the radioactive decay products of fission and her calculations

152Way to Wheeler, April 27, 1983. (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68).

> of the effectiveness of control modes of special geometries were of direct value to the construction of the Hanford production reactors".[153]

This last passage brings us back to the crux of this chapter: nuclear fission. "If we had only known it" sounds here like a mere observation made in hindsight, without many regrets – markedly different from the later "Had we followed her lead...", which instead suggests a concrete but neglected possibility, or even a responsibility. To understand this distinction more clearly, let us add a few elements to Wheeler's remark.

At the 1938 New York meeting of the American Physical Society (Mehra, Rechenberg 2001, p. 990), Way presented part of the research she made during that period, even if not directly related to the topic of her dissertation. The paper's title was *Nuclear Quadrupole and Magnetic Moments* and she was considering the cigar-like deformation of a spinning nucleus by trying different models, among which the liquid drop model. Here is Wheeler's recollection from 1977, not long before the nomination letter above, when he took part in an important Minnesota symposium organized by R.H. Stuewer, in which eminent personalities of nuclear physics in the 1930s (those who were still alive, at least) gathered and discussed the developments of those years (Stuewer 1979):[154]

> "What about the rotation of heavier nuclei? Nothing was more obvious than to see what one could get out of the liquid drop model. The usefulness of this model had been demonstrated in von Weizsäcker's semiempirical formula for nuclear masses. Could one not go further and consider the implications of a surface tension for nuclear dynamics? And what was more natural than to go from statics to dynamics by the intermediate step of a steady rotation? Katherine [sic!] Way and I asked each other what would be the order of magnitude of the magnetic moments one would expect for atomic nuclei on the liquid drop model. One day she came in and reported a difficulty. The equations gave no solution for the case of a sufficiently highly charged nucleus turning at a

153Wheeler to Henry Motz, 15 August 1978. in John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 68. The same folder also contains a copy of Gertrude Goldhaber's letter, from which we learn that she first proposed the nomination to Wheeler, who then enlarged the circle. In Alvin Weinberg's statement, also preserved in the same folder, we can read that "It was through her [Way's] foresight more than 30 years ago that the first nuclear information system was set up. Nuclear science could not have survived today had it not learned the lesson Kay Way taught: that rational handling of nuclear data is a key to a coherent and manageable nuclear science". Speaking of rational handling and planning, we may notice *en passant* that the motto of Barnard College is *Ἑπόμενη τῷ λογισμῷ,* somehow translatable as "Following the way of reason".

154As Robert Wilson said when he introduced Wheeler, "he knew the men, he was present at the moments. No one is better qualified to discuss this subject" (Stuewer 1979, p. 215).

> sufficiently great angular velocity. It was clear that one had to do in this case with some kind of instability. It took only 1939 and the discovery of Hahn and Strassmann to recognize the nature of the instability: nuclear fission. Why did we not go to the analysis of higher order terms in the deformation energy and predict fission in advance of its discovery? It was not any difficulty in the mathematics. It was a difficulty in the model. It failed to give the right magnitudes and the right trends for nuclear magnetic moments. […] We were not in the domain in which a statistical or liquid drop model of rapidly rotating nuclei is possible" (Wheeler 1979h, p. 266).

This is a quite sober recollection: Wheeler hints that, in retrospect, they could have dedicated more attention to that instability and perhaps discover nuclear fission a few months in advance, but no such claim is made and, actually, a sort of rationale is provided to explain why they did not think of going down that road.

A couple of decades later, however, while having a series of interviews with Kenneth Ford which resulted in Wheeler's already quoted autobiographical book (Wheeler 2000), the recollections have a more dramatic element. The year is 1939. Bohr, accompanied by Rosenfeld, got some very confidential news about Meitner and Frisch's results on fission while he was departing for the US.

> "By the time Bohr shook hands with me and the Fermis on the dock, he had a pretty good idea of a direction to go in to give a theoretical account of fission. That is what would occupy us intensely for the next few months. But at that shipside greeting, he said nothing about fission. In his characteristic way, he wanted to be sure that Meitner and Frisch got the credit they deserved before the news spread widely. Not even during his day with Fermi did Bohr breathe a word of the discovery" (Wheeler 2000, p. 15).

Rosenfeld was accompanying Bohr but, "unaware of Bohr's concern about priority for Meitner and Frisch, spilled the beans to me on the train. I was excited. Here was a whole new mode of nuclear behavior that we had overlooked" (*ibidem*, p. 14). When he found out that Rosenfeld had spoken, Bohr was quite upset, apparently, but at that point the only thing left was to discuss the new physics and its implications.

> "To me, just as to Bohr, fission seemed immediately believable. I felt stupid not to have realized, several years before, that nuclei should be able to split. My student Katharine Way at the University of North Carolina had investigated magnetic properties of nuclei using the liquid-droplet model. Her equations had no solution when the nucleus rotated too fast. This told us that rapid spin could make a nucleus become unstable and fall apart. It would have been natural to ask ourselves whether there were other ways to make a nucleus come apart. Had we

followed her lead, we might have thought of fission" (*ibidem*, pp. 21-22).

A general remark, first: in the later narrative we may notice a seeming change in emphasis on Meitner and Frisch, as compared to the 1977 "Hahn and Strassmann", but, in part, it is just an effect of the choice of the relevant quotations here. There is probably no need to overread it: after all, as early as 1967, in the semi-popular *Physics Today,* Wheeler had published, with Frisch himself, a sort of historical joint piece, where Meitner's work is certainly not glossed over (Frisch, Wheeler 1967), nor is it in the full text of the Minnesota talk.[155] Furthermore, in another passage of the latter, Wheeler was clearly stressing that, *at the time of the events* (right after Bohr's Atlantic crossing), what there seemed to be to physicists like him was, on the one hand, an experimental result – "Hahn and Strassmann" – and, on the other, an interpretative "proposal" (Wheeler 1979h, p. 272), a "broad-brush picture" (*ibidem*, p. 273), that of Meitner and Frisch (who was at the symposium, too). It was not a downplaying of Meitner's role – likewise, the fact that there is no reference to Katharine Way in the 1967 paper is entirely understandable in a text of a few columns published alongside one of the *actual* discoverers of fission about its effective discovery.

The order of storytelling in Wheeler's recollections is quite important: in 1977 he soberly recalls Way's work, contextualizes it within the issues they were pursuing at the time, and after half a dozen pages there is Bohr's arrival with the news about fission.[156] In the later autobiographical book, when

155We will return to Wheeler's appreciation of Meitner in the second section.

156Here is, for the sake of completeness, the 1977 text: "Across the stormy North Atlantic, unbeknownst to any of us, it brought the fateful find of fission from the Old World to the New: a few words spoken by Otto Robert Frisch to Niels Bohr right before he boarded the ship; a few words spoken by Bohr to me after his arrival. Coming with me to meet Bohr and his son Erik and Leon Rosenfeld were Enrico and Laura Fermi. They took father and son off for an overnight visit in New York before Bohr's three-month stay in Princeton, where he was to lecture on the quantum theory of measurement. Rosenfeld, his collaborator in the preparation of these lectures, I took on the train to Princeton and induced him to speak at the evening Journal Club on Hahn and Strassmann's discovery, still unknown in the U.S., on Meitner and Frisch's proposal that this was the breakup of a liquid droplet, and on Bohr's conclusion, worked out in conjunction with Rosenfeld on the voyage over, and written up four days later, that this new process fits in naturally with the compound nucleus theory of nuclear reactions. Rosenfeld's account created great excitement! It also greatly distressed Bohr when he heard about it. He felt obliged to protect Meitner and Frisch until their publication should have appeared (February 11, 1939); and to protect Frisch until his intended ionization chamber experiment at Copenhagen should have been done (January 16) and published (February 25, 1939). For that reason he had said nothing about the discovery either at Columbia or to the Fermis. Bohr once arrived in Princeton, we set to work to go from Frisch and Meitner's broad-brush picture to a detailed analysis of the mechanism along the lines of the compound nucleus model and liquid drop model that Bohr – and I – had already been expounding and applying. This work took not only the three months of Bohr's stay in Princeton but two additional months of finishing up until I could send it in for publication (June 28, 1939)" (Wheeler 1979h, pp. 272-273).

Wheeler mentions his student's work, the effect is clearly different, as is the claim about the anticipation of fission. It would be perfectly reasonable – as much as generic – to suggest that, by the end of the century, many years had passed for Wheeler, memory fails, the oral dimension of interviews is quite fluid, and so on: clearly, in that last comment of his, that "several years before" is an improper expression (at most, it seems that it could have been a few months). However, apart from these considerations of mere common sense, an exploration of Wheeler's archives reveals that he and Ford did some quite extensive fact-checking between the interviews and the "autobiographical" book born out of them and, for instance, Wheeler kept among his papers[157] a work about the discovery of nuclear fission written by Spencer Weart, former director of the Center for History of Physics of the American Institute of Physics, whom he had known for quite a long time (Weart 1983). It was actually Weart himself who sent Ford a copy of his historical reconstruction, which was certainly read by Wheeler.[158] Two of Weart's claims are of particular interest here: that those who had come closer to theoretically identifying the sausage-like stretching of the nucleus (*Kernwurst*) leading to fission were Wheeler and his student Way[159] and, independently, Weizsäcker and his student Wefelmeir; and that these hints were not followed because scientists working on the topic were thinking within a paradigm (inasmuch, at least from a theoretical viewpoint, fission was not to seem a Kuhnian revolution), with its blinker effect.[160] Even if Weart's mention of Way's work was not entirely independent from Wheeler's own recollections, the fact that he had framed the latter in a broader context, supported by historical research, may have definitely sounded like a full corroboration and may have thus prompted Wheeler to make "bolder" claims in the autobiographical book. As for the paradigm, as we shall see particularly in the next section Wheeler does not seem totally satisfied with that "explanation", but at the same it may have been Weart's work to ignite some questions that haunted Wheeler's last years.

Besides comparing Wheeler's recollections and their refraction in the work of someone else, we can actually independently assess, at least in part, the soundness of his statements. As a matter of fact, Katharine Way, in spring 1939, did publish a paper based on the work she presented in 1938. The title is *The Liquid-Drop Model and Nuclear Moments* and it appeared in May 1939 in

157John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 208.

158See Ford's letter to Wheeler dated 3 March 1994 and Ford's letter to Weart copied in Ford's letter to Wheeler two days later (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 142).

159Her name is only mentioned in the reference given in a footnote – and from the references, overall, we can see that Weart too, for this at least, was depending on Wheeler's talk at the Minnesota symposium.

160More specifically, Weart argues that, from the beginning of the century on, the consideration of relatively small changes in nuclei – such as an alpha or beta particle – had been enough to explain what was discovered; furthermore, Gamow's successful theory of alpha decay discouraged from thinking that a "piece" larger than an alpha particle could escape, according to the barrier penetration model, from the nucleus.

Physical Review (Way 1939). At its very beginning, as in a sort of introduction, there is a brief mention, without reference, of the new results concerning fission, but, especially if we already know about Wheeler's story, it may almost sound like an appendix or something added later. Then there follows the technical corpus of the paper, which could have definitely been done without knowledge of the extremely recent results about fission; finally, some conclusion, not flamboyant at all (we have already remarked about the unassuming tone of Way's writings), which comments on the lack of solutions within the framework of the liquid drop model. Overall, the impression is that there is no reason to contest what Wheeler says, especially in 1977 – but that does not mean that we have to naïvely embrace his later comments on that "missed opportunity". Yes, the lack of solutions could have suggested an instability and that the nucleus could not remain intact, so to speak, and it may have thus provided a heuristic hint that something else was happening. This, in turn, together with other hints, may in principle have guided someone to nuclear fission. "Never think a small chance nil / For what can happen surely will". However, it was also reasonable to say: the liquid drop model here no longer works, let us try something else. The alternative, in a sense, was between jumping out of the model or staying within its framework and taking the breakdown as a *physically* meaningful indication in the map of our exploration of nuclear regimes.

This, nonetheless, may have not been a radical *aut aut*: Wheeler did not simply ignore Way's results and, somehow, he did try to keep them into account – but in negative terms: since the picture of a turning body did not seem adequate to nuclear rotation, he was considering other options in one of his papers with Edward Teller (Teller, Wheeler 1938).[161] The predominant difficulty, however, was that, in the largely unexplored realm of nuclear behavior, different models, emphasizing different traits, were also inducing people to think of the nucleus in different terms, intuitively hard to combine.[162]

161Wheeler makes this link – if it may be called that – explicit at the Minnesota symposium, right after mentioning Way's results: "If turning as a rigid body did not give an acceptable picture for nuclear rotation, what model would? Edward Teller had ideas on this subject and I had case examples, which we developed together in a paper on nuclear rotation. The main point was simple. The very low-lying rotational energy levels that one would have expected on the basis of rigid rotation would of necessity be "promoted" in energy for an elementary reason: A rotation, followed by a minor displacement of the particles in the system, would restore the set of particles to a configuration, identical up to a permutation, with the original configuration. Therefore, it was all important to know what kind of potential energy barrier had to be overcome to perform this slight displacement. We examined several idealized models. They showed how sensitive is the position of low-lying states of high angular momentum to the energy of the deformation. We concluded that it is reasonable to believe that certain low-lying levels are indeed rotational states" (Wheeler 1979h, pp. 266-267).

162For a technically detailed historical treatment one should also consider papers such as (Wheeler 1937), but for our purposes here we can resort again to Wheeler's synthesis at the Minnesota symposium: "By that time the experimental evidence on nuclear spins and magnetic moments, so impressively correlated by Maria Mayer and by Haxel, Jensen, and Suess, had made it inescapably evident that nuclei show "independent particle" properties.

And that is also why there is a big difference from the impression one can have in hindsight and the actual historical situation, with all its fog. Nonetheless, while there does not seem to be any trace that Way further developed those aspects of her work[163] or any sign of regret that she did not, Wheeler apparently insisted on reproaching something to himself: in order to better understand that on multiple levels, we have now to broaden the horizons of our analysis.

3. Wheeler's uses of the past, daring conservatism, and the place of "heroines" in his narratives

The role of women in the early phases of nuclear physics is a topic Wheeler commented upon and was directly involved with, so that, besides the episode of Katharine Way, there is actually some interesting material to illustrate and interpret. However, it is first necessary to introduce a *caveat* about Wheeler's uses of the past. Readers of his papers may notice – besides his exuberant rhetoric and his language rich in metaphors and anecdotes from the past – some grand preludes, charged with historical pathos. That is quite idiosyncratic but, in Wheeler's case, it is not just ornament and rhetoric: it actually runs much deeper. In the light of his vast archival material, different facets of Wheeler's engagement with the past can be identified and, for the sake of simplicity, categorized according to the famous Nietzschean tripartition: we can thus see an "antiquarian" effort, aiming at the preservation of the past for its own sake; of a "monumental" use of history, in order to build grand narratives and spur collaborators or students in some directions of research, or at least to make them feel part of a great and still-alive enterprise;[164] and of a "critical" gaze, capable of selectively identifying analogous traits in past situations and re-functionalizing or transfiguring them

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Niels Bohr and I were having to come to terms with The Great Accident of nuclear physics - the circumstances that the mean free path of particles in the nucleus is neither extremely short compared with nuclear dimensions (as assumed in the liquid drop picture) nor extremely long (as assumed in the earliest days of nuclear physics), but of an intermediate value. When we took this fact into account we found that we could understand how a nucleus could at the same time show independent particle properties and yet behave in many ways as if it were a liquid drop" (Wheeler 1979h, p. 267). All this is clearly interesting also from the viewpoint of philosophy of science: see e.g. a recent discussion in (Massimi 2022, pp. 87-109).

163There was little reason, as they were explained within a few months, with all their implications for life and research in the years that followed.

164There is, of course, a whole Anglophone tradition of monumental history (intertwined with Nietzsche's reflections as well), from Carlyle to Emerson and beyond. The former, curiously enough if we want to stay close to nuclear physics, was studied by Enrico Fermi's wife, Laura Capon (Fermi 1939). It would be interesting to evaluate the more or less mediated impact of this tradition on Wheeler, but that is not the purpose of the present work. We may however still add that also Niels Bohr's wife, Margrethe Nørlund, shortly after meeting her future husband, urged him to read Carlyle's *On Heroes and Hero Worship* (Aaserud, Heilbron 2013, p. 155). In Bohr, possibly, Wheeler did not just find a hero for his own narratives…

in the present. By all accounts, Wheeler was very good at transmitting a kind of feeling of belonging to a tradition: thanks to his teaching and his way of involving students, even in open research questions, physics no longer seemed something done mainly in another continent during previous centuries, but a great collective effort they were made feel part of.

> "What of the girl or boy who reads about Newton and Maxwell and Bohr and Einstein and says, 'I want to build on what they have built; I want to add to the sum of knowledge about the most basic laws of nature'? That child has gained somewhere, somehow, even more than average confidence in his or her own capabilities" (Wheeler 2000, p. 84).

Aside from teaching *stricto sensu*, a similar process can be highlighted when it comes to the grand narratives that Wheeler built in order to support and, in a sense, justify his own speculative ideas, still in lack of empirical corroboration or possibility of confrontation.[165] However, as shown at length by his promotion of historiographical research (we will soon see an example),[166] it is fair to say that Wheeler also had a genuine respect for the past: we are not dealing with a mere rhetorical strategy to better sell his ideas or to offer some pedigree to his own speculations.

Now, a question that we can ask, perhaps also due to Wheeler's military commitments such as the Matterhorn Project, against what he perceived as the Soviet threat, or the relatively conservative political positions, nowadays quite easily trivializable according to stereotypes,[167] is whether those narratives and monumental use of history were strictly "masculine", so to speak, and gender-biased. Of course, Wheeler's uses of the past mirror somehow, in their content, the asymmetries that were part of that same past – but the point here is not about some percentage or statistics, but rather about female personalities in

165It is quite easy to guess the relevance of all this for today's approaches in speculative fields such as quantum gravity and, in a sense, the considerations we will develop here should also make one cautious about the dangers of "philosophizing" on superficial or distorted historical grounds, as often happens with partisan accounts.

166Already in the 1950s Wheeler had a crucial role in setting in motion the vast project *Sources for History of Quantum Physics*. See Chapter 1 and Appendix B for a contextualization of his reasons and aims.

167The following passage by Leonard Susskind (a recollection of when he first met Wheeler in 1961) may serve as a good example to convey both a first impression and its overcoming: "The only way I can describe the man who greeted me is to say that he looked Republican. What the hell was I doing in this Wasp's nest of a university? Two hours later, I was completely enthralled. John was enthusiastically describing his vision of how space and time would become a wild, jittery, foamy world of quantum fluctuations when viewed through a tremendously powerful microscope. He told me that the most profound and exciting problem of physics was to unify Einstein's two great theories – General Relativity and Quantum Mechanics. He explained that only at the Planck distance would elementary particles reveal their true nature, and it would be all about geometry – quantum geometry. To a young aspiring physicist, the stuffy businessman exterior had morphed into an idealistic visionary. I wanted more than anything to follow this man into battle" (Susskind 2008, p. 146).

those grand narratives of his. And the answer to the question "Are there some?" is: Yes, definitely, and there are beautiful pages dedicated to them. We would not gain many insights by simply labeling (or *de facto* dismissing) Wheeler's narratives as "male tales", echoing a formula by Traweek (1988): aside from the fact (as suggested by the quote above) that Wheeler meant to provide inspiration to anyone, regardless of gender, we are rather going to examine his narratives to show their complex intertwining with the heuristics he was pursuing at a given moment or even, as we shall see, with his psychology and personal experience.[168] If we do not keep this in mind, the risk of misunderstanding him or remaining baffled at his unusual kind of remarks is high and, given also his prestige, it may easily result in some uncritical spreading of claims he made in certain situations (such as, perhaps, the quasi-discovery of nuclear fission by a former student of his). As an antibody, then, it is useful to give a taste of what can be hidden beneath Wheeler's texts.

The first example of a woman scientist in Wheeler's historical narratives is an icon that is almost unavoidable when speaking about the exploration of the microcosm: Marie Curie (1867-1934). If that is a predictable choice, luckily Wheeler turns to something a bit less conventional already from the title: *Maria Sklodowska-Curie: Copernicus of the World of the Small* (Wheeler 1968d). This is not one of those awkward expressions that can be found in magazines and newspapers with improbable comparisons or juxtapositions – not entirely, at least, as we shall briefly explain. When this piece was later included in an anthology of Wheeler's writings, the title was slightly changed: *Maria Sklodowska Curie and the World of the Small*, even though the previous one was still assigned to the last of the sections into which the reprinted paper was divided (Wheeler 1994c). Pronounced in Warsaw in October 1967, for the centenary of her birth, it was written in a period that marked the beginning of a crucial turning point in the development of Wheeler's ideas: that is indeed the moment in which his geometrodynamical program – all the ambitions he had nurtured for the previous fifteen years, while dusting off and developing general relativity – started showing its limitations and entering into a crisis, after which Wheeler came to question the meaning itself of physical law. The paper opens with a sort of curious, fatal (really with a sense of destiny), almost cinematographic parallelism between Marie Curie's birth and first years of life and Maxwell's discoveries and future expectations:

168 I would even suggest that Wheeler's case, rather than calling for easy labels, represents an opportunity to rethink our picture of science and scientific life against old and stiffened abstract schemes: his status as a key figure of 20th-century physics is not contested, but the full reasons for that are somewhat vague and elusive. To fully grasp his role, we have to take into account a heuristic dimension (all the suggestions and guiding ideas he disseminated), a strong sense of conviviality in practicing science, and so on. If someone wants to contest a merely "resultatistic" picture of science, Wheeler's case is then a resource. By analogy, *mutatis mutandis*, Hermann Weyl's words about Emmy Noether, pronounced shortly after her passing away in 1935, may easily come to mind: "Her significance for algebra cannot be read entirely from her own papers; she had great stimulating power and many of her suggestions took final shape only in the works of her pupils or co-workers. And one cannot read the scope of her accomplishments from the individual results of her papers alone" (Weyl 1981, p. 130).

> "The month of November 1867 that brought Maria Sklodowska into the world saw James Clerk Maxwell winning new insight into the laws of electromagnetism. Four years later, in the month of October, while Maria sat pouring water from one bottle to another and asking her childhood questions about how and why, Maxwell was delivering his introductory lecture on experimental physics at Cambridge University. After describing the new facilities and stressing the importance of experimental work for the young man and for society, Maxwell offers his vision of physics" (Wheeler 1968d, p. 1197).

If making use of Maxwell is typical of narratives about the unification of physics – with some grounded reason, of course – Wheeler's evocation is nonetheless quite peculiar. Yes, he says, "Maxwell held fast to the long-term dream of an underlying unity. Yet to him 'unity' meant not so much one law as one substance" (*ibidem*, p. 1197), thinking in terms of a field ontology (an attempt that, *mutatis mutandis*, Wheeler himself was pursuing in that phase of his career: deriving everything from the fields of general relativity). It does not really matter here whether such a characterization of Maxwell's vision is accurate or nuanced enough: the point is that it prepares the next step (almost a dialectical one), that is the passage from what Wheeler calls a "physics of substance" to a "physics of law". The key figure in this shift is indicated by him in Marie Curie.[169]

What does this mean? In Wheeler's own words, "The study of substance revealed law. Law in turn explained substance" (Wheeler 1968d, p. 1197) – but here law does not mean any kind of law: it means something fundamental and as broad as a framework: "Three laws the great investigators gave us: the relativity principle, both special and general; the quantum principle; and electromagnetism" (*ibidem*). In this sense, from the empirical study of substance we got insights into some fundamentally overarching principles, but then it was these overarching principles to guide our understanding and exploration (I emphasize the heuristic aspect) of realms more and more distant from everyday experience. One has to trust these "laws", take them "seriously": "Electromagnetism, already discovered, was in effect rediscovered when at last it was taken seriously in the world of the small. To that end no one contributed more than Marie Curie" (*ibidem*).[170] Now, this might just sound like an idiosyncratic take on the epistemology of science and the history of physics; but what is actually fascinating is how Wheeler, with much more eloquence than it can possibly appear from some brief quote, is at

169For Wheeler's attitude towards "physical laws" in that period, we redirect to (Blum, Furlan 2022).

170A much later passage significantly insists again on that "seriously": "But the Maxwell equations held more. Forty years later, Einstein invented special relativity as a way — the only way — to assure the complete validity and self-consistency of Maxwell's equations. By taking them seriously and insisting on their universal validity, Einstein showed that space and time are relative concepts and that mass is energy! Hardly conclusions that a casual glance at Maxwell's equations would reveal" (Wheeler 2000, p. 166).

the same time speaking, in the watermark, about his own heuristic methodology and research program. When at the beginning of the 1950s he decided to dedicate himself to general relativity, he did not just intend to study another area of physics or tackle some very specific question. He decided to take general relativity "seriously", that is: try and squeeze everything possible from it, without caring too much for all the confusing novelties of the particle zoo, that is all the new unaccounted-for particles that were being found. With a half-playful nod to a slogan by Eisenhower, he gave this heuristic methodology a name: daring conservatism (Blum. Brill 2020; Furlan 2022). This attitude towards already well-established physical laws and the guidance they can provide in the exploration and ordering of new phenomena remained for him a compass – also because Wheeler (at least according to what he suggests) learned it from one of his main inspiring figures, Niels Bohr. In 1967, however, the daring conservative development of general relativity, as we have already mentioned, was starting to show some cracks – and it is interesting to notice how, in the paper dedicated to Marie Curie, Wheeler still raises the stakes and makes her not only a heroine of daring conservatism, but implicitly a person of a sort of Holy Trinity (the other two being Einstein and Bohr, occasionally replaced by Planck) which is mirrored by the three great "principles": relativity, the quantum, and electromagnetism. In the midst of such considerations, there is also some "lyrical" passage that gives life to the (quasi-)historical characters conjured up by Wheeler:

> "If the sad and lonely figure of Mme. Curie touches anyone's heart, and if he hears from those who knew her that she never smiled, let him read her works. A new step forward, by whomever made, captured her admiration. To her the search was one great enterprise; and all searchers, partners. How did she respond to the movement from a physics of substances towards a physics of law? She welcomed the new laws, she followed them, she preached them" (Wheeler 1968d, p. 1198),

and then he lists her achievements. It should not sound surprising, now, that I spoke of a "monumental" use of history. After that, Wheeler goes on with his typical way of jumping back and forth between the past and the future, pointing out alleged "anticipations" of important results and, at the same time, on that basis, asking some questions for a future still to come – or better: for the future of physics as he was envisioning it.

What about the comparison with Copernicus, however? The reasons for this parallelism, once we know of the title of Wheeler's speech (*Copernicus of the world of the small*), are actually easy to guess, besides the association to Poland, and he makes them explicit while evoking, in the conclusions, a sort of mental theater – or a black and white movie – in which the protagonists of the early Solvay events (among whom the no longer sad Madame Curie) take the floor again and give us hints on finding nature's secrets:

> "We see her in her later years, packing her suitcase with such happiness for a Solvay Congress, where she would walk and talk again with

Lorentz, Planck, Einstein, Ehrenfest, and Bohr.

We see the magic circle and see Planck speaking. He repeats his great and familiar message. There is only one truly fundamental length in nature; a length free of all reference to the dimensions and rate of rotation of the planet on which we happen to live; free of any appeal to the complex properties of any solid, liquid, or gas; free of every reference to the mysterious properties of any elementary particle; what we call today the Planck length [...] and what we identify with the characteristic scale of the quantum fluctuations in the geometry of space.

The light shifts, the figures are regrouped, and Einstein is giving his famous account of the quantum fluctuations that pervade the electromagnetic field in every part of space, forerunner of modern quantum electrodynamics – the greatest triumph of theoretical physics since World War II – and happy guide to the meaning of quantum fluctuations in the geometry of space at the Planck scale of distances.

The Solvay Congress fades away, we are in an old shed in Paris, and we see a young woman working intently at her radium. She gave us the projectiles to penetrate a new world of small distances. She did more than anyone to open the door to 10^{-13} cm, as her countryman Copernicus did more than anyone to alert us to movement and meaning at the previously unimaginable distance of 10^{+13} cm. [...] Copernicus directed our gaze out to the domain of the unbelievably remote, and today we have come close to plumbing the greatest distances that we know how to conceive. The discoverer of radium by her life and work directs our gaze down to the world of the small. There many new decades of the distance scale still wait to spring into life and meaning, all the way from 10^{-16} cm to Planck's 10^{-33} cm. Marie Sklodowska Curie is our Copernicus in the still continuing voyage of exploration into the world of the unbelievably small" (Wheeler 1968d, p. 1200).

This passage makes even more manifest the intertwinement with Wheeler's own quest, from the scale of relativistic cosmology to that of quantum foam, as well as with his own Blake-like gaze "to see a world in a grain of sand". Interestingly enough, Copernicus, within six years, would also become a character in Wheeler's grand narratives, the occasion being once again provided by an anniversary, his 500th birthday in 1973 (Wheeler 1974). By that time, Wheeler had moved beyond his previous conception of physical laws and, once again, he would venture into bold parallelisms between "now" and "then" in order to provide new perspectives – it does not seem out of place to suggest that his meditations on the figure of Marie Curie as "Copernicus of the small" prompted him to make a similar operation to give voice to his own ideas while celebrating Copernicus later. But this is another story (Blum, Furlan 2022).

A decade later, at the already mentioned 1977 Minnesota symposium, *Nuclear Physics in Retrospect* (Stuewer 1979), since among the discussants were also people like Wigner, Bethe, Frisch, Segrè, clearly Wheeler could not just go "free storytelling mode", but he made some unusual comment on Marie Curie nevertheless. Building upon the historical inquiries he had made to prepare the address for Marie Curie's centenary, he told of his surprise at finding an "anticipation" of the conclusions he himself had later reached only thanks to the Polanyi-Wigner formula, so important in suggesting a way of considering nuclear behavior in Wheeler's own decisive work with Bohr on fission.[171] He was thus building the latter's "prehistory", so to speak, and he was not afraid to expose it in front of other renowned experts – that was not a mere rhetorical strategy in front of a more or less generic audience, clearly.

Wheeler had not interacted personally with Marie Curie: for those "lyrical passages" he could only rely on tales of people that had met her, on books, and on his own imagination. In other cases, however, he could add his own first-hand experience, which made his peculiar form of storytelling even more effective. We can now consider, then, another example – a later one – and another easily guessable name, Lise Meitner (1878-1968), whom the young Wheeler met personally, already back in the '30s. He actually wrote a foreword to Patricia Rife's book *Lise Meitner and the Dawn of the Nuclear Age*, published in 1999. Actually, already in 1984, when Rife contacted Wheeler after finishing her Ph.D. Dissertation dedicated to Meitner, he strongly supported her initiative and gave her indications ("I'm delighted at your project" – with "delighted" underscored by Wheeler himself).[172] The

171More in detail, here is the actual passage: "Years later, reading the works of Marie Sklodowska Curie in preparation for a celebration of her centenary, I was astonished to discover that she had thought about the breakup of a nucleus in just such terms. She referred to Rutherford and Soddy and their 1902 and still standard theory of radioactive decay. She recognized, as they did, that they were dealing with a process that transcended the understanding of the time. At the 1913 Solvay Congress she called attention anew to the mystery of the exponential law. She stressed the experimental evidence that an atom, if it had not yet decayed, had not aged at all, no matter how long it had lived. She proposed "to look in the interior of the atom for the element of disorder necessary to explain the application of the law of chance." She brought forward the suggestion of Debierne, first, that in the center of the atom there may exist a temperature much higher than the external temperature and second, that the mechanism involved may be identical with that of a monomolecular chemical reaction. She asks us to imagine "a molecule which is moving about in the interior of a box endowed with a tiny hole." Marie Sklodowska Curie goes on to say, "When the molecule in the course of its motion meets the hole it leaves the box and the system is radically changed. If we have a great number of boxes each containing one molecule, and if the initial velocities and positions of the molecules are random, it may happen that the escape phenomenon is governed by the rule of chance, even though the constitution of the system itself is relatively simple." Mme. Curie was in advance of her age. She put forward the right idea to describe nuclear fission during an epoch when she had to deal with the leakage of alpha-particles through a potential barrier!" (Wheeler 1979h, p. 280). Rather than merely dismissing this as a "teleological" historical remark, however, it may be worthwhile to relate it to Weart's aforesaid comments about the role of Gamow's model of alpha-decay (Weart 1983).

172Letter to Patricia Rife dated 19 April 1984, John A. Wheeler Papers, American

foreword to the book, then, was just a natural – but certainly telling – continuation of the genesis of the book itself he had followed. What is striking in those few introductory paragraphs is the admired characterization that Wheeler offers of Meitner's "style", so to speak: "Excelsior! Or, in everyday language, ever higher. That, in a word, says to me what I remember of Lise Meitner as unique. Identify a central and decidable issue of physics, devise a way to go after it, and pour on the attack" (Rife 1999, p. ix). It is not coincidental that this characterization is reminiscent of Marie Curie's resolute explorations of the world at lengths far removed from our everyday experience. However, it is also reminiscent, due to that sort of three-step description of Meitner's course of action, of what Wheeler used to call the "triology of action" of the "seekers of the larger view" (such as Einstein, Darwin, Hutton, and so on): "to rise to the larger view – and from that vantage point recognize what is missing, and fill the gap" (Wheeler 1980c, p. 185). Thus, once again, if we aptly connect Wheeler's passage to his other writings, we can find much more than what meets the eye – and in this case we can appreciate how the praise is indeed of the highest caliber. Curiously enough, at the end of that foreword Wheeler also mentions that some unspecified "postwar Hollywood filmmaker" intended to create a movie about Lise Meitner; some of her friends suggested her to make Wheeler "her representative in negotiating the wording for her part in the film" (Rife 1999, p. xii). But, in the end, she was not satisfied or comfortable with that project and withdrew from the initiative. At least, Wheeler adds, this offered him a last chance to see her (then, it happened before 1968, when she passed away) and "appreciate anew the force of her character and her drive to 'Identify the Central Puzzle and Clear It Up'" (*ibidem*).

Once we speak of Lise Meitner and Wheeler, we stumble upon nuclear fission again, needless to say, and we have already remarked in the first part how her work was duly mentioned not only in the Minnesota symposium, but also in the previous work that Wheeler published in accordance with her nephew Frisch. In that case, there was no need to come up with little known episodes or hardly appreciated "anticipations": Meitner was a central part of the story (as well as of Wheeler's version), regardless of what some people in Stockholm may have thought. But what is important to stress here, in what we have seen, is again Wheeler's "methodological" emphasis. The *fil rouge* that, in his recollections, links women to fission or more generally to the early exploration of the microcosm is as concerned about contents as it is about method, broadly speaking. The latter aspect can also be seen in the case of another quite famous figure who gets portrayed in a perhaps unusual light, Maria Goeppert-Mayer (1906-1972). She had collaborated with Karl Herzfeld, Wheeler's advisor in Baltimore at the time of his Ph.D., and, even if no direct link to fission is suggested in this case, here is a quite telling paragraph from the Minnesota symposium, which again resonates very much with Wheeler's values and his way of conceiving research and teaching in physics:

"Maria Goeppert-Mayer often, and from time to time her husband

Philosophical Society Library, Philadelphia, box 60.

> Joseph Mayer, crossed the lawn from chemistry to physics to participate in a seminar or consult Herzfeld. The higher administration had denied her any proper position. She did not teach. She nevertheless taught as effectively as anyone – by her questions and comments in seminars and colloquia. Her concern for whatever the issue was made her an example to us all. It is impossible to forget her quiet firmness, the rising emphasis at the end of her last sentence, and *her inability to leave a problem until it was clarified*" (Wheeler 1979h, p. 225; my emphasis).[173]

A few years after this recollection in Baltimore, Wheeler, in 1934-35, would go to Copenhagen to work with Bohr, and this was truly a life-changing experience also on a personal level. While he was there, he also met, among many other well-known names, Lise Meitner, as already said, and – he would add *en passant* in a later interview (Wheeler 1988a) – Hertha Sponer. Furthermore, one cannot fail to notice how Wheeler repeatedly spoke of the important role, even if not directly involved with physics research, of Margrethe Bohr: it would be interesting to draw some parallelism between what he says about the Bohrs' hospitality in Copenhagen (e.g. Wheeler 2000,

173Wheeler's later recollections about her are worth quoting as well, also as a sign of his attention to the condition of women in science: "Another theorist at Hopkins at that time was Maria Goeppert Mayer, later to win a Nobel Prize for her work on the structure of nuclei. She and Herzfeld ran a seminar course in which a few of us sat around a table going chapter by chapter through the new German language book of Max Born and Pascual Jordan on quantum theory. It was an exciting way to learn the subject. Maria's husband, Joe Mayer, was a professor of chemistry at Hopkins. She came to Hopkins as a newlywed with a fresh Ph. D. from Göttingen in 1930, when she was just twenty-four. Suffering the fate of many women academics, she had no proper position, being treated as a guest, with little if any salary. Herzfeld had the good sense to recognize her ability and brought her into the workings of the department. Maria Mayer's situation got worse after the retirement of Joseph Ames as president of Hopkins in 1935. In the eyes of the new president, Isaiah Bowman, she suffered by being not only female but foreign. This made it easy for her husband, Joe, to accept a position at Columbia University in 1939. Even there, she was not appointed to a regular faculty position. She taught at Sarah Lawrence College while conducting her research at Columbia. During World War II, I had the chance to admire her abilities again when we worked together at the Met Lab in Chicago. After the war, while her husband, Joe, held a professorship in chemistry at the University of Chicago, she held half-time, nontenured research positions at the university and at Argonne National Laboratory. Not until 1960 did she get a professorship herself, when she and her husband moved to the University of California, San Diego. Her Nobel Prize was awarded in 1963. Despite the injustices she suffered for most of her professional life, she remained always cheerful and always vigorously active in theoretical physics. To her colleagues she was a valued full partner, whatever status she might be assigned by local administrations. A heavy smoker Maria Mayer died in 1972 at the age of sixty-five" (Wheeler 2000, pp. 96-97). She clearly crossed paths with Katharine Way, not just because of locations but also of research topics, but not much else seem to be known besides an acknowledgment by Goeppert-Mayer: "The author is indebted to Dr Katherine [sic] Way, who pointed out the connection of the closed shells with neutron absorption cross sections" (Goeppert-Mayer 1948, p. 238).

pp. 127-128) and what some of Wheeler's students remarked about his welcoming house and the role of his wife Janette, whom we have already seen mentioned in Katharine Way's little poem.[174] After that experience, the young Wheeler went back to the US and soon received a position at Chapel Hill, thus meeting Katharine Way.

However, a shadow that would haunt Wheeler's European memories in his old age, regardless of the absence, in this case, of an element of personal reminiscence, was still to emerge: Ida (née Tacke) Noddack (1896-1978). Her name is missing from the acts of the Minnesota symposium – not just from Wheeler's contribution, but from the analytical index of the entire volume. In Wheeler's case it was probably due to the lack of contacts and the relative oblivion in which she had fell, but, more generally speaking, there may have been other factors.[175] A decade earlier, however, Frisch, in his section of the joint publication with Wheeler in the semi-popular *Physics Today* (Frisch, Wheeler 1967, p. 48), had briefly mentioned her; Weart too discussed her

174There would be no shortage of testimony (we shall meet one in the following section, for instance), but I would like to offer here an exceptional and unexpected perspective, that of someone whose life was also intertwined with the long chain of events triggered by the understanding of nuclear fission. In Wheeler's archives (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 70) we can find a letter by no less than Ya.B. Zel'dovich, dated 18 February 1986, congratulating Wheeler and his wife Janette on their golden marriage: "Every physicist knows John, it is an axiom. But I am happy to remember Tbilissi [sic] (Georgia, USSR), where I met you, Jeannette. Having seen you and spoken with you I understand better why is John so clever and good-humored and healthy as he is". The wish of "many more happy years and everlasting peace", coming from a man who three decades earlier was one of the directors of the Soviet project to develop the H-bomb and addressed to one of the leaders of the US H-bomb project, is a precious document also from a human point of view. Ten years earlier, as witnessed by a letter of Zel'dovich dated 9 September 1976, the latter's wife had suddenly died while on holiday on the Black Sea. Shortly before, Wheeler had sent them a "kind letter", "the very interesting Bargman [sic] book with" an "excellent article" by Wheeler himself (we can certainly infer that the volume was *Studies in Mathematical Physics: Essays in Honor of Valentine Bargmann*, which was indeed published in that year), and a present for Zel'dovich's wife, who "enjoyed" it "much". Then Zel'dovich, in his "broken English" (to borrow Hendrik Casimir's once famous expression among physicists), which here only adds to the humanness of the communication, goes on saying: "Our meeting in Warsaw and trip to Moscow were among the best days in the happy part of my life. I fear that never more I will feel myself the same as before". "I met your wife in Tbilisi many years ago. I remember exactly the nice Georgian garden and our conversation. It was a strong impression of integrity, moral courage and deep ethical principles, just what is needed from the wife of a scientist and mother of family. Please give her my best whishes [sic]". "Be careful with her. Womens [sic] are often overstimating [sic] their forces and they whish [sic] not to worry us - and mens [sic] are so often egocentric!" All this, besides the element of personal loss, clearly adds further depth to Zel'dovich's message ten years later.

175See (Magalhães Santos 2014), where it is underscored the role of the influential stories told by figures such as Fritz Paneth and Emilio Segrè – both of which had to leave Europe because of their Jewish ancestry –, portraying the Noddacks (Ida and her husband Walter) as Nazi supporters and adding more episodic allegations of scientific dishonesty.

work (Weart 1983, p. 95) and that may have been one of the catalysts of Wheeler's "rediscovery" of her. In his autobiographical book, as a matter of fact, she is inescapably present – but this time the "anticipation" of fission is not accompanied by a sense of regret, but almost a breath of relief:

> "Even when the German chemist Ida Noddack suggested in 1934 that Fermi had in fact split the uranium nucleus, no one paid attention. It was, at the time, too radical a thought. (One can't help wondering whether Noddack's insight would have found a more receptive audience if it had come from a man instead of a woman.) In retrospect, the blindness of physicists and chemists to fission in the mid-1930s can be regarded as a blessing. Had scientists in Germany – and elsewhere – followed up on Ida Noddack's suggestion, it might well have been the Germans, not the Allies, who got the atomic bomb first. The history of the world could have been different" (Wheeler 2000, p. 15).

In Wheeler's archives it is actually possible to see that, circa 1995 (that is, shortly after the interviews with Kenneth Ford for the book just quoted), in a list of topics ("Wheeler grab-bag") he was eager to discuss with students as advisor, at the very first place there is "the mystery of Ida Noddack".[176] Even in a 1998 letter to Patricia Rife[177] he encouraged her, since her project about Lise Meitner was over, to investigate the life of Ida Noddack (or more precisely: "a life of Ida Noddack and how Germany would have won the war if physicists Hahn and Fermi had believed her insights into fission").

A psychological remark is now in order, since this is not to suggest that Wheeler was obsessed with some sort of Philip Dick-like Nazi dystopia or idly fantasizing about some alternative timeline in which Katharine Way and he had accelerated the understanding of fission. We are dealing with a trauma. All the events of those years marked Wheeler's life not just because of their historical (and scientific) weight, but also for the loss of one of his dear brothers, Joseph ("Joe"), who was killed between Florence and Bologna towards the end of 1944.[178] Wheeler still got a postcard from him with the invitation to "hurry up" with their nuclear project, hoping that it would put an end to the war (and it is not coincidental that this is how Wheeler's autobiography opens). The few months between his brother's death and the actual end of the war, plus – as he saw it – all the other human lives that were lost in those final phases, always remained for Wheeler a huge "What if...?", which in a sense became an "attractor" (or fixed point) for regrets, counterfactuals, and other events he would have liked to see, or to be more

176John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 189. To be precise, the typescript is not dated, but in the text there is an element that identifies 1994 as *terminus post quem*; keeping in mind that Wheeler was 83, however, it is safe to assume that he was not going to act as advisor much later than that.

177Letter to Patricia Rife dated 6 October 1998, John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 157.

178See the dedication of (Wheeler 2000), where the story is also narrated (pp. 18-19).

sagacious to promote.[179] Wheeler, also via his "methodological" remarks, was somehow reproaching himself the lack of that daring conservative attitude that he would later display and even celebrate in the figure of Marie Curie or Lise Meitner – or, at least, if not a full-fledged daring conservatism, a similar kind of attitude: that of taking "seriously" one's theoretical tools and bringing them to their extreme consequences before throwing them away or laying them down. The missed jump from Way's results to fission may become a matter of regret only in hindsight, possibly also due to the personal feeling of having been almost touched in advance by History. Around all of this, at the end of the century, when Wheeler was approaching his nineties, there seems to be that soft light that shrouds distant memories when someone looks back over their long life: for sure, some contours are blurred and unclear, there are parallax effects, some spots are no longer in plain sight, but all of that, taken together, is definitely a lived experience, not a contrived and fanciful construction. Within Wheeler's rich and eventful recollections, it is not irrelevant, both factually and symbolically, that he paid tribute, in the way we have seen, to the work of Katharine Way. But sensationalism about the "quasi-discovery" of fission has to be avoided and tempered by understanding the nature of Wheeler's regret.[180] The statement he made in the 1978 nomination of his former student for the Bonner Prize is arguably the most accurate and sober description: "She discovered that a heavy nucleus had no stable configuration if it rotated too fast, precursor – if we had only known it – of nuclear fission".

This "retrenchment" of Wheeler's claim about her quasi-discovery of fission does not diminish the value of Katharine Way's scientific activities: she certainly deserves better than the kind of attention that has been given to her so far. Hopefully, after this discussion of the sources, reference to her work, at least in the historical and philosophical literature, will not be made depending nonchalantly on a single paragraph in Mehra and Rechenberg's *The Historical Development of Quantum Theory* (Mehra, Rechenberg 2001, pp. 990-1), which in turn depends (for that) on Wheeler's contribution to the 1977 Minnesota symposium. One does not need a lifetime commitment to historiography to take a comparative look at the few sources available and check the actual paper by Way – that would be just homework diligence: its

179There are even accounts of how, late in life, Wheeler, speaking in public on topics with some association with nuclear fission and thus (in his mind) also with all that, burst into tears and had to interrupt himself. I wish to thank Guido Bacciagaluppi and Paul Halpern for a couple of such testimonies.

180Another regret, perhaps with some sort of *coquetterie* but also with a core of seriousness, was that, because in those days Bohr had to work with him on fission, Wheeler had in a sense deprived Einstein of the possibility of going on with his disputes with Bohr, and thus deprived the world of what could have come out of that discussion between his two revered mentors. See e.g. (Wheeler 2006): "But the news of nuclear fission, which Bohr received shortly before boarding his ship, changed the agenda. I like to say that I feel guilty for my role in preventing these discussions from taking place in anything like the extended and leisurely form that Bohr and Einstein had hoped for". In a sense, Wheeler would try to dialectically develop their conflicting stances in his own mind for the second half of the century.

lack is quite cheap, both in historiographical terms or as a basis for philosophizing. Furthermore, when dealing with Wheeler, as I tried to convey, one has to properly problematize his texts: not (or not only) for the sake of skepticism, but also to get a better understanding and human depth. The respect that we wish to pay here to Katharine Way is different from sensationalism and copy-pasting: it is to be hoped that these few pages will spur further research on her work and that, more in general, while people are planning operations in order to fill gaps and rewrite part of the history of physics, these considerations will be somehow useful also at a methodological level – at least to ask: what kind of historiography do we wish for?

Intermezzo

"In July 1977 after you had first interviewed me, I slipped on the wet grass and fell upside down over a cliff at the outlet of the famous Fiumi Latte near the shores of Lake Como in northern Italy. As I was falling and my head bounced from rock to rock, I felt the end had come; but strangely enough, I felt resigned to whatever was going to happen".
– Wheeler in (Goodman 1981, p. 79). That was when he enunciated "law without law", at the Varenna lectures.

Part II

Und das Chaos sei willkommen, denn die Ordnung hat versagt.
– Karl Kraus, *Die chinesische Mauer*

4. Merging Labyrinths: Leibniz in Wheeler's Quest

As already anticipated, in this second group of chapters we are going to do some "core drilling" to identify the main strands of Wheeler's manifold ideas from the 1970s on and look at them from different angles. In this chapter, more specifically, the focus is on Wheeler's new "intracranial colleague" starting from the end of the 1960s, nobody less than Leibniz himself. We are going to examine the original way Wheeler drew on his thought and the kind of "conceptual character" he thus created. The resonances that Wheeler perceived and tried to coagulate around the name of Leibniz can offer us a useful guide for the complex decade of transition between the crisis of geometrodynamics and the "it from bit" phase.

I would gladly give an arm or leg to ask Leibniz
"How come space and time? How come existence?"
– Ninety-year-old Wheeler[181]

1. A new colleague

In Chapter 3 we have chosen 1967 as an important year in the development of Wheeler's activities. Of course, it was in part a symbolic and arbitrary choice, but a meaningful one nonetheless: in public we saw him adopting the name "black hole" as well as exposing in lectures the *summa* of his quantum geometrodynamics, while in private we detected a form of restlessness that was a prelude to the radical change in views in the early 1970s. It is therefore all the more remarkable that it was in that same year, in the midst of those problems and reflections, that the spark of Wheeler's interest in Leibniz was ignited. Needless to say, the very fact that a physicist like Wheeler, while struggling with frontier issues at the end of the 1960s, could look for inspiration in Leibniz's *Theodicée* or *Monadologie* is linked to his relation with the past and his spirit of intellectual journey. The result was not, or certainly not only, one of those typical references to the Leibniz-Clarke debate that identify two "archetypal" attitudes toward the nature of space and time, but an inner dialogue on multiple levels – as befitting Leibniz – with a new "intracranial colleague" that would accompany Wheeler for the rest of his life. Or, to speak less metaphorically, the outcome was a complex "conceptual character" that Wheeler created by merging together various issues that went well beyond the realms of conventional physics.

181John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 148, folder "Leibniz Society".

As we have already mentioned in the Introduction as well as in Chapter 1, with specific reference to this case, its interest lies not only in the importance it had for Wheeler's ideas or that it could have for the history of the reception of Leibniz in the 20th-century: also from the methodological point of view it represents an atypical but certainly stimulating way of investigating the relations between physics and philosophy (or their respective histories), in line with the hermeneutics of archival material that we have sketched with reference to historical epistemology. That is not to say that some of the resonances that Wheeler perceived between his own issues and Leibniz could not be perceived from a conceptual viewpoint: already (Gale 1975), although confusedly and not really on point, hints at that, while much more recently we could recall (Lupacchini 2017). These, however, are exceptions: even if Wheeler "dropped" Leibniz's name in widely read texts such as *Gravitation*, in particular in the last chapter (Misner et al. 1973, pp. 1214-1217), or in his paper on "The Computer and the Universe" (Wheeler 1982a), it was not taken theoretically seriously, or it was just not understood. As we have already anticipated, Wheeler's nonchalant references have probably contributed to that, with their seeming oddity or superficiality.[182] However, if we take "Leibniz" as a placeholder and we try to understand how he used it, or more roughly if, instead of speaking of an unambiguously defined and suprahistorical Leibniz, we ask "Who was Wheeler's Leibniz?", then an archival exploration may start to look promising – and, indeed, it revealed a number of surprises, as the chronological aspect already underlined at the beginning of this chapter (whose epigraph, after all, shows that Wheeler was quite serious about it!).

Before embarking on this work of reconstruction, a few general words about Wheeler's change during the 1970s. At the end of Chapter 3 we have seen the "phrenological" diagram (Fig. 4) that concludes *Gravitation*. If we pay attention to the name given to the different areas, we can notice that "Pregeometry" is associated with the frontal lobe: while we are not trying to overread the disposition of the various labels, this one at least does not seem coincidental. "Pregeometry", as already fleetingly said in that chapter, is not (or not yet) some technical expertise one could master and use: it was rather the name for Wheeler's next big question. If space and time cannot be fundamental, as he thought the black hole had shown, how could we characterize a deeper level from which they could somehow emerge, and by which "mechanism"? As soon as we say "mechanism", however, we have to

182In 1974 a student of Thorne's wrote a good-naturedly satirical paper that was circulated under the name of John Archibald Wyler and the title of "Rasputin, Science, and the Transmogrification of Destiny" (Wyler 1974). That attests that people could indeed hear Wheeler speaking about Leibniz!

be cautious, mindful of the other hint (Wheeler 1973) offered by physical laws being "transcended": there may be no central machinery of the world, working on its own independently from the observer. Wheeler's quest for "pregeometry", thus, at the same time seems to designate all the attempts at devising a formalism for spacetime emergence in the context of quantum gravity (Huggett, Wüthrich 2024) and to deny an objective, naturalistic, or even formalistic character to this deeper level. He himself pursued and proposed more than one option, as we shall discuss – but the point is precisely that he was looking for new ways of thinking and suggestions anywhere, not to leave any stone unturned. If a daring-conservative attitude somehow persisted in looking for some untapped potential of past ideas and in the radical attempt at extrapolating some assumption, Wheeler clearly had no solid ground to start a new cycle of daring conservatism applied to well-established principles. "Pregeometry", thus, epitomizes the need for a "prefrontal synthesis". Why not asking Leibniz for inspiration?

2. Our sources and Wheeler's sources

This occasional appearance of Leibniz in Wheeler's publications, as already said, may look something quite marginal or superficial, the kind of pseudo-historical remark that would, at best, make the Leibniz *connoisseur* smile with condescension. What else to think about someone who, right after mentioning the Antikythera mechanism, could go on saying

> "Great Leibniz, to be sure, had a deeper vision both of computers and of physics. Goal establisher for the very different enterprises of Gödel and von Neumann, he envisaged a device that would automatically go through the 'yes, no' steps of a logical proof and in that way bring the power of logic to bear on everyday problems of the greatest variety. On the physics side, 'yes, no' Leibniz was inspiration to Kant, Mach, and Einstein" (Wheeler 1982a, p. 558)

and then indicate in a "monad" an act of quantum measurement which admits binary answer? If we were to put someone in front of a single excerpt from Wheeler's notebooks, the perplexity would be the same: an understandable reaction when reading "Me & the monad principle" ("physics at the very small must somehow replicate the physics of the universe") right next to calculations titled "Matter collapse", a reference to Mendeleev, a worried comment by Jan Oort to Wheeler's wife about her husband's mental health and, in the next page, a self-exhortation to persevere in the same way Melvin Calvin did while

trying to understand how photosynthesis works?[183]

By now, however, we have the interpretive tools not to be shocked like Oort and, by properly coupling published papers and private notebooks, to see a method in that "madness". Our sources, then, are the usual ones: the papers from the 1970s on that we are going to reference *in itinere* and, of course, Wheeler's archives. Since, however, Leibniz was not a fantastical character or somebody that our storyteller had met, we also need to pay particular attention to Wheeler's sources – and realize that we have to integrate the usual documentation with some further consideration or, in a sense, with "oral traditions". As as matter of fact, although Wheeler did not have an education in philosophy and its history, we could very well underline how he had learned *viva voce* from some of the decisive scientific thinkers of the century, who, on their part, were certainly imbued with the great tradition of philosophy. Here we should mention, in particular, Hermann Weyl. In a beautiful and rich speech for the latter's centenary (Wheeler 1986b), Wheeler, besides recollecting the walks and conversations they had in Princeton, mentions Leibniz quite a few times, along the lines that we shall soon examine. Moreover, as can be seen by the references of that paper, Wheeler certainly read Weyl's books, in particular the extended English edition of *Philosophie der Mathematik und Naturwissenschaft* (Weyl 1949),[184] where Leibniz's presence is obvious from the very first pages until the end, as has been noticed and studied (Scholz 2012; Sieroka 2018): we could very well say that Leibniz was an "intracranial colleague" for Weyl, too.

Besides Weyl's book, however, it is not so easy to identify Wheeler's sources, since he used to peruse a variety of texts with nonchalance, sometimes referring to the original work of authors, sometimes not feeling embarrassed to redirect the reader simply to a voice of the *Encyclopedia Britannica*. In the case of Leibniz, he did both. Nonetheless, we may also name a few scientists with whom Wheeler interacted and who had made, or would make, their own use of Leibniz, such as Gregory Chaitin, Ilya Prigogine, David Finkelstein. Perhaps also the presence of Kurt Gödel within walking distance could be relevant: although it was not easy to persuade him to talk about highly speculative topics (Wheeler 2000, p. 309), the fact that he had been up to his own version of monadology as well may have been a stimulus. Conjectures aside, we have enough material to assess Leibniz's importance for Wheeler and reconstruct the reasons for this interest.

183Relativity Notebook 18, pp. 18-19.

184Incidentally, on the back of the 1963 edition of the book there is a quote from a review by V.F. Lenzen, which applies well, *mutatis mutandis*, to Wheeler as well and that he must have certainly appreciated, if he saw it: "He demonstrates the value of historical learning for progressive science by introducing the insights of earlier thinkers into the context of contemporary thought".

3. A complex tapestry

Having specified this, it is almost unnecessary to add that Wheeler did not proceed "philologically" in his newly-born interest in, and then inner dialogue with, Leibniz. However, we are not just going to forgive him just because the creative use he – a distinguished personality – made of this author represents an interesting episode in the latter's reception. Wheeler had *thought from within* all the aspects that shaped his Leibniz: he had been personally involved with those problems and had reached unusual angles about them. There are six main threads that can be identified and disentangled (Furlan 2020b, p. 129), before interweaving them again while following Wheeler's trajectory:

1. Leibniz belonged to a tradition, of which Einstein and Weyl were part as well, that remarked the harmony of nature and its intelligibility.
2. Leibniz, with his theodicy and the idea of God's calculation over possible worlds, had developed ideas somehow analogous to Wheeler's long-cherished hope to apply, in a sort of "optimization problem", a Feynman-like quantization over all possible geometries to our whole universe, and thus even derive some unexplained features such as its dimensionality.
3. Leibniz had suggested that space and time are just *phenomena bene fundata*, and thus not fundamental, like Wheeler was convinced after embracing black holes.
4. Leibniz came "close" to Bohr's ideas on quantum measurement, up to the point that one could speak of a "quantum monadology".
5. Leibniz asked the question "Why something instead of nothing?", that Wheeler was starting to consider as synonymous of "How come the quantum?"
6. Leibniz, with his pioneering ideas on binary systems, could be seen as a forefather of informational perspectives, and, more in general, with his example of how to gel logics and physics, mathematics and metaphysics, provided an inspiration to inquire about the pregeometry of the universe.

We are now going to examine the preconditions of the 1967 spark of interest and then see how these orders of ideas – with the necessary explanations to make sense of them – got intertwined with Wheeler's story.

4.The black hole, the crisis of geometrodynamics, and Leibniz

As we have anticipated, Leibniz, at a precise point in Wheeler's career, became a sort of center of coagulation for problems, projects, and more or less vague ideas. The year is 1967: Wheeler's attention was dominated by the issue of gravitational collapse and its implications for the geometrodynamical view he had been pushing during the last decade. In Chapter 1, however, we have also mentioned how Wheeler thought of geometrodynamics not just as Einstein's legacy, but also as the completion of a grand arch going back to Newton. What is more, the way he was "using" the geometry of space to build everything up was at that point very substantial and quite distant from any vaguely Leibnizian position. However, the development of geometrodynamics and, in particular, the analysis of black holes would lead him to challenge his viewpoint about the nature of space, but that is not all. Two of Wheeler's main ideas had already some potentially Leibnizian overtones, although he realized that only later.

First, the black hole did not represent for Wheeler a merely astrophysical phenomenon, but much more: indeed, it was both a factor of crisis and a resource for Wheeler's vision. On the one hand, it used to pose a challenge for the endgame of his geometrodynamics, by which he was hoping to show that "everything is geometry", including the purported elementary particles: if, in the final phases of gravitational collapse (at least when enough mass is involved), the continuum itself of general relativity seemed to be torn apart, how should one consider the black hole in relation to the geometrodynamical program? On the other hand, precisely because of this question, the black hole was also used by Wheeler as a resource to further propagate his ideas and expectations: *quantum* geometrodynamics would take care of that. The black hole, moreover, could be considered as a sort of toy model to understand the destiny of the universe itself, since, at least in the closed universe which represented Wheeler's cosmological *credo*, a Big Crunch seemed unavoidable. Thus, gravitational collapse was in Wheeler's eye *the* physical process tying together the extremely large and the extremely small, the relation between which always remained in Wheeler's, as we shall see when speaking of *his* "monadology".

Second, we should recall another of Wheeler's guiding ideas (and catchy expressions), quantum foam. As the name pictorially suggests, Wheeler expected the smoothness of the classical geometry of space to be replaced, near the Planck scale, by a foam-like dynamic structure due to quantum fluctuations. Such fluctuations were conceived as altering even the topology of space, since they were generating or destroying "handles" (wormholes) of the space manifold. Then, as we have already discussed in Chapters 2 and 3, in the light of the results he had reached together with Misner (resurrecting an idea by Rainich), these wormholes were considered responsible for "charge without charge", that is Wheeler's attempt at reducing electromagnetism to geometric properties. The alleged elementary particles, whose typical length scale however is still around twenty orders of magnitude larger than the Planck

scale, could perhaps be imagined as coherent "clouds" of those charges, which are due to quantum fluctuations of an otherwise empty space. Of course, this scheme has little in common with Leibniz, except for a sort of "dissolution" of material bodies. However, we are aware that Wheeler's idea of quantum foam, quite differently from the somewhat generic meaning that has assumed in today's quantum gravity (pretty much the pictorial aspect evoked by the metaphor), was accompanied by much stronger claims: in those fluctuations Wheeler saw a sort of interference of the geometries of other *possible* universes according to the laws of geometrodynamics. Wheeler was wishing for a quantization *à la* Feynman of general relativity. If the key idea of the sum over histories, to put it roughly, is to consider all possible behaviours of a given system and to sum them in a properly weighted way, Wheeler even ventured to consider a similar sum over all possible geometries, topologies, and dimensions, hoping to obtain the features of our four-dimensional spacetime as the result with the highest weight.[185] The principle of least action is a crucial ingredient in order to perform such a calculation (in Feynman's case: Wheeler's "omnidimensional geometry" never reached that point). We can thus already grasp a Leibnizian overtone (even if Wheeler became aware of that only later): after all, what Wheeler had been envisioning was a calculation that involved an "optimization" among possible "worlds" and resulted in ours, even though, of course, "optimization" had not the same meaning as the one we may expect with regard to theodicy.

With these two "docking points" in mind, let us go back to the challenge of the black hole for Wheeler's "visionary" geometrodynamics and let us reassume here a few elements that are going to be instrumental in the following. Gravitational collapse was the tie between the large and the small: that also meant that Wheeler's idea of quantum foam was not confined at the minimal scales of nature, but would become relevant in the final phases of the universe as well. Among Wheeler's sketches for the quantum version of geometrodynamics, capable of facing the new issues, he introduced a "superspace" whose points represent the possible different geometries of the universe (Wheeler 1968c). In such superspace, Wheeler required quantum indeterminacy, so that the trajectory or storyline of the universe, in its dynamic and evolving geometry (according of course to relativistic cosmology), is not actually one trajectory or a single and well-defined storyline: it may seem uniquely defined in the intermediate phases, such as the one in which we live, but in the extreme ones, when approaching the Big Crunch, the interference or interconnection of stories and possibilities becomes manifest, depriving of any meaning questions of time-ordering such as "What happens *next*?". If, on the one hand, this idea of superspace looks "large enough" to have even some multiverse-like overtones, on the other it would ultimately turn out to be insufficient to fully express Wheeler's vision. Nonetheless, after what we have

185Letter to von Neumann, dated 12 October 1954, in Relativity Notebook 1, inserted between p. 78 and p. 79.

said about the blueprint of Feynman's sum over histories – always present in the back of Wheeler's mind –, we can easily guess that superspace, by analogy, could play the role of the *ensemble* of the possible worlds over which the Leibnizian God calculates. This proto-multiverse aspect is even more evident if we take a look at Wheeler's notebooks: in 1966, more precisely,[186] he realized that he had in any case to correct his "everything is geometry", since the laws of geometrodynamics, dictating the evolution of different possible geometries, were exceeding our universe only. The new slogan had thus to be "more than everything is geometry". Interestingly, in the same annotations Wheeler also spoke of "parallel existences": even if Feynman's formalism is arguably the first, more important and even sufficient inspiration behind a calculus over worlds, the choice of language seems here to suggest that Wheeler was also thinking about the ideas of another student of his, Everett.[187]

We are approaching the turning point: as we have seen in Chapter 3, progress in the hoped-for direction was lacking and by then, as Wheeler would recognize a few years later (Wheeler 1973), his grand geometrodynamical view could certainly not claim to have the last word about nature. Wheeler thus started to look around for new, powerful ideas – not only "around", actually, but also in the past. If the arch going back to Newton needed new foundations, Wheeler turned to Newton's arch-rival: Leibniz. We are now going to see how this "meeting" happened, but it is worth emphasizing that it was not a mere change of "characters" in Wheeler's narratives, since it actually mirrors his efforts to come up with a new worldview.

5. The Emperor's New Mind*, twenty years before its publication*

In January '67, in a discussion with his group and a familiar guest, Roger Penrose, Wheeler suddenly brought up the name of another of his previous students, Peter Putnam, who used to mix the variety of his interests – from the history of philosophy to neural activity, from psychology to biology – with physics in quite peculiar ways, that Wheeler evidently found intriguing but also "confusing" (Wheeler 2000, p. 254). During that '67 seminar, then, after hearing about a range of topics that included the limits of computation (just to add a Leibnizian flavor...), Wheeler made this bold – to say the least! – conjecture:[188]

"I brought up Peter Putnam, his suggestion or rather argument that acts

186Relativity Notebook 14, p. 17.

187More in general, Everett's presence in Wheeler's notebooks would deserve a proper study, since, from more than a few impressions, I could say that it never fully disappeared, contrary to what the *vulgata* suggests. Such an operation may very well lead to a reassessment of the Wheeler-Everett connection.

188Relativity Notebook 14, p. 129.

> of will are involved in all these and that therefore I anticipate the possibility that we may ultimately be able to link four things – the nature of man, the Gödel problem, the problem of measurement in q. mech., and the structure of spacetime".

The name of Leibniz does not appear yet (or at least, if somebody happened to mention him, Wheeler did not take note of that), but the merging of "labyrinths"[189] echoed in the title of this chapter is starting to emerge, in a peculiarly Wheelerian fashion but also with some Leibnizian shades. In the few lines above we can recognize elements that we have already mentioned, but what is a non-standard expression such as "Gödel problem" supposed to mean? From the notes it is not entirely clear, but we can make a very plausible guess, I would say. Penrose, in that occasion, touched upon a series of topics: possible developments of his nowadays celebrated – and back then recent – results on singularities in general relativity, but also Turing machines, the limits of computation, the halting problem; the sketch of a diagram also showcase the relations of inclusion between sets of numbers (complex, real, rational, natural...). Anyone vaguely familiar with the views that Penrose would later express also in popular books, starting from "The Emperor's New Mind" (Penrose 1989) on, can easily recognize here some of the fundamental ingredients of his argumentation about the alleged "implications" of Gödel's incompleteness theorems for the nature of human consciousness, the latter's relation to mathematics, and the depths of physics. If, in January '67, he had tried something similar, then Wheeler's remark quoted above looks much less outlandish.

As a matter of fact, during the following years, in a sort of expansion of that comment, Wheeler would try to link the issue of the structure of spacetime (in the light of the crisis of geometrodynamics, of course) to Leibniz's relational view; the "Gödel problem" to his own idea that logic may ultimately reveal some basic principle of the universe and of our own consciousness as well, thus contributing to the "pregeometry" quest; the nature of man to anthropic considerations in cosmology and fundamental physics; and quantum measurement to a sort of "monadology". It all seemed ready to gel together, at least in his own mind.

Only a couple of months later, in March '67, Wheeler was debating with people of his circle about the issue of "initial conditions" (more about which in a moment) and Leibniz is finally mentioned explicitly:[190] the next page is titled "Best of all worlds?" (on the margin: "'Best'? or 'cheapest'? or 'most probable'?") and Leibniz's name makes its appearance with reference to "Dicke's version of Leibniz argument that this is the best of all possible worlds

189"There are two great labyrinths of the human mind, one concerning the composition of the continuum, and the other concerning the nature of freedom" (Leibniz 1989 [c. 1689], p. 95).
190Relativity Notebook 14, pp. 162-ff.

(cf. rebuttal in Voltaire's Candide)". Just a few pages later,[191] there is a section with the title "The Smallest Universe or Theophysics" and, shortly after that,[192] Leibniz gets coupled with Ernst Mach under the aegis of a relational view of space ("space no meaning ohne particles"). "Monadology" is also mentioned, together with series of brief, cryptic, and possibly confused generic notes on other philosophers from "Aristotle or Plato – cheapest universe" to "Medievalist – concept of plenitude", followed by "Leib. this together in prin. of mon."[193] and Descartes. This is truly the moment of Wheeler's spark of interest: the naïve, basic character of these notes, in a sense, confirms that he had not previously taken him seriously, while now there seems to be the typical enthusiasm of a new perspective opening in front of one's eyes. [194]

To make order in these fragmentary notes, we have first to properly understand the meaning that a few expressions had for Wheeler at that time. "Initial conditions": we may be tempted to just conceive them according to the blueprint of the initial conditions which are familiar from mathematics and classical physics, but we should also recall that, in Wheeler's superspace, a point represents the geometry of the whole universe, and thus fixing the initial conditions means to fix some features of the universe itself at its "beginning" (granted that the latter, like "ending", is an improper expression for the reasons we have already outlined). Interference of stories notwithstanding, there is a regime that allows us to speak with good approximation of *the* primordial stage of our universe: that is where the issue of the initial conditions was connected by Wheeler to the questions that his Princeton colleague Robert Dicke was starting to raise about the seemingly fine-tuned values of fundamental constants that could allow the emergence of life as we know it (Wheeler 1968b). This order of ideas would soon lead to the so-called "anthropic principle": the "nature of man" in Wheeler's remarks is not a discussion *de essentia hominis*, of course, but touches upon the possible nexus between the existence of the universe and that of the human observer, as we shall articulate in the following.

191Relativity Notebook 14, p. 172.

192Relativity Notebook 14, p. 174.

193Already at this point, interestingly enough, Wheeler speaks of monadology as a *principle*, as he would later make explicit in his own way.

194That is not to say, of course, that Wheeler had never heard about Leibniz, something hardly possible for a physicist. Here we could also recall a series of meetings at the Stevens Institute in Hoboken, at the beginning of the '60s. These meetings used to be a sort of *rendez-vous* for Wheeler's group (Princeton) and Peter Bergmann's (Syracuse). Thanks again to Dieter Brill's notes, we can get an idea of the character of those meetings, where people did not seem afraid to speculate and discuss daring ideas. Furthermore, David Finkelstein was actually based there, and some Leibnizian overtones were already perceptible in his logical and mathematical attempts at providing a new basis for quantum physics and spacetime. Even if Wheeler heard about Leibniz in such occasions, I would say that only after the '67 spark these possible references to Leibniz (including those made by Weyl in his books or possibly during his walks with Wheeler) got "activated".

Regarding "Best of all worlds?" and the hesitation "'Best'? or 'cheapest'? or 'most probable'?", we have already identified the basic analogy with Leibniz's theodicy and deflated extra connotations while commenting upon a Feynman-like use of the principle of least action; even the extravagant "Theophysics", rather than signaling theological "intrusions",[195] seem to denote, with a touch of irony or flamboyant playfulness, the excitement about discussing – *within* physics – questions whose origin is lost in the mists of time. What about the reference to *Candide* and optimism, then? In order to understand this "placeholder", I think that we should not take it as a repetition of the commonplace about Leibniz "philosopher of optimism": rather, the expression meant for Wheeler that warm faith in the intelligibility of nature that he had learned from Einstein, as we discussed in Chapter 1. Leibniz's *harmonia praestabilita* became simply that, although it was not unrelated to Wheeler's "theophysics", either. In Jena, in 1980, he would even say:

> "Leibniz, one of Einstein's great heroes, more clearly than anyone was intellectual great-grandfather of Einstein's lifetime question, is there room for "any choice in the creation of the universe" – and of other queries tributary to that central issue: absolute space? absolute time? and space and time as preconditions for knowledge?" (Wheeler 1983a, p. 24).[196]

We know by now how to read these unusual connections, which actually can be used to clarify Wheeler's thoughts *expressed elsewhere*. In this case, how not to recall Einstein's famous sentence "I want to know how God created this world. I am not interested in this or that phenomenon, in the spectrum of this or that element. I want to know His thoughts, the rest are details"?[197] Likewise, it is easy to link it to Wheeler's early ambition and hope that a Feynman-like quantization of general relativity could even "derive" the dimensionality of spacetime; as well as to his attempt at tying together the values of fundamental constants and the nature of the observer – they are all aspirations to a theory without free parameters. Moreover, Wheeler's "anthropic" considerations, as we are going to clarify in Chapters 6 and 7, are clearly related to an idea of natural harmony, as his phrases "The Universe as Home for Man" (Wheeler 1974; 1975) or "At Home in the Universe" (Wheeler 1994c) can easily attest.

Just to conclude this brief commentary on the March '67 page, we should notice that "space no meaning ohne particles" seem to suggest a shift, or a dialectical overturning, of the geometrodynamical construction of particles. However, the first part of Wheeler's career – "everything is particles" – had apparently exhausted this slogan, so the '67 note probably

195See Chapter 6.

196We will return to that vaguely Kantian "preconditions for knowledge" in particular in Chapter 7.

197As quoted in (Salaman 1955).

does not simply mean something like "particles are ontological priors, space is emergent": that was his viewpoint in the '40s. I would rather say that Wheeler was starting to perceive a sort of duality of possible descriptions: perhaps also because of the dead ends that he was meeting in his hope to derive particles out of space, he considered also a complementary point of view – not to "ontologically" reduce space (or fields) to particles, as he had tried to do decades earlier, but as an equally legitimate way of considering general relativity. As a matter of fact, in the immediately following years Wheeler would be impressed by Sakharov's idea of considering an "elasticity" of the vacuum in terms of particles (Misner et al. 1973, p. 1206) and would consider it a possible "window" on the core lesson of general relativity in equal terms with the other formulations (Wheeler 1973). These two clashing points of view, the geometrodynamical-substantial one and "space no meaning ohne particles",[198] pushed Wheeler to look for a deeper level than both: after all, a quite obvious strategy to make sense of a duality is to say that both descriptions emerge from an underlying level, not involving – in this case – neither particles nor space and time, as paradoxical or inconceivable that may sound. The name for that unknown was – we already know – "pregeometry". In other words, Wheeler embarked on a search for what could reveal space and time as *phenomena bene fundata*, to speak in Leibnizian terms. If their "emergent" character, in recent decades, has become a commonplace in quantum gravity-related areas, we should not only notice that Wheeler was one of the first to ask the question in such strong and radical terms, but also that he did not stop there, possibly invoking Leibniz as an ancestor, but intertwined this issue with other Leibnizian resonances, that we are going to examine in the next section.

The open character of the quest for pregeometry – the attempt at a "prefrontal synthesis", as we were saying – is suggestively expressed in a '73 letter to Paul Cohen, whom Wheeler wished to meet due to the following conviction:[199]

> "I'm winding up twenty years' involvement with gravitation physics and relativity with the conclusion that the mystery of things lies still deeper, in the quantum principle; that the quantum principle is connected in some deep sense with logic and the calculus of propositions; that the structure of the universe is connected with our own existence in some deep Leibnizian sense; and that only when we recognize how strange the universe is will we be able to understand how simple it is. I have no

198Regarding Mach, who was the other name Wheeler associated with that note, it is doubtful that he was referring to some specific written passage, but we may say that he had long had a sympathy for (and, as usual, made some personal variation on) Mach's principle to think in a relational way about inertia. See (Blum, Furlan 2022).

199John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 7.

special axe to grind. I am simply in search of deeper understanding".

After all, he was saying ironically, "the good Lord [of Einsteinian memory!], I'm afraid, didn't have the benefits of the modern university business office, with precise allocations of so much to physics, so much to mathematics, and so much to philosophy". The connection between our existence and the structure of the universe – Wheeler's "anthropic" reflections of that period – is nonchalantly called Leibnizian, thus confirming our previous commentary; the quantum principle being deeper than general relativity is the outcome of the parable of daring conservatism and geometrodynamics, as we have seen; and we have still to clarify that reference to the "calculus of propositions". Before moving on to the next section, we can just notice that the January '67 "conjecture" had become, by January '73, the aspiration towards a synthesis with a clear Leibnizian flavor and a few relatively more "precise" guidelines of research.

6. Merlin's principle and a new cosmology

At the beginning of the '70s, about a decade after Bohr's death, Wheeler, while claiming to go back to his lessons, actually embraced quantum physics in (almost) all its plurality of forms: another name for "the quantum" became "Merlin's principle", alluding to its somehow elusive and shapeshifting core (Wheeler 1974). If in (Wheeler 1973) he had examined all the different "windows" on general relativity, from Cartan's formulation to Sakharov's more recent ideas, now he did with quantum physics. It is quite important to realize that Wheeler was not really interested in what one may call an "interpretation debate": he did not care about defending one position and claim its superiority over the others, because he was aiming at going beyond the level of quantum mechanics. The different formalisms could then be heuristic resources or, again, "windows" and provide hints about the central question that accompanied his last decades: "how come the quantum?" What is the core idea of quantum mechanics that could be manifested in such a variety of "shapes", from matrix mechanics to wave mechanics, from Birkhoff and von Neumann's quantum logic to Feynman's sum over histories and Everett's views?[200] In the early '70s, also due to Wheeler's dialogue with Wigner (as we shall discuss in Chapter 7), a key notion certainly seemed to him that of the observer-participator, which, *at this point at least,* is conceived as a conscious and even anthropomorphic being (Wheeler 1974). If there is no

200In (Wheeler 1974) they are all put on equal footing, even if, admittedly, they are not equally developed. What is striking at first, but perfectly consequential in Wheeler's trajectory, is the absence of any "interpretation" that tried to restore a classical level beneath the quantum: that must have seemed to him in contradiction to the lessons he drew from the adventure of geometrodynamics.

central machinery of the world (Wheeler 1973), the role of the observer, in a sort of rough ontologization of Bohr's epistemic considerations about the observer's choices in quantum mechanics, becomes constitutive of physical reality.

While this may look like a distinct quest (and in principle, or according to more conventional perspectives, it certainly is), Wheeler strictly intertwined it with the search for pregeometry – after all, both the latter and the quantum were supposed to be deeper than general relativity and its spacetime continuum. The fact that we have mentioned Birkhoff and von Neumann's attempt at a quantum logic back in the '30s may be quite surprising, especially if compared with the other shapes of Merlin and we know about Wheeler's interests and style. However, that is the key to understanding also the reference to the "calculus of propositions" in the letter to Cohen. Just a few years later, Finkelstein would write *The Leibniz Project,* where ideas similar to the ones alluded to in Wheeler's letter were dealt with in some technical detail (Finkelstein 1977). Since those musings had been entertained by Finkelstein for a couple of decades,[201] it was possibly thanks to him (in a more or less mediated way) that Wheeler developed some interest in von Neumann and Birkhoff's program of putting a quantum logic at the basis of quantum mechanics. Regardless of this possible link, Wheeler, as the very fact that he asked for a meeting with Cohen without knowing him attests, was hoping that the great results in modern logic, such as Gödel's and Cohen's, could reveal something about the pregeometrical level of physics. Wheeler did not delve into technicalities, but was fascinated enough by those results, which had made logic "the ethereal eyrie at the center of mathematics" (Misner et al. 1973, p. 1212). What in particular seemed to have intrigued him is self-referentiality, as if that were the point in which mathematics had started to make statements about itself. The analogy that, somehow "rhabdomantically", Wheeler had in mind was with the "self-referential" cosmology that he was developing, once he began to thematize the observer as an inner part of the universe that looks at itself. But let us outline the development of this idea.

Previously, Wheeler's cosmology, within his geometrodynamical view, was cyclic: a closed universe undergoing expansion and contraction, in a series of Big Bangs and Big Crunches (Blum, Furlan 2022). However, he had also added a touch of originality, intertwining this model with another issue he had been considering, that of fundamental constants. If his sensitivity as a theorist had long made him dislike the free parameters represented by the constants' numerical values (so that he was hoping to somehow derive them from deeper principles), we should recall again that, in the Princeton *milieu* (and in quite close contact with Wheeler's group), Dicke had been raising questions about fundamental constants and their seeming fine-tunedness as to allow for the emergence of life as we know it. Wheeler's peculiar cyclic

201As we have already noticed in relation to the Stevens meetings.

cosmology was a purely naturalistic (in the sense of autonomous and observer-independent) machinery which, from cycle to cycle, assigned randomly (in a quantum way) new sets of values to fundamental constants: if they seem to be fine-tuned to our life's prerequisites, it just means, since we are here, that the universe happens to be in one of the cycles with values compatible for life. With the crisis of geometrodynamics and the questioning of its implicit metaphysics, however, Wheeler changed cosmology, too: getting rid of cycles, he tried to link the participatory role of the observer to the fundamental features of the universe – "the structure of the universe is connected with our own existence in some deep Leibnizian sense". The *pars destruens* of his twenty years of geometrodynamics – laws getting "transcended" – had been illustrated at the great Trieste symposium for Dirac's 70th birthday, in October 1972 (Wheeler 1973). In that same period, Wheeler was also taking action to finalize the organization of the celebrations of the other great anniversary recurring a few months later: 500 years since the birth of Copernicus. Wheeler was at the head of the Smithsonian event that was to take place in April: there and then, as we have seen, he would sketch the *pars construens* for a new physics, or at least his hopes for it. The speech itself, besides (and before) getting published in the proceedings of the celebration (Gingerich 1975), was published in the American Scientist (Wheeler 1974). Accompanying the text, a stylized portrait of Copernicus with a flower in his hand is suggested to represent the human mind, the "flower of creation".

We have still to clarify the "deep Leibnizian sense", however. We can listen to Wheeler himself, in his "Copernican" speech:

> "One view holds that as we keep on investigating matter, we will work down from crystals to molecules, from molecules to atoms, from atoms to particles, from particles to quarks - and mine to forever greater depths. A very different concept might be called the "Leibniz logic loop". According to this view the analysis of the physical world, pursued to sufficient depth, will lead back in some now-hidden way to man himself, to conscious mind, tied unexpectedly through the very acts of observation and participation to partnership in the foundation of the universe. To write off the power of observation and reason to make headway with this question would seem to fly against experience" (Wheeler 1974, p. 689).

The choice of the expression "logic loop" can be understood in the light of what we have been saying about the "self-referentiality" of logic and the resonances that Wheeler was somehow perceiving; not by chance Gödel and Cohen are mentioned even in this speech. Calling it "Leibniz logic loop"

seems more arbitrary, but, thanks to what we have been saying in the previous pages, we can at least guess what kind of associations Wheeler was making in his mind. More importantly, we should also realize that the post-geometrodynamical turn was at once physical, cosmological, and metaphysical, as we are going to reiterate in Chapter 7. When implicitly criticizing the search for the fundamental "blocks" of matter, scale by scale, via the construction of more powerful accelerators, Wheeler was not just expressing his methodological disagreement with the particle physics community, as he had done at the time of the particle zoo: by rejecting a pyramidal or hierarchical naturalistic ontology, he was challenging a much more widespread mindset, which is arguably also one of the reasons why he has puzzled many physicists (and philosophers or historians of science) accustomed to think "naturalistically". By analyzing the universe in depth, Wheeler said, we should not expect to find the ultimate "piece" of matter (or its conceptually more refined, but still *given,* versions): we are supposedly led instead, in a loop, to "the acts of observation and participation". Likewise, Leibniz had rejected *res extensa* or material atoms as the basis of the world and introduced the monads, as centers of perception and "spiritual" activity. The ground for a new "monadology" was ready.

7. The shifting nature of the observer and the upgraded monadology

Wheeler's '73 exploit was not isolated, not even in written publications: he would go on developing those ideas in other papers, notably (the titles are telling) *Is Physics Legislated by Cosmogony?* (Patton, Wheeler 1975) and *Genesis and Observership* (Wheeler 1977). This phase, however, was transitional. As typical of Wheeler, he never rejected the proposals he put forward in that trilogy of papers, but kept elaborating on them, with tacit but crucial changes. By the end of the '70s, for instance, it is clear that Wheeler had abandoned even the overtones that could make his '73 speech resonate with Wigner's positions about quantum mechanics and the role of consciousness (Wheeler 1978). A gradual "soberification" of Wheeler's views was taking place: this was in part due to his move to Texas in '76 and the new *milieu* that he encountered there (and that he contributed to create), with an attention to the foundations of quantum physics closer to experimental situations.[202] In particular, as we are going to better document in the next chapters, the observer-participator that could contribute even to cosmogony (since only a universe with the possibility of the appearance of the observer

202This alone, of course, deserves some future specific study.

could come to existence),[203] as mentioned a few moments ago, was getting de-conscientialized, since the observer or the monad was not necessarily a human or conscious being: Wheeler, echoing Bohr, started to repeat that "[n]o elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon" (Wheeler 1982a, p. 560), no consciousness was strictly required to set the cosmic quantum game in motion. Monadology too, after all, is not anthropomorphic or anthropocentric – actually, I would even suggest that Wheeler's own monadology contributed, as a sort of scaffolding, to the above de-anthromorphization of the observer. After having identified the ground for a new monadology, then, we have to actually examine Wheeler's documents.

From a linguistic point of view, it is not trivial to provide a precise assessment (assuming that a precise one is indeed possible) of the ways he spoke of monadology. We have previously seen how, in his notebooks, he spoke of a "monad principle", making it sound like a macro/microcosm correspondence – that is actually quite legitimate, if every monad "mirrors" the world. When doing physics, however, such a kind of correspondence is certainly a very limiting and specific constraint. Nonetheless, Wheeler always had a penchant for it: as early as 1953, in the first notebook he was filling during the new phase of his career, Wheeler was for instance writing: "Most exciting idea of each particle being a universe, perhaps identical with our own".[204] On the same page: "Looks like a proton on the outside, but is a whole universe on the inside". This sort of echo of William Blake's famous line "To see a world in a grain of sand..." would be apparently dismissed, but actually transformed and articulated, in Wheeler's geometrodynamical view of particles: if on the one hand they are supposed to be clouds of fluctuations, and thus more difficult to use directly for a micro/macrocosm correspondence, on the other they are nonetheless constituted by that same quantum foam that, via the large-small binding of the universe due to gravitation (and made explicit in gravitational collapse, whether of a star or the whole universe), was to dominate everything. In *From Mendeleev's Atom to the Collapsing Star* (Wheeler 1971b) – already the title is meaningful with respect to what we have just said – there is even a section titled "Monads and fluctuations", where we can actually read: "A fluctuation in the geometry of space at the Planck length is a small scale version of the expansion and recontraction of the universe itself" (p. 230). On the same page, Wheeler writes:

"Of all the developments that Leibniz gave the world, from the

203And therefore, since observer-participancy is a lesson of the quantum, the question "how come the quantum?" becomes also "how come existence?", as we have already seen in the epigraph of this chapter.

204Relativity Notebook 1, p. 128.

> calculus in its modern form to the principle of least action, and from the principle of sufficient reason to the concept of the best of all possible worlds, there was none on which he laid greater weight, and none more puzzling to his contemporaries, than the idea of a world made of monads, each of which however subsumes inside itself the whole world, as a microcosm" (Wheeler 1971b, p. 230).[205]

In '71 we can also find the following annotation in the notebooks:[206]

> "The large and the small must be in some sense one and the same – a particle only knows how to be exactly like another particle of the same type because each in some sense mirrors the same universe (my "updating" of the monad principle of Leibniz)".

If we now take a look at a few pages of the ending chapter of *Gravitation* (Misner et al. 1973, pp. 1214-1217), we can see that monads, there, are again put next to particles, in a manner that, at first glance, may very well seem an arbitrary misuse of the Leibnizian expression (since, of course, monads are not particles, changing notions of matter notwithstanding). In those pages, the "mirroring" of the harmonious monads gets associated to particles of the same kind with the same numerical constants.[207] Leibniz's famous image of the pond with fishes inside a monad becomes in Wheeler's hands a view on an entire world: how come? Wheeler's answer resorts to a geological analogy: if the features of rocks can reveal us important clues about the Earth's past and the processes in which they were shaped – and that is why rocks of the same kind share some characteristics, particles can tell us something about the primordial (possibly even "before" time) phases of the universe in which they were somehow formed with specific values, that are shared by those of the same kind.[208] All these, however, were just vague suggestions: why the fundamental

205Wheeler's footnote here says: "For a brief account of the concept of 'monad' see for example the *Encyclopedia Brittanica* [sic!], article on Leibniz"!

206Relativity Notebook 18, p. 176.

207This is of course related to Wheeler's theoretical ambition of getting rid of free parameters, as we have already commented.

208In that same period Wheeler organized some considerations in a way that can recall the "fractal" view of the pond within the monad in a subtler sense: on the basis of some relation between particles and the whole universe, he could start from something as generic as a drop of water; allude to the laws regulating its formation, shape, and properties; from there take a bold step such as the particles/rocks analogy outlined above; and thus evoke once again his grand vision of the cosmos. "On this view a particle mass is not a basic quantity of nature. It has as little claim to that title as does the mass of the water droplet that hangs from the ceiling of the shower. Ask why it has its mass, and find oneself asking why one takes a shower where the value of g happens to be 980 cm/sec^2. Ask why the particle has its mass, and end up asking

physical constants had those precise values remained unclear. At first, in his cyclic cosmology, a random quantum mechanism was supposed to assign them, but then this (no-)explanation was replaced by the "loop" involving the observer and the existence of the universe, that is by anthropic considerations.

That, however, is far from exhausting Wheeler's use of the word "monad", luckily. A decade later, Wheeler, besides referring directly to the *Monadologie,*[209] makes his thoughts more explicit:

> "One who comes from an older time and is accustomed to the picture of the universe as a machine built out of 'atoms' is not only baffled but put off when he reads Leibniz and Leibniz's conception of the ultimate building unit, the monad (Leibniz, 1962):
> '1. The Monad, of which we will speak here, is nothing else than a simple substance, which goes to make up composites; by simple, we mean without parts.
> 2. There must be simple substances because there are composites; for a composite is nothing else than a collection or aggregation of simple substances.
> 3. Now where there are no constituent parts there is possible neither extension, nor form, nor divisibility. These Monads are the true Atoms of nature, and, in fact, the Elements of things.
> …
> 7. There is also no way of explaining how a Monad can be altered or changed in its inner being by any other created thing, since there is no possibility of transposition within it, ... The Monads have no windows through which anything may come in or go out ....
> ...
> 9. Each Monad ... must be different from every other ...'" (Wheeler 1982a, p. 560).

This is immediately followed by "These words of Leibniz about the 'monad' are more relevant to 'quantum phenomenon' than to anything one has ever called an 'atom'", thus totally confirming the analogy we drew at the end of the previous section. Wheeler does not articulate much more the parallelism between the quotes from Leibniz and Bohr's quantum phenomenon, but he does give a few suggestions. This vagueness is due, of course, to our lack of understanding of "how come the quantum?", of the elementary phenomenon itself, but that is also why he is trying new analogies, after all.

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why we happen to be living in this particular cycle of the universe" (Wheeler 1970, p. 31).
209The edition Wheeler refers to in the quote is (Leibniz 1962).

> "The elementary quantum phenomenon is a great smoky dragon. The mouth of the dragon is sharp, where it bites the counter. The tail of the dragon is sharp, where the photon starts. But about what the dragon does or looks like in between we have no right to speak, either in this or in any delayed-choice experiment" (Miller, Wheeler 1984, p. 140).

The '70s "Merlin" became the '80s "smoky dragon", "Bohr's great smoky dragon": "like a great smoky dragon through the vast intervening reach of space and time" (Wheeler 1986b, p. 370).[210] If this reminds us that Wheeler is considering the quantum as deeper than spacetime (and, after all, space and time are supposed to be conceived relationally, once we have introduced the monads), it also alludes to the shortage of words when dealing with the quantum realm (and to his awareness of being a storyteller!). Nonetheless, Wheeler does make explicit the crucial point of his unusual juxtaposition Leibniz-Bohr: "The building element is the elementary 'yes, no' quantum phenomenon. It is an abstract entity. It is not localized in space and time. Its interior is inscrutable, untouchable. The combinatorics of such entities is a new and rich problem" (Wheeler 1982a, p. 570). These few words would certainly require a longer commentary, but we are now in the position to grasp their meaning. The result of the simplest act of quantum measurement is a yes/no answer: that is, the most basic act of observation consists in *asking a question* (Bohr's trademark in Wheeler's narratives, as we know) which admits a binary answer. That is not an idea that Wheeler reached in the '80s: as we are going to discuss in Chapter 7, he had something like that in mind already at the beginning of the '70s, and that also explains in a straightforward and easy way why he briefly considered the calculus of propositions (with their binary truth-value) as a candidate for pregeometry. The combinatorics of the acts of observer-participancy would then somehow mirror the composition of propositions in their calculus. There was, however, a clear shift in emphasis: the earliest speculations about pregeometry as calculus of propositions at the very beginning of the '70s are too "objectively" formalistic and have little to do with the role of the observer; what we are seeing in the '80s is instead a sort of synthesis of that with the "loop" of the observer-participator. The combinatorics of a large number of acts of observer-participancy, likewise, clearly reflects the idea of a statistical character of physical laws, or "law without law", which is after '77 (Wheeler 1978)

In the fundamental binarity indicated by Wheeler, moreover, we can detect another Leibnizian ingredient, so to say, as much as, at least at the best

210No wonder that R. Dawkins once presented Wheeler thus: "We are fortunate to have unique thinkers among us like Wheeler, to lead us a little further into the 'Here be Dragons' badlands of modern physics than we might otherwise dare to enter" (Dawkins 2008, p. 379)!

of my knowledge, there does not seem to be some explicit attempt by Leibniz at linking the binary code, that had intrigued him so much, to monads. In any case, once we speak of binarity in the '80s, we actually realize that we have reached Wheeler's "bits" – the more successful name for (the result of) those acts of observer-participancy. For what we have just said, they are clearly not an abstract unit of information which gets reified: in a sense, Wheeler's bits are made, not given.

> "In considering this problem it is an encouragement to tell over one by one the fields of knowledge where other entities come into play in large numbers; but among them all it is difficult to name one with more relevant insights than the theory of computers and of information generally. Will we not sustain the tradition of Leibniz, Kant, Mach, Gödel, and von Neumann if we suppose that we will someday understand 'physics as information'?" (Wheeler 1982a, pp. 570-571).

Bits and binary-code machines (after all, we have been quoting from *The Computer and the Universe* – a couple that, clearly, in '82 was not as frequent and abused as today) thus play a key role in the exhumation of these Leibnizian themes. Nonetheless, we should also specify that, in the light of what we have been saying, Wheeler, after announcing the obsolescence of the view of the universe as a machinery of some sort, did not simply intend to replace it with "the universe as a computer": as the conjunction in the title suggests, he kept the two of them separate and discussed possible analogies as well as disanalogies. After all, there was a smoky dragon to face, beyond space and time: "In every other large-number problem we have entities that we can touch and rules for moving them around and a preexisting framework in which to do the moving. Here, however, we start with an almost terrifying austerity: no time, no space, and no law" (Wheeler 1982a, p. 570). How everything could emerge from this "austerity" was to remain unanswered. As much as this was only "an idea for an idea", it should not be conceived, presumably, according to the simple blueprint of phase transitions, as often happens when speaking about "emergence". It was rather meant as a hierarchy of constitutive factors, and that is why Wheeler kept repeating to the end of his days that the quantum principle was the overarching feature of contemporary physics.

We may just conclude this Leibnizian *tour de force* with a couple of more general considerations. Sieroka, after examining some recently-made analogies – by far much less complex and interesting than Wheeler's – between Leibniz's thought and recent physics, comments that

> "Even though the reference to the *content* of modem physics is anachronistic, the method of comparing philosophical and physical notions and of finding structural analogies is not. It is very Leibnizian and might be spelled out in terms of Leibniz notion of 'expression'" (Sieroka 2016, p. 287).

We do not intend to use these words to fully "legitimize" what Wheeler did – there is no need and it would be preposterous, at this point. Rather, we can underline that Wheeler's passionate dialogue with his intracranial colleague may in part act as a stimulus also for more "orthodox" interpreters of Leibniz or of some other great thinker of the past: in the end, if the interpreters do not perceive, even "empathically" so to say, some analogies with their own situation and experience, the risk is that of having just barren reconstructions and a dusty antiquarian history. If, instead, they were to tentatively adopt new toolkits and filters, previously neglected aspects may be more easily identified or seen from new angles. Therefore, even if here we were interested in Wheeler's use of Leibniz in its own right, without caring for *his* historical or philological "correctness", we do not exclude *a priori* that some ideas could be stimulating for the Leibniz-in-his-own-time interpreter too, in a mediated way at least: after all, what is an interpreter if not a mediator? In the meanwhile, we can for sure state that we have detailed one of the most original episodes in the reception of Leibniz during the 20th-century, which has also provided guidance across the intricate ideas of Wheeler's last transition period.

5. Aesthetics of Visionaries and Engineering

This chapter aims at suggesting a different route to cross the complex transition period between the crisis of geometrodynamics and the "it from bit" phase. If, in the previous chapter, we used Wheeler's interest in Leibniz as a guide, here we are going to pay attention to his long-standing relationship with engineering, or at least an engineering-like attitude. We are thus going to examine how the latter played a role in the different parts of Wheeler's career, re-read the spirit of daring conservatism and his heuristics in this light, and remark on the conceptual metamorphoses that were arguably fostered by the Texas milieu, starting from 1976, and a different way of dealing with quantum-foundational questions.

> They would be said to be uncomfortable within the bounds of space and time. They interpret rather than imitate, and they transfigure more than interpret. They are not content with our universe, and while the study of its forms satisfies most artists, for them, on the other hand, the formal study is but a provisional framework or, if you will, a starting point.
> – Henri Focillon (1926), *Esthétique des visionnaires*

1. Introduction: a skillful dosage

Wheeler, as we have already discussed at length, is nowadays known among larger audiences for "baptizing" something as exotic as black holes or for his visionary perspectives such as *it from bit*. Nonetheless, this would be a crude and almost caricatured version, unsuitable for accounting for the decisive impact that this scientist, "whose mind has the combination of inventiveness and independence that seems so characteristic of American men of talent" (Buckely, Peat 1979, p. 51), has had on various generations. It is also clear that, in the "wrong" hands, Wheeler's daring speculations and his flamboyant style can quite easily turn his words into a goldmine of sensationalism about the extreme frontiers of physics and related speculations. Against such tendencies, but also against the opposite excess of embalmed formalistic accounts of "how science really works", here we shall examine some of the ways in which Wheeler's highly speculative *verve* was often accompanied by an engineering-like component, without of course trying to present him as a theory-driven engineer. We can make all this explicit on two levels, primarily. One is Wheeler's search for mechanisms of visualization and understanding, even when facing the most remote or "abstract" questions in the physical

world. The other is his skillful dosage of a bold theorizing accompanied by the perception of what can be concretely explored with available tools. The latter point, as will be better shown in the following, is not to be trivially confused with a mere attention to testable consequences, since it also involved, on Wheeler's part, a shrewd re-functionalization or exaptation of resources and results developed in more strictly technological contexts. To show this synergy, we are going to (1) take another look at the complex heuristic trajectory that, in a more than decade-long journey between the 1950s and 1960s, led Wheeler from being an opponent of the first pioneering results on black holes to becoming their enthusiastic godfather; and, later, we are going to (2) consider a series of daring speculations that made him reach the famous slogan *it from bit*. With a few highlights from this engrossing scientific adventure we can also offer the chance to adjust overly "theoreticist" views of science. I am not only referring to its most speculative frontiers, where a truly *explorative* role of experiments seems to have been forgotten by lack of technical means: I am also speaking of some relatively diffused tendency in philosophy of science, especially when highly mathematized, that tries to show off how "updated" it is in terms of specialized notions, but reveals how poor its heuristic sense and its attention to scientific practices (including conceptual ones) actually are. In such cases, all those dimensions of research we have alluded to often end up being omitted from the resulting picture – and that is, in general, untenable. Finally, as a conclusion, reference will be made to a little-known speech given by Wheeler in Venezuela in 1961, in which his general view on the relationship between engineering and science found eloquent expression.

2. "If I can't make a picture, I don't understand": Wheeler and visualization

In an extensive study on scientific visualization, K. Hentschel (2014) suggested, also according to what he himself once communicated me,[211] that he had uncovered a pattern through the examination of a variety of scientists from different disciplines and eras: from Hooke to Wheeler, what these figures have in common, upstream of their visualization strategies, would be an engineering background. It is easy to object that, over such a wide time span, the very meaning of physics and engineering has varied to such an extent as to make this assertion somewhat questionable. Moreover, in the case of a theoretical physicist like Wheeler (or someone else of recent times), it might be pointed out that, to frame visualizing tendencies, we can just consider the

211 At the 2020 conference of the European Society for the History of Science in (virtual) Bologna.

type of mathematical language that gets favored: in this sense, a mathematician's or physicist's propensity to visualize may manifest itself in a preference for a geometric or topological treatment, as opposed to more algebraic-analytic tastes. Both of these objections may capture important points; in Wheeler's case, nonetheless, a thesis similar to Hentschel's can actually be supported and articulated in more detail.

The predilection for visualization that will be addressed here should be understood on several levels. The most obvious and closest to what is suggested by Hentschel concerns the impact that Wheeler's engineering studies had on his *modus operandi*. Secondly, that experience made Wheeler not only prone to collaborate with worthy individuals having engineering backgrounds, but also attentive to the epistemic potential, so to speak, that instrumentation and techniques originally developed for practical purposes could disclose in more theoretical realms. A remarkable case, as we have already mentioned, was Wheeler's farsighted repurposing of computer tools – developed in military contexts – to questions of astrophysics and, indeed, even of fundamentals physics. If people like Ulam, Fermi, and of course von Neumann had early realized that the computational power thus gained could open new frontiers also in theoretical (and not just "applied") research, in Wheeler's case we can find both the direct use of such computational resources for numerical explorations and the exaptation of tools which were first developed within the context of the Matterhorn Project and later transferred to the modeling of supernovae explosions. Thirdly and finally, or rather concurrently, there is a perhaps more elusive but no less important level that made an engineering-like perception relevant, that is Wheeler's „flair" for entrusting students and collaborators with research topics which were formulated in the first instance as concrete problems, on which it was possible to work with manageable approximations: they were building blocks for his grand view, but also results in their own right.

These various levels are nicely captured by Wheeler's own words in a couple of passages. One is from his recollections:

> "Perhaps because I grew up in an environment where problem solving and achievement (as well as service) were the respected virtues, where the mind was supposed to do something, not just know something, I did not distinguish early between science and technology, between mathematics and devices. Although I gravitated in college to science and mathematics, I never lost my fascination with technology and devices" (Wheeler 2000, p. 84).

The other comes from one of his working notebooks of the 1950s: in the margin of admittedly incomplete heuristic considerations, Wheeler wrote about «advant[age] of training in building things out of junk, not new lumber».[212] We might also rephrase: the art of making do with what one has.[213]

This being said, the most obvious way to start making an assessment is simply to examine Wheeler's trajectory as a student: thus we find that, indeed, in 1927, he enrolled in the School of Engineering at Johns Hopkins University in Baltimore. In his own words,

> "At the time, I was as intrigued by mechanical devices as by atomic theory. I had devoured books about both. Engineering seemed like the only way to translate my general interest in science and technology into a living. As a fifteen-year-old bent on making my own way in the world, saying "physics" would have been like saying 'pottery making'" (Wheeler 2000, p. 86).

There is no doubt that physics, especially in its more theoretical areas, had, back then, a quite different institutional status from that of recent times, which is why it is better to avoid gross back-projections. However, at least in this case, we should not fall into another excess and regard that choice merely as an irrelevant transitional period in which Wheeler, after making a sort of concession to the tendencies of the *Zeitgeist*, found his own way elsewhere.

These are not merely psychological considerations: it is possible to show how Wheeler's engineering interests had more distant roots and, of course, persisted thereafter in his military work and beyond. Simply by following his biography or considering the composition of his family, we discover that Wheeler, on his mother's side, had two uncles who worked in mining engineering and one of them, in the summer of 1928, offered him the possibility of having a learning experience in the silver mines of Zacatecas, Mexico. To that we can add Wheeler's passion, even as a boy, to prepare explosions: if, at first glance, this seems an ironic comment, it will instead prove to be a common thread in the later activities that we will examine. Digging further back, it is again Wheeler himself (Bernstein 1990; Wheeler 2000, p. 82) who informs us of the importance, when he was a child, of a book

212Relativity Notebook 3, p. 63.

213But also with some guiding idea in mind, as Wheeler would later put it: "To ask the right question, however, one must have, as is well known, some glimmer of the answer. It is also old experience that in order to break out of blank puzzlement and into the right question-and-answer circuit, one must try and try again. One must, if necessary, make a fool of oneself many times over, thus following the example of the engine inventor, John Kris, with his familiar words about each new model - 'Start her up and see why she don't work' [sic]" (Wheeler 1986a, p. 304).

of mechanical devices, rich in illustrations that appealed to his imagination and guided him in his early experiments: *Mechanisms and Mechanical Movements* by Franklin Jones.[214] This may sound like the usual and quite cheap *cliché* of the young scientist in the garage, as heard *ad nauseam* particularly in biographies of overseas physicists, but it is interesting to note, for our considerations on visualization, how Wheeler himself felt it necessary, in retrospect, to add something else to mechanical gears: visual arts. In this way, we can get a more well-rounded account of the origins of Wheeler's need for pictures, or even "iconophagy".[215] Such additions can also supplement Hentschel's thesis, as he himself seems to somewhat realize.[216] To be more

214It is rather interesting to note how this same aspect and the reference to the book by Jones have also been emphasized by Galison (2012), in an attempt to capture more generally the peculiarities of Wheeler's visualizations. Galison's underlying attitude is shareable, as effectively summarized by the following sentence: "Wheeler was, quintessentially, the scientist who insistently cycled philosophical questions of meaning through the technical work. This is a mathematics set deep in the hewn-out limestone caves, far below the luminous forms of Plato's heaven" (*ibidem,* p. 58). However, the argument made therein is partly undermined by some historical inaccuracies regarding the development of Wheeler's thought and by some misleading suggestions about the specific weight of some of his ideas or proposals, especially in the final section, "Theomathematics" (even if it must be acknowledged that serious reconstruction work was still to be done a decade ago, it just seems incomprehensible to place Wheeler's late '60s-early '70s "reprocessing of the universe" about twenty years later – unless we are playing with verbal associations: reprocessing of a computer, therefore *it from bit* phase). Highlighting Wheeler's way of conceiving mathematics as a machinery of some sort works quite well when discussing his presentation of the tools of differential calculus (1-forms, 2-forms, covariant derivatives, etc.) or other already systematized notions (teaching subjects, we may say): students with some relatively advanced problem-solving experience in mathematics and physics may recall repertoires of partly similar techniques such as (Levi 2009). However, Galison's stance does not seem entirely adequate to capture the evocative-visionary character of Wheeler's boldest heuristic proposals (see Appendix B), especially those of his last decades, as we shall soon specify.

215The expression is borrowed from (Costa, Furlan 2023) and is actually a readaptation of a comment once made about none other than Picasso.

216See (Hentschel 2014, p. 111), where he redirects to (Bicak 2009). After all, as Hentschel remarks with reference to the celebrated textbook *Gravitation* (Misnet er al. 1973), the variety of its visual strategies, from perspective to foreshortening, from zooming to the display of topological relations, is remarkable, and they are occasionally combined together in powerful new ways, even shrewdly (we may comment that there is a reason if "cunning" has the same root as the German word "Kunst"...). We have already noticed how Galison's attention too is mainly (or most effectively) directed to *Gravitation* and its visual gears, so to speak. But what is important to emphasize again is that, while *Gravitation* is indeed the kind of visual feast suggested by these comments, Wheeler's use of pictures was not limited to that illustrative-pedagogical dimension. Those were run-in gears, well-oiled, but there are many of Wheeler's pictures that are much more rhetorical and heuristic (and the two, in his case, cannot be easily disentangled). They may provide a concrete picture for a somewhat vague idea to be pursued; or they may just be an iconic "condensation" of the considerations and lines of research that Wheeler is sketching in his papers (see Appendix B). We can simply flip through his papers from the 1970s on to realize the great importance (and originality) of such pictures, but we have also to realize that their *pragmatic* dimension - what they ask the reader or beholder to do – is very different from that of the pictures commented by Hentschel and Galison, or, more generally, those in a typical physics text. When we see (Wheeler 1980a, p. 362) a capital "U", standing for "Universe", with an eye on the left top looking at the right side of the letter, we

precise, we can consider the following passage from a late interview with Kenneth W. Ford, during which Wheeler stated:

> "F: John, a characteristic of your later research was the wonderful ability to make diagrams, make almost an art form of conveying the information. Did you have that characteristic already in your earliest work?
> W: Well, I certainly feel today if I can't make a picture, I don't understand what I'm talking about. But making pictures: I had the great good fortune of having a course in engineering drawing as part of my required training in engineering. But that's scarcely the place to make pictures. And then I can recall being sent Saturday mornings to the art gallery in Youngstown, Ohio for a course in painting and drawing, and that was fun. I would have loved to go on in that. And then, in the year we spent, 1949, in Paris taking lessons with a French artist, that was not the business of expressing ideas in pictures; we were just drawing pictures" (Wheeler 1994a).

What is more, even the mention of Jones's book is immediately joined by another "less practical" title, *Introduction to Science*, by naturalist Arthur Thomson (Wheeler 2000, p. 82). This way of proceeding on double tracks, so to speak, can also be seen later on,[217] particularly if we try to cast a glance over the entirety of Wheeler's activities. After he fully began to devote himself to physics, the first part of his long career, roughly until the early 1950s, was primarily dedicated to nuclear issues, by which adjective, however, people used to mean a much broader and frontier area, obviously, than the term might evoke today. What is interesting to recall is how Freeman Dyson (2015, pp. 140-141) once spoke, as we have already seen in Chapter 1, of two different aspects of Wheeler, which manifested themselves (also) as writing styles: on the one side, the prosaic, artisanal, skilled problem-solver – on the other, the

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cannot act as if we were in front of a "scientific" diagram that requires some standard expertise to be read or used. It is easy to say that the former kind of pictures – that addressed by Galison – is, at least in part, rooted in Wheeler's engineering-like search for "mechanisms"; but it is worth suggesting here that the dissemination of the second kind of pictures seems to explode after Wheeler stopped believing in the existence of a central machinery of the world.

217Another example, perhaps a bit generic but, because of that, pointing towards a more general cognitive value: "As Brooke Hindle, the historian of science and technology, points out, who better than a surveyor, a designer or an artist to picture the trial placements and adjustments of critical parts and who could better envisage the resulting device as a system in daily use?" (Wheeler 1980c, p. 186). We shall return to this when referring to Einstein's experience at the patent office. The same paper we have just quoted, but even earlier (Wheeler 1956) (devoted to the "sibyls" or heuristic aids he often resorted to), are rich in examples ranging from engineering to art.

poetic, disconcerting, unorthodox visionary. To exemplify the former, Dyson mentions the young Wheeler's famous collaboration, in the late 1930s, with Bohr, with whom he achieved crucial results on fission; for the visionary Wheeler, instead, there are many examples, as we shall see. It is precisely because of the co-presence of those two souls in Wheeler that, as we are suggesting here, that happy union of bold speculation and solid foundations was possible.[218] This is also reflected in Wheeler's own heuristic methodology, or better in its meaningful oxymoron *daring conservatism*.

In what we have been just saying, however, there seems to be already, between the lines, a point that should not be overlooked, namely a sort of tension between Wheeler's visualizing streak and the extreme caution, in the makers of quantum mechanics gravitating around Copenhagen, in the use of classical and intuitive (*anschaulich*) images and concepts, inadequate for dealing with the world of microphysics, which is so distant from our everyday experience. This tension easily vanishes[219] if one does not fall into the superstition that the formulae of physics directly reveal, *sic et simpliciter*, what "reality" is like, and if we slightly refine the notion of image. Availing oneself of visual tools to handle a theory and its implications or to solve problems does not necessarily imply that such tools are a mimetic copy of some sort of reality "out there":[220] to put it simply, they are rather effective and useful strategies for achieving a deeper orientation or manageability of the issues under exam (De Regt 2020). This is perhaps a consideration of simple common sense:[221] in the recent work just cited, it is rightly accompanied by an

218"Wheeler's poetic imagination – with its deep, almost philosophical questions such as How come the quantum? and How come existence? – combined with his engineering common sense that brought many of his lofty ideas down to earth was his trademark way of doing physics. This is his enduring legacy: Do not be afraid to think big, but make sure that in the end you have a blueprint for an experiment" (Misnet et al. 2009, p. 46).

219We may simply give a different meaning to "intuitive" as well: instead of considering it in a loosely Kantian way, anchored to space and time, we may just refer it to getting insights on the physical content of formulae – similarly to the move made by Heisenberg in the *Anschaulichkeit* debate. "We believe we understand the physical content of a theory [intuitively] when we can see its qualitative experimental consequences in all simple cases and when at the same time we have checked that the application of the theory never contains inner contradictions" (Heisenberg 1927, p. 172), according to the English translation that can be found in and – even more significantly – was made by (Wheeler, Zurek 1983, p. 62). This passage can be usefully kept in mind when thinking about Wheeler and the "mental simulations" of physical phenomena that he wanted.

220For some discussion in the Anglophone area, see e.g. (Kaiser 2000). Setting the various positions aside, the choice of speaking of "superstition" in the sentence above is simple and radical – it is directed against any attitude that forgets how those pictures are man-made and takes them instead as some sort of *acheiropoieta*. See Appendix B.

221It is nonetheless a form of "common sense" that may also lead to asking historical questions about (conceptual) practices all too often taken for granted. The genesis,

emphasis on the need to actually acquire skills in order to master and employ such visualization techniques. Indeed, when Wheeler or whoever else treated the atomic nucleus according to the liquid drop model, for example, he was resorting to an evocative picture, an analogy that emphasized certain features and so on, but that admittedly was also an approximation. In other words, in dealing with specific problems and related equations, one needs as much technical expertise (at least in analogous situations) as a good or decent deal of awareness and sagacity in making approximations that are useful in those specific circumstances: while neglecting certain aspects, not too many relevant details should be sacrificed, so that, overall, there is a gain in understanding. The vagueness of "not too many" and "relevant" is, of course, linked to the fact that there is no universal recipe. Even when visualization tools become standardized and widely used (the obvious example for these ambits are Feynman diagrams), they nonetheless require practice and training to learn how to employ them. In all these senses, skills must be acquired to make use of visualization, which is not always something obvious that simply emerges from a theory once its "basic ingredients" get displayed and schematized (as fashionable in some trends of philosophy of science), especially in areas where any naïve or pseudo-photographic sense of visualization proves inadequate. The various engineering traits mentioned above, even if not logically linked to the topics Wheeler would work on, can be counted among the "skills" he acquired and be considered functional to his aspiration to always have some sort of imagery.[222]

Wheeler's first prominent results, such as those on nuclear fission, proved to be of considerable importance, during World War II, in the military applications whose possibility recent nuclear physics had opened up. However, if in the case of Tomonaga, Schwinger or Feynman, that is the main future originators (along with the aforementioned Dyson) of quantum electrodynamics, the practical and engineering experience they had during that

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dissemination, canonization, persistence, and subtle metamorphosis of visualizing techniques are not secondary subjects, just to be left to the historian's meticulousness; the training they require does not take place outside of space and time, either.

222 In Wheeler's use of pictures, nonetheless, it is easy - but also important - to distinguish (as we have already remarked in slightly different terms and as we are explaining *in itinere*) between (1) actual theoretical tools, such as Feynman diagrams or Wheeler's early use of Regge calculus (Wheeler 1964, pp. 467-ff.), (2) "mental simulations" of physical processes (such as stellar collapse), on the basis of some theoretical treatment, and (3) evocative illustrations that just try to capture or suggest some fundamental trait of Wheeler's speculations, as if they were indeed a visual slogan (e.g. the U-with-an-eye picture for the observer-participator). Speaking of Regge and Wheeler's mental simulations, in physics folklore there is a story about Wheeler writing a paper with blank spaces and then giving it to Regge as a sort of questionnaire to be filled out with appropriate mathematics. Is it just a legend? Not at all: in Relativity Notebook 4, p. 139, there is actually the "skeleton draft" (Wheeler's expression) he sent Regge.

period familiarized them with mathematical techniques that would later be important for their theoretical work,[223] in Wheeler's case it is not easy to put the finger on anything specific that would prove decisive for him later on. That was partly because his military involvement was not limited to that exceptional period, unlike the other figures mentioned, but continued intensively in the following years, given his belief about the Soviet threat and the need to develop hydrogen bombs. It was in the context of such tasks, however, that Wheeler had the opportunity to gain further experience and come into contact with personalities with one foot in engineering and one in physics, who would prove to be of great importance in his later research in a seemingly distant field: general relativity.[224]

In another interview, Wheeler recounts how this reorientation of his interests towards general relativity came about:

> "I can remember coming back from the first hydrogen bomb test in the Pacific at Eniwetok on an airplane. And then I came to Honolulu, was there a few hours, and at that moment a tidal wave came – which had nothing to do with the hydrogen bomb, it had to do with the great earthquake in Kamchatka. But I thought how small the efforts of man are. Even the biggest explosion that the United States ever made, which my group at Princeton did the design work for – working for and with Los Alamos – even that greatest explosion was a thousand times smaller in energy than the energy of a hurricane, a thousand times smaller than the energy of an earthquake. And then I could not help thinking of the big bang and the expansion of the universe so much larger, and as one flies over the infinite distances of the Pacific ocean suspended between the heaven above and the ocean below, one feels he is somewhere in the space between the stars like man's position in the universe, and one realizes what great mysteries surround us. One asks himself, how can I

223(Schweber 1994; Galison 1998); corrections and clarifications can be found in (Blum 2017; Wüthrich 2018; Ito 2017).

224Nonetheless, it can be said that Wheeler's involvement in understanding the process of nuclear fission and its consequent technical possibilities, with the epochal fallout they had, also offered him a constant topic of reflection in years to come. See Appendix A. Wheeler repeatedly availed himself of tentative and quite unexpected analogies between topology (while thinking of general relativity!) and the fission of nuclei (Wheeler 1968c, p. 263), for instance, but also meditated on the decisive events of those years on a historical and personal basis. On another level, it really seems that Wheeler's military projects put him in "trading zones", partly due to the notions he came in touch with, partly due to the people he was able to recruit or work with, even outside of that context (another example is his interaction with Martin Kruskal). Similar considerations about Wheeler's intertwinement of physics and military matters in the immediate postwar period can be found in (Galison 1997, pp. 264-271) (these pages, incidentally, were brought to Wheeler's own attention: a photocopy of them is preserved in box 198 of Wheeler's archive, American Philosophical Society Library, Philadelphia).

> get at the heart of this mystery of the universe. And I've never seen a more central place to get at the heart of this mystery than gravitational collapse" (Bicak 2009, p. 681).

With respect to what actually occurred in the immediately following years, this recollection is, in part, both a simplification and an anticipation, as we can judge from the story reconstructed in Chapters 2 and 3. In any case, there is no reason to doubt that explosions offered Wheeler matter for similar considerations: Tullio Regge, who on these very general-relativistic topics was soon to collaborate with Wheeler, once suggested half-jokingly that the latter's passion, if not obsession, with explosions was the actual "cause" of his participation in the Manhattan and Matterhorn projects (Regge 2012, p. 37). We also know from other sources (Sanger, Wolner 1995) that even a ballad of *Lom and the Bomb* circulated, in which "Johnny the Genie" made an appearance.

If Wheeler's mental associations in the quote above are quite unexpected, at least if one does not know him, we may add that, drawing an analogy with some pictures of underwater explosions, he started endorsing a model of a closed and cyclic universe (that is, one going through expansions and contractions as permitted, under certain conditions, by general relativity), which represented a guiding idea for him until the early 1970s. He had seen those pictures during a consulting period for the Convair company, where a design for nuclear-powered submarines, among other things, was being scrutinized (Blum, Furlan 2022, p. 302). Those two – underwater explosions and relativistic cosmology – are areas with no obvious connection to each other, to put it mildly, but that is, after all, the power that analogies and various inspirations can wield in the heuristics of someone as versatile and creative as Wheeler. Apart from these partly marginal considerations, it is now instructive to highlight some aspects of Wheeler's long struggle with the conceptual challenges that the still unnamed "black holes" posed to physicists in the 1950s.

3. The long road to black holes

As evidence of how Wheeler's various experiences were not set aside by him, but remained part of his repertoire even following his immersion in new fields, it is important to recall that the question of black holes was not approached by him in the way one might naively think by back-projecting today's standard teaching about the Schwarzschild solution and so on. His background as a nuclear physicist, as well as his confrontation with Oppenheimer-Volkoff's

and Oppenheimer-Snyder's results, led him to set the question primarily in terms of the fate of matter that, during gravitational collapse, is compressed beyond a certain threshold. In other words, in contrast to the paradoxical and hardly visualizable conclusions previously reached by Oppenheimer and collaborators, with a never-ending collapse and with masses becoming isolated from the rest of the universe while continuing to have a gravitational pull, Wheeler tried to set up and visualize the problem in terms of a many-nucleon system. We can find a peculiar *Gedankenexperiment* (for its context, see Chapter 3) in the proceedings of the 11th Solvay conference of '58 in Brussels, where Wheeler opposed the conclusions of Oppenheimer's preliminary investigations. Here we are not much interested in the technical details, but in the shape of the argument. As we have already seen, Wheeler wondered what might happen if, to a star (simply modeled as a sphere) that had reached the critical mass, another small mass is added. He considered the possibility that the added mass would not go to increase the star's mass, but would be radiated away in the form of energy. At this point,

> "If the limit $M = M_{crit}$ could be attained, one could operate in principle an idealized machine to manufacture matter at no cost in energy as follows: A gram of matter added to the sphere will give off its entire mass as radiation. A gram of antimatter added to a similar but remote critical sphere of antimatter will give off its entire mass as radiation. The radiant energy from both sources can be caught and used to create in the empty space far from the spheres another gram of matter, and another of antimatter, to be dropped on the two spheres to keep the process going" (Adams et al. 1958, p. 129).

Aside from the physics supposedly involved, which in any case had to go through major revisions later on, the curious aspect that we wish to emphasize here is how, in the midst of those exotic speculations, Wheeler suddenly introduced a "machine" connecting (in principle) the ordinary matter star and the analogous antimatter star. Or better: what is interesting is the form of the argumentation, resorting to such a machine in a quite similar way to that used in classical mechanics when one considers hypothetical situations that would allow for *perpetuum mobile* machines and thus reach a kind of *reductio ad absurdum,* as analyzed for instance in Mach's famous work on the history of mechanics (Mach 1883). However, the machine envisioned by Wheeler is actually a variation on that, since it would not be a *perpetuum mobile*

generator, but a device capable of creating matter *ad libitum* without energy cost – and there must be some process preventing that situation.[225]

Regardless of this thought experiment (quite vividly pictorial in character, we may notice), and however erroneous Wheeler's expectations and assumptions would later prove to be, such a way of approaching the problem had important merits, as we have already discussed. First of all, questions of nuclear physics thus became deeply intertwined with general relativity, which, after the spectacular early successes that had consecrated it, long remained in a kind of isolation from more recent developments in physics: an elegant theory untethered from other fields, left more to mathematicians than to physicists, who were engrossed in exploring the realms of quantum mechanics and quantum field theory. In this way, Wheeler brought new problems to general relativity – problems that students and collaborators could concretely work on – and he did not fail to involve other people in his quest, in accordance with his convivial vision of science. For instance, as we have already said in Chapter 2, he had Masami Wakano numerically explore, thanks to the computer wanted by von Neumann in Princeton,[226] the equation of state that Wheeler believed should govern stellar matter in the extreme stages of collapse; these results, to which the name of B. Kent Harrison should be added, were presented by Wheeler himself at the aforementioned Solvay conference (Adams et al. 1958). Like Fermi and, of course, von Neumann

225Speaking of hypothetical machines and black holes, Wheeler would later introduce with Ruffini the *term* "ergosphere" (Ruffini, Wheeler 1971b). Speaking of ergosphere, around the same time of the paper, in Relativity Notebook 18, p. 149, we can also find the following passage, which astutely makes a concrete comment on energy efficiency (even if, concretely speaking, we are dealing with a process that is close to science fiction…), then evokes frontier theoretical research, only to conclude by hinting at imminent experimental possibilities: "JOHN A. WHEELER'S STATEMENT TO TIME-LIFE ON THREE EXCITING DEVELOPMENTS OF 1970. Princeton student Denetrios Christodoulou this last year following up work of the year before by London University's Roger Penrose laid the foundation of a method to convert up to twenty nine percent of mass to energy. This contrasts to the one percent released by nuclear fission or fusion. This process draws on the energy stored in a stellar black hole formed by the complete gravitational collapse of a rotating star. Even better is a superstellar black hole formed by the amalgamation of a billion stars in the nucleus of a galaxy. A star coming into the sphere of action of such a black hole will give rise to mechanical and optical activity that should assist the intensive hunt row on to detect the first black hole" (Relativity Notebook 18, p. 149). This plurality of communicative levels (that is, of different kinds of people to address) was certainly a feature of Wheeler's *savoir-faire*, as we shall remark also in the conclusions. After all, just to give another example, even when it came to research in "pure" general relativity, Wheeler (more generally, that whole flourishing field) had been able to make leverage on military fundings related to hopes about "anti-gravitational" devices: see e.g. (Lalli 2017).

226"Von Neumann had the vision to see the great future potential of computers, and he set about designing one for the Institute for Advanced Study in Princeton" (Wheeler 2000, p. 209). The extent of Wheeler's engagement with von Neumann's ideas (even after the latter's premature death) is still waiting for a proper assessment; we will mention something more in Chapter 7.

himself, Wheeler had soon realized the potential of computers far beyond their military use: the one just mentioned is only an early example of a practice that, in the decades that followed, he would always foster, even to the point of developing, during the 1980s, audacious ideas about the epistemological shift in scientific activity brought by computers, both regarding visualization possibilities and the very meaning of the search for physical laws (Wheeler 1983b).[227]

Moreover, since the physical process at the center of Wheeler's reflections was stellar collapse (also related to supernovae explosions, of course), back in the late 1950s it was soon realized that some of the computer tools developed for the H-bomb project lent themselves to a rather easy re-functionalization to understand the violent final phases of stellar evolution. As we already know, an important colleague for Wheeler, but one which, in part because of the classified nature of his work, has not yet received worthy attention from historians, was Stirling Colgate, who, after electrotechnical and nuclear studies interspersed with some experience on merchant ships, met Wheeler in the context of the Matterhorn project and, in the late 1950s, decided to repurpose what he had developed by applying it not to bombs but to supernovae. Having Livermore Laboratory and its powerful calculator as his base, Colgate was soon joined by a number of collaborators with expertise in informatics, such as Richard White, who, also thanks to the assistance in physics provided by people from Wheeler's circle, over the course of a few years reached important results on supernovae and, already in the mid-1960s, on the formation of a black hole. We have already evaluated how Colgate and collaborators' achievements played a role in Wheeler's "conversion" to black holes. An interesting point to stress here, against "compartmentalized" accounts of the role of computation, is that the results reached via computer seem to have been gradually "merged" by Wheeler with the kind of mental simulation he was trying to build, using them as heuristic support or constraint (not strictly analytical: Colgate's first results were *not* implementing the kind of general relativistic treatment that would legitimize a "cautious" philosopher of science to draw inferences). It would be misleading to consider them, already back then, only as a self-standing sort of experiment *in silico*. They rather contributed to a "hybrid" heuristics, as we have detailed in Chapters 2 and 3.[228]

227In nuce, after being convinced of the statistical character of physical laws, Wheeler considered computer simulations of a large number of events as a way to see patterns and regularities on the screen.

228Curiously enough, partly similar considerations may be inspired by another episode related to early black hole research and tentative visualization ("visualization" now meant in a more concrete and ostensible sense), while trying somehow to show the invisible. When Jean-Pierre Luminet, in 1978, attempted to draw "realistically" the surroundings of a black hole, he

Another crucial factor, which further underscores the importance of visualization to Wheeler, was a deeper geometric understanding of the solutions of general relativity, accompanied by the development of a useful type of representations called embedding diagrams – the result obtained by Beckedorff under Misner's guidance, of course. Progress in various directions was being made in Wheeler's own circle: that was not a coincidence or a stroke of luck, but something which is also to the credit of Wheeler himself, who had first framed those problems or set those research directions, even against his own beliefs, and saw how to connect them to others. Wheeler became convinced even more of the importance of investing decisively in that issue and thus he brought from coast to coast – from Princeton to California – part of his own circle, so that those working at Livermore could be instructed and helped to implement a more adequate general-relativistic treatment in their computer programs.

There is another episode in those years which is at least worth mentioning,[229] as it shows once again the intertwining of Wheeler's frontier explorations and his collaboration with more engineering-minded figures: it is the case of gravitational waves. To put it simply, in light of Wheeler's geometrodynamical picture, which was considering space and thus its perturbations almost as a substance, he was persuaded of the existence of such waves and urged Joseph Weber, who had studied engineering and had some experience in the navy, to embark on their search. Weber, as is quite well known, devised detectors that gave signals convincing him to have found something, although that appeared in the eyes of many to be controversial; in those years, moreover, the very possibility of gravitational waves was not ground for universal theoretical agreement yet. Weber did not give up and persevered for a long time and with some understandable bitterness, which perhaps only the recent confirmation, in 2015, of gravitational waves could have partly alleviated – but he had long since passed away. Wheeler, in turn, certainly did not change his mind and continued to encourage him; he would later confess: "I sometimes ask myself whether I imbued in Weber too great an enthusiasm for such a monumentally difficult task" (Wheeler 2000, p. 258).

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did not have a computer simply running a simulation and giving a picture as output. "The drawing was made at the time that numerical simulations were done by 'punched cards, and no visualization device was available, so that I had to produce the final image by hand from numerical data.' After performing a series of calculations by hand and writing the computer program on punched cards on an IBM 7040 computer, Luminet obtained rough illustrations from a drawing device available with the machine, and then began the stages of drawing" (Skulberg, Sparre 2023, p. 397).

229 That would undoubtedly deserve a specific and extended work: the fact that there is none, despite much talk in recent times about gravitational waves, is quite eloquent about the "mindset" prevalent in these areas, still polarized between a substantially anti-historical focus on physical content and a form of sociologism that waters down individuals – with their peculiar heuristic paths – into anodyne collectivities.

4. It from bit?

As we have seen, in the early 1970s Wheeler – by then in his sixties – realized, partly because of what he considered the conceptual implications of black holes for cosmic order, that his geometrodynamics could not aspire to have the final word about the universe: his pangeometric program, even in its most ambitious and visionary form, was lacking. Now more than ever he radically felt "uncomfortable within the bounds of space and time", to recall the epigraph of the present chapter. Trying to dig deeper, Wheeler renewed his meditation on Bohr's lessons and the foundations of quantum physics. The direction he took at first was highly speculative and certainly problematic: as we have sketched in Chapter 4, Wheeler, in some ways pushing the "Kopenhagener" dichotomy between observer and observed system to the extreme (the whole universe is under observation), and in others distorting and ontologizing it, he assigned to the observer not only a perturbative or, said otherwise, "participatory" effect, but a cosmological – indeed, cosmogonic – role. This overlapped with anthropic considerations inspired by one of his Princeton colleagues, Robert Dicke, as well as by discussions with Brandon Carter (to whom the expression "anthropic principle" is usually attributed).[230] Wheeler's cosmology itself changed: he abandoned the previous cyclic vision inspired – *inter alia* – by submarine explosions, as we have seen, and tried to conceptualize the strange loop by which only a universe capable of generating an observer could come into being, thanks to the same observer performing acts of measurement and giving "reality" to the universe, for instance even influencing photons emitted billions of years before (Wheeler 1986a, p. 309). There is of course room for endless discussion about all these terms, but, setting aside the most speculative aspects, it is noteworthy that Wheeler's thinking took such a turn due to a quite strong new conviction of his: since general relativity – and the "philosophical" outlook that accompanied geometrodynamics – proved inadequate to fulfill Wheeler's vision, perhaps there was no "central mechanism" of the universe at all, working on its own behind a glass for us to behold (Wheeler 1973). In a sense, Wheeler was thus abandoning not only a naïvely naturalistic mindset, as we have already underscored in the previous chapter, but also what he had been looking for in the previous decades, driven by his thirst to visualize the nexuses of the universe and how they "objectively" work, like the pictures of mechanisms that impressed him as a child. The place of the central machinery was to be taken by the observer-participator, as much as the recovery of known physics

230See also (Blum, Furlan 2022).

from that could actually entail some still-unthought "mechanism", in a broader sense,[231] capable of accounting for the observer's role. Wheeler would look for hints about it for the rest of his life: the *metaphor* of the "circuit" (Wheeler 1986a) took the place of any "foundation" at some alleged basis, which is another way of referring to the strange loop (the "Leibniz logic loop" we discussed in Chapter 4) of the observer and the universe.

During all the years Wheeler had left to live, he never formally disavowed the new ideas he developed at this stage; it is evident, however, that, already by the end of the 1970s, there was a shift in emphasis and even a recovery of a greater sobriety ("sobriety" that is, however, somewhat relative, given his character and style). The reasons for this are complex, but among them we can certainly count the fact that Wheeler, in the mid-1970s, retired from Princeton and moved to Texas: in that new environment, with all the resources he had at his disposal, Wheeler began to deal with the foundations of quantum mechanics in a more concrete manner (if one can call it that), paying attention to the preparation of experiments and the preconditions of physical knowledge. Thus he headed toward his last phase, which can be placed under the aegis of *it from bit*, another extremely visionary and speculative idea, which however, by placing some notion of information at a more fundamental level than "things" themselves, proved particularly fruitful and inspiring in the Texas *milieu*. Clearly, if we just put it like that, it may seem as if he merely replaced a series of speculations with another. However, what is important to stress is that his notion of information was developed out of specific physical issues he had long been working on, as well as philosophical suggestions and a growing interest in the work on communicative channels by broadminded engineers. Among the latter, we can name John R. Pierce (with whom he interacted quite extensively also due to their common involvement in the Battelle Memorial Institute, which, not by chance, used to focus on applied science and technology) or IBM-related theorists such as Charles H. Bennett or Rolf Landauer, who were not just considering "information" in the abstract, but in specific physical settings and with related limitations (see Chapter 7). In front of this new metamorphosis of Wheeler's outlook, we can just remark that it was no small feat, for a septuagenarian, to be able to renew himself once again and to keep trying to look into the future further than others, while offering fruitful suggestions.

One aspect, however, that is punctually misunderstood, partly because of Wheeler's exuberant rhetoric and variety of parallel suggestions[232] and partly because of the lack of an adequate historical-epistemological perspective on

231 With some Darwinian inspiration, too: Wheeler would repeatedly use the expression "higgledy-piggledy", borrowing the expression Herschel used after reading *The Origin of Species*. See e.g. (Wheeler 1978, p. 3; 7; 79).

such matters, is how the reflections of this last period should *not* be interpreted according to the usual "naturalistic" scheme, in which the fundamental ingredients of the world are given "out there", *sic et simpliciter*. Circuit, not foundation! Wheeler, in his last phase, was not merely changing his "guess" about those allegedly fundamental constituents, as if he had first tried with particles, then with fields, and now with some abstract notion of "information". Apart from pointing out that "information" can be – and has been – interpreted both in a more reified way or, in continuity with Wheeler's earlier positions on the role of the observer, with "idealistic" overtones, *ex parte subiecti* so to say,[233] I would suggest that the naïve realism vs. idealism dichotomy does not properly represent the theoretical alternatives at the heart of Wheeler's interests and considerations. As a matter of fact, all that, besides offering a mere repetition of worn-out philosophical debates, would once again entail, in both cases, an overly "theoreticist" view of science, in which the experimental component plays at most a verification role or something similar. Wheeler's new ideas were very distant from that and, as we shall see in a moment, displayed in a new fashion that sort of engineering-like inclination that we have been emphasizing in these pages. He did so by embedding his research on the deeper roots of quantum physics in an on-going meditation about the preconditions of our physical knowledge, the meaning of measurement, and the role of experimental set-ups (Wheeler, Zurek 1983). It is interesting to notice also how, in one occasion, Wheeler (1978, pp. 162-165), *after* having considered and dismissed the quantum views of his former student Everett, went back to a conversation with him and recalled his modeling of the observer as "servomechanism, or – if I may go beyond Everett in explicitness – the computer of an aircraft gun" (*ibidem*, p. 162), then spoke of radars, detected enemy planes, computers, and their memories. All that in order to get insights about the "[r]ole of the memory in linking observation with action symbolically represented" (*ibidem*, p. 164) and the meaning of "now". The Cold War background of such considerations is simply evident, as well as its links to Wheeler's and Everett's interests during the 1950s and in subsequent years. What in that long text – the series of lectures that Wheeler gave in Varenna in 1977, when he announced "law without law" – is remarkable is that it also discusses Bohr's views on quantum mechanics in relation to the computer technology that had been developed in the meanwhile (*ibidem*, pp. 20-ff.): it is as if Wheeler, in his search for the actual core of quantum physics, was not just considering various theoretical options, but also

232One may just take a look at (Wheeler 1980a) or (Wheeler 1990) to get a sense of what I mean.

233If the former case is exemplified by many Wheeler-inspired "it from qubit" slogans, the latter is the case of the QBism of Fuchs. We shall return to these "complementary" outcomes of Wheeler's suggestions in Chapter 7.

relating them to their technological background – of course, not as a historical study *per se*, but in order to reveal something as some sort of mere contingency, or to use new tools to get further insights. Nonetheless, perceiving *in nuce* the very possibility of discussing and studying quantum foundations in relation to the changing technological background could be an original and intriguing perspective also for the philosopher or the historian.

But let us go back to information: *it from bit* has thus not to be taken as the "assertion" that, somehow, everything consists of ontologized bits, perhaps in their qubit version. That would be a form of naïve naturalism with the concept of information at its basis – a concept which is at the very least problematic when taken so radically and, moreover, liable to idealistic interpretations, as already mentioned. To positively state what *it from bit* is about, however, has repeatedly proved tricky and ambiguous in Wheeler's own writings (but that is also why he has been able to inspire so many people with different aims and assumptions). First of all, we should add, with a typically Bohrian-Wheelerian maieutic attitude, a question mark after the phrase "it from bit": not only to signal the tentative character of these ideas, but also the active, constitutive, participatory role of the questioner-observer. The simplest experimental situation conceived by Wheeler was that of a quantum system offering just a binary answer to a measurement question: hence the suggestion of a fundamental binarity or bit. This is not surprising, but, even before that, we have to recognize what in Wheeler's eyes was the *result* of his explorations over the previous years: the participatory role of the observer and the priority of the quantum character of nature even over space and time (that is, the latter are considered, in some sense, dynamically emergent). Bits are produced, or perhaps better are the result of observer-participancy: they are not simply given, as we already underscored in the previous chapter. The "novelty" in this new phase of Wheeler's thought is twofold.

First, it was a matter of fully recognizing the role of the experimental set-up, thus moving away from the conscientialist drifts, so to speak, of his friend Wigner (often oversimplified and summarized by saying that it is "consciousness" that makes the wave function collapse).[234] At this point, Wheeler more firmly recognize the pivotal role of the experimental apparatus and of the preparation of the experiment itself, with the subtle tradeoff of constraints it imposes and possibilities it leaves open. The central focus was no longer the observer as such, whatever that meant (was the observer supposed to be human? Or just in some sense conscious, intelligent? Wheeler had previously left it ambiguous): we may even say that he started emphasizing the "agency" of the experimental set-up – a theme that has been

234In Chapter 7 we are going to discuss and clarify the interactions between Wheeler and Wigner.

underscored for years in historical epistemology.[235] At this point, there is clearly no question of assuming a sharp and naïvely assumed dichotomy between subject and object of knowledge, statically given once and for all, and then attempting to dissolve the subject into the object or *vice versa*, depending on how one wants to (mis)understand *it from bit*. Indeed, the key role now assigned to the experimental apparatus points in the opposite direction to caricatured idealistic positions. Instead, it is that "impure" interplay between theory and experimental exploration that breaks new ground or discloses, to echo Galileo's famous eulogy of the Venetian Arsenal, a "largo campo di filosofare".[236] Wheeler's merit, in this late phase, was to recover a fruitful interaction of theoretical speculation with actual practices and techniques. The result is quite different from pure speculations as well as from simplistic pictures of engineering and technological aspects that either depict them as a banausic end in itself, or minimize their conceptual role.[237]

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235 The following words from (Rheinberger 2021, pp. 86-89) may offer a perhaps unexpected but insightful commentary: "Experimental systems can be seen as the actual and actualizing technical setups for things of epistemic interest, for objects to become constituted as epistemic entities at all. A context of this kind is needed in order to endow an object with the very character of a thing of knowledge. For the experimenter, this context presents itself primarily as an instrumental one, as a necessary condition of manipulation. At a second look, however, one realizes that this context always consists already of what can be called "sedimented" knowledge, taking up an expression of Edmund Husserl. Research technologies are materialized knowledge environments. […] Setting up an experimental system revolving around an epistemic object and exploring some of the inexhaustible aspects of its thingness means to undercut the traditional subject-object relation in the sense of a face-to-face relation between an observer and something being observed. In an experiment, the act of observing is mediated by a technical arrangement of sorts that one brings into interaction with the epistemic object. […] Experimenters are specialists in creating situations in which such finding becomes possible. The movement of finding in science neither obeys the logic of mere chance nor that of pure necessity. It obeys a logic of its own, composed of elements of both, and in so doing, undercuts the stochastic rigor of the former *and* the deterministic rigor of the latter. It is a peculiar engagement with the material world that, on the one hand, requires intimacy with the matter at hand, and on the other, disentanglement, the capacity of *Verfremdung*".

236 Cf. also (Steinle 2016) and his notion of "exploratory experiments", *contra* ways of conceiving experiments as mere fact-checkers or tests for pre-formed mental pictures. "Si, dans une expérience, on ne joue pas sa raison, celle expérience ne vaut pas la peine d'être tentée", as Bachelard (1936) put it.

237 "Let us turn for illustration to the humblest 'seeker of the wider view' of them all, a most improbable person, the countryside driller of wells. He is no geologist, but he knows something of geology, the folds and strata of the local rock, which are porous and which are not. He is no historian, but he knows enough of the history of wells drilled in his county to know which were dry and which gave water; what their depths were, and what their yields. He is no reader of Einstein, but what Einstein told us of his search for the laws of nature the well driller knows from his own seeking for the right places for his wells: 'There is no logical path leading to [them]. They can only be reached by intuition based upon something like an intellectual love of the objects of experience'" (Wheeler 1980c, p. 188). Against abstract and oversimplified pictures of scientific knowledge (the *epistemologia imaginabilis* attacked and dismissed by Ludwik Fleck), it is worth stressing once again how the visionary John Wheeler,

Second – and this was the most interesting and daring move – Wheeler, after discarding the primary role of consciousness (Wheeler 1981), actually extended, in some sense, the notion itself of set-up: the role of the observer could be played not only by experimental equipment as usually understood, but by much more. For instance, Wheeler conjectured (Misner et al. 1973, pp. 1214-1217), even the so-called "elementary" particles in primordial stages of the universe, prior to their stabilization with the properties currently known to us, may be considered "viewpoints" capable of encapsulating information about their environment and bearing traces of its physical processes – similarly to rocks that allow us to understand the dynamics and phenomena that shaped them in remote ages.[238] The expression "point of view" is not accidental here, for these Wheelerian reflections are inspired by a bold and highly original reinterpretation of Leibnizian monadology, as we have discussed in the previous chapter: this is another exquisite example of how Wheeler knew how to combine wild and idiosyncratic speculations with current research problems.[239] Bits, monads, and a participatory cosmos: it should not be necessary to point out that, if we scratch their somewhat bizarre surface, these reflections are of greater complexity than a sensationalistic and rather crass naïveté of the type "our universe is a quantum computer", which was already discussed with due caution and critical awareness in (Wheeler 1982a). At this point, if anything capable of amplification and recording can be seen as a "participant" probe that interacts with its environment, what

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the very same "prophet" of black holes, quantum gravity or *it from bit*, could write something like the passage above. We shall return to Wheeler's notion of the "seeker" in the next chapter, but here we could mention that the paper from which we have just quoted contains various engineering-like examples, and the reference to Einstein also reflects the latter's ability (in Wheeler's eyes) to combine a practical-engineering dimension (at the patent office) with a theoretical one: "Day after day, Einstein had to distill the central lesson out of objects of the greatest variety. Who knows a greater way to learn what physics is and how it works? It is no wonder that Einstein always delighted in the machinery of the world – from the actions of a compass to the meandering of a river" (Wheeler 1979g, p. 67).

238Although this may seem like a fanciful suggestion, it is quite in line with what Wheeler had already been proposing for a couple of decades – since the early days of his geometrodynamics – about how the so-called elementary particles would perhaps be considered in the future. As much as Wheeler was then quite outside of the "mainstream" research that flowed into the Standard Model, the idea of considering certain properties, such as mass, not as a characteristic intrinsic to the particle (given once and for all), but dynamically generated, later became widespread and ended up pointing in a direction similar to his. Something analogous can be said, to some extent, of more recent attempts to account, in a deeper and unified way, for the various properties of "elementary" particles: the unexplained values of some property are thus not only an *explanandum*, but possibly also a hint, a trace of primordial processes.

239In other words, monadology, albeit creatively transfigured, helped serve as a scaffold in the heuristic path that led Wheeler from the cosmogonic observer to ideas close to that of "quantum decoherence", as developed, in part, by physicists in his circle or in contact with him during the 1980s.

seems to matter in the quantum process, with its observer/observed dichotomy, is a sort of co-constitutive relationality.[240] If, therefore, we follow Wheeler's expanded (even if admittedly quite vague) perspective on what can in principle serve as a probe, we also realize that the distinction between technology or experimental apparatus and nature is ultimately ungrounded. Likewise, to speak of natural contemplation, pure science or engineering seems in this view to be more a matter of nuance or degree, rather than a set of genuine distinctions.[241] This, more or less implicitly, was not only reflected in the late Wheeler's marked transdisciplinarity, but had long been an integral part of his views on scientific activity,[242] as will be reiterated in the next section.

5. Toward the Future

We shall now briefly examine a speech that Wheeler gave in Caracas, at the centenary congress of the *Colegio de Ingenieros de Venezuela* in October 1961: *Leadership in Engineering Science and the Shape of Our Future*. The text is published in Spanish translation (Wheeler 1962b), but the original English version, which Wheeler sent to Oppenheimer, can be read in the latter's archives in Washington DC. It is not clear, at least in the light of the documents that it has so far been possible to examine, what the actual circumstances of Wheeler's participation in that event were: perhaps some sort of role as a Princeton representative, as the exchange with Oppenheimer, back then director of the Institute for Advanced Study (and not exactly Wheeler's favorite interlocutor), may suggest. It is a speech that, presumably, had a considerable effect on the audience: it represents a good example of Wheeler's peculiar rhetoric, which, in hindsight and with some historical detachment, may now look like a curiosity with some flamboyant traits, but is actually more interesting (and telling) than the not-so-original "philosophical" outlook about technology that is implicit in the text. Thanks to what we have examined in the previous pages, we are in a position to better grasp and contextualize those aspects.

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240 As is quite well-known, that is an idea developed by others in more recent times and in more conventional fashions, though sometimes seasoned with *Indian spices* for the general public.

241 Abstractly blurring these distinctions does not seem *per se* an insightful operation (as much as quite fashionable), but, if we also examine the actual historical articulations and shifts of such boundaries, we can at least have a useful tool to dispute essentialist and a-historical dichotomies of the type "man and technology" or "physis kai techne".

242 That, of course, does not mean that Wheeler's views on science and technology did not change: see Chapter 7 for further details, which do not compromise our reasoning here.

The whole text vibrates with enthusiasm for "science", which often forms a sort of hendiadys with "engineering";[243] it is the same engaging excitement that made so many of Wheeler's students feel involved in a grand collective enterprise. An inspiration, a confidence, an *élan* that may well be described as Baconian are readily recognizable, and Wheeler himself titles a section *The Attitude of Hope that Goes with Engineering and Science*: that is a hope pragmatically and virtuously self-sustaining thanks to past and present successes.[244] Besides this, there are, nevertheless, also peculiarities that deserve some further attention. Science, open to all, spreads by contagion – Wheeler writes – and has indeed an infectious quality: undoubtedly his style of disseminating it was particularly efficient, but also different from the usual trumpeting that accompanies the march of progress ("le magnifiche sorti e progressive", as Giacomo Leopardi sarcastically called them), only looking boorishly forward. Wheeler also knew to look at the past and draw from it: his message and its form are not mere rhetoric, in the verbose sense of the word, but a *sui generis* mixture of historical pathos and visionary ideas, evoking a grand narrative that flows from other ages (whose legacy is by no means dismissed as obsolete or entirely archived) and gets enriched by the enormous legacy left by Wheeler's inspirational figures, primarily Einstein and Bohr. The whole thing gets then amalgamated by Wheeler's own personal experience, memories, and prestige. This is how his powerful visions were firmly rooted; his effective and fascinating metaphors, in turn, contributed to make such evocations seem within reach in a nearby future, filled with new fruits that were finally ripe and hanging from the branches of the great developments of 20th-century science. In Wheeler's eyes, this future, thus well-grounded, appears, in general, potentially better and better, thanks to the impact of the new and imminent achievements that will affect society at large.[245] The predictions for the following years, however, were not just concerned with almost-immediate practical consequences: among them, for instance, we can find, in assertive terms, the discovery of gravitational waves (the reader may recall what was mentioned above about J. Weber), which, however, would still have to wait for more than half a century. The reason for pointing this out is not, of course, to make some trivial hindsight assessments

243It is not a mystery, after all, that positivist ideas were impactful in 19th-century South America (see e.g. Hurtado 2008) and the institutionalization of *colegios de ingenieros* bore traces of that, obviously. While Wheeler's outlook, as expressed in this speech, is resonant with that legacy, it would be misleading to attribute such views to him *tout court*.

244"That every mystery can be unveiled is not of course a theorem to be established by logic, but an article of faith, to be justified by its consequences" (Wheeler 1956, p. 362).

245Not surprisingly, we can also find later (1973) expressions of interest in Peter Medawar's "meliorism" (John A. Wheeler Papers, American Philosophical Society Library, Philadelphia, box 17).

of what occurred as expected and what did not: it is rather to note how, even in the circumstances of a speech and audience such as those in Caracas, Wheeler's vision powerfully intertwined frontier research, engineering, and all the various aspects that we have already discussed.

In conclusion, it may well be said that here we see "Wheeler at his best, a man in love with science and intoxicated with the mystery of the universe" (Dyson 1974, p. 1161), but also that personality whom "politicians, government managers, and business executives […] seemed to regard […] as a solid scientist (in truth, they would probably say brilliant scientist) but with a practical head that was screwed on right" (Wheeler 2000, p. 277).[246] The form of "leadership" invoked by the title itself of the speech is not to be trivially understood in a corporatist or motivationalist sense, but rather refers to a distinction with which Wheeler concludes, that between light and heavy intellectuals, "between those who keep the world going, and those who move the world ahead", adding with a *captatio benevolentiae* that he regarded those in Caracas as "leaders among the heavy intellectuals" of a great nation.[247] That, however, should not be confused with a positivist or scientistic vision on the model of the distinction between "hard" and "soft" sciences: it is rather about coming up with powerful guiding ideas that can make people take

246It might be stimulating to compare Wheeler's considerations and attitude with those of Hendrik Casimir, who quite famously spoke of the "science-technology spiral" (Casimir 1983). Incidentally, we may mention that they both had ties with Bohr; both had been reflecting in original ways about the vacuum and its quantum fluctuations; and in Wheeler's archives there are folders that testify to to some interest in Casimir's work (and recollections, within the context of the project "Sources for History of Quantum Physics", which Wheeler had contributed to set in motion). At the very end of Wheeler's Relativity Notebook 4 there is a cartoon possibly mocking, in the spirit of the Copenhagen "jocular physics", Wheeler's idea of wormhole; its caption says: "After Casimir 10 June 1956 at Beekbergen". Indeed, back then Wheeler was Lorentz professor in Leiden (some further insights on the Dutch context he came in touch with may be gained by looking at (Baneke 2011); in that same period, however, Casimir became a member of the board of directors of the Philips company, gradually getting away from the frontiers of theoretical physics research. Even if he did not abandon his interests, that was a kind of experience quite different from Wheeler's manifold activities at the same time. Moreover, Wheeler, in the early 1970s (John A. Wheeler Papers, box 6, folder Casimir), also took notice that Casimir was urging scientists to desist from military work. Nonetheless, their meditations drawing upon the variety of such experiences may still be compared - of course, Wheeler definitely seems more enthusiastic and optimistic, in general, but that is not really the point here, nor the whole story. Besides the Venezuela talk, Wheeler, around the period he moved to Texas (1976), also gave an unpublished speech about *Physics and Industry*, that can be read in his Philadelphia archive together with another manuscript titled *Science and Industry* (boxes 79 and 187, respectively).

247In another little-known speech by Wheeler, at the Sino-American Conference on Intellectual Collaboration held at the University of Washington in July 1960 (Wheeler 1962c), he resorted to the same categories, which evidently belonged to his diplomatic vision at that time. Wheeler's involvement in such events, as well as his reflections on them, may certainly offer some material to "science and diplomacy" studies, in addition to what has been treated in (Lalli 2017).

action.[248] Leadership, then, is inextricably intertwined with the kind of foresight and breadth of horizons of which Wheeler himself was offering a glaring example. Nowadays, when on the one hand there seems to be much confusion and uncertainty about what is "culture" (besides its anthropological sense) and, on the other, a closed or self-satisfied attitude in one's own small area of specialization seems perfectly normal and legitimate, Wheeler's exhortation can still resonate as a challenge, just as his whole story is capable of providing a fruitful opportunity for reflection. From his words there seems to be little doubt about the scientific and cultural value to be assigned to engineering as well. The problem, today perhaps more than then, remains that of developing an integrated vision that lives up to it. Hopefully, stories such as this can provide us with cogent and all-around accounts of how different dimensions of knowledge and its practices interact in synergistic ways.

248Of course, not just as a crowd instigator, but by being pragmatically able to take into account scientific developments and their repercussions. In 1982, in a speech titled *Dealing with Risk* (John A. Wheeler Papers, box 78), Wheeler evoked the figure of the "statesman-engineer" who has this pragmatic ability – but he also promptly specified that "engineer" was to be taken in a broad, non-technical sense: he was not projecting the ideal of some technical government.

6. A Seeker in the Atomic Age

More than once we have alluded to a dimension of research that transcends institutional and disciplinary boundaries. In this chapter, we are going to re-read Wheeler's intellectual trajectory, and his dialogues with thinkers and texts of various ages and cultures, in the light of his own notion of the "seeker". In doing so, we are also going to clarify his relationship with religion and gain better insights into the new worldview he was trying to develop: that of a "universe as home for man".

Weil er überall Wege sieht, steht er selber immer am Kreuzweg.
– Benjamin, *Der destruktive Charakter*

1. Introduction

"I am become Death, the destroyer of worlds": this is the line from the *Bhagavad Gita* that famously came to Oppenheimer's mind when he witnessed the first successful nuclear test. As such, it may be taken as epitomizing the actual beginning of the Atomic Age.[249] Here, however, we will not be talking mainly about Oppenheimer, but about another figure, a very different one, who had many contacts with him, not without tensions. This is John Wheeler, of course: the man who adopted the name of black holes and popularized them, thus releasing in a sense another picture of ultimate destruction into collective imagination. As we already know, a crucial role in this research about exotic astrophysical entities was actually played by Wheeler's military commitments in projects aimed at building atomic bombs and (here is already a tension with Oppenheimer, who was contrary) hydrogen bombs. Also inspired by those experiences – quite bizarre to say, but we have heard his own words in the previous chapter – Wheeler developed a grandiose cosmological vision that made him say, ideally replying somehow to Oppenheimer with a quote from the *Brahmavaivarta Purana*: "I have known the dreadful dissolution of the universe. I have seen all perish, again and again,

249 After all, Oppenheimer himself repeated the line various times, even in a "staged" way. This, coupled with some "high-brow" showing-off that other physicists perceived in his attitude and in that of his circle of imitators, led to some gross misunderstanding of the meaning of such a quote, easily fostered by ignorance about the source-text (the recent movie – 2023 – was far from helpful in this specific regard). For anyone who has read the *Bhagavad Gita*, the analogy that must have been felt by Oppenheimer between himself and Arjuna, faced with the task of fighting and annihilating his fellow kinsmen, should appear quite obvious; and yet, with very few exceptions such as (Hijiya 2000), the line keeps being repeated without any awareness of its meaning in that context.

at every cycle. At that terrible time, every single atom dissolves into the primal, pure waters of eternity, whence all originally arose" (Misner et al. 1973, p. 752).

Still, Wheeler was not going to stop there and a few years later, as we have previously discussed, he developed a new and more radical cosmological view that did without universal cycles. Many were the metamorphoses of his thought and, before such a variety, it is easy to get lost: indeed, even this very brief presentation has already alluded to many faces of Wheeler. Who was this man that, at the same time, could appear to some as a warmonger, but was almost unanimously characterized by his warm conviviality, to the point of befriending, still during the Cold War, his Soviet "counterparts" that were, not many years earlier, at the head of thermonuclear projects? The scientist that released black holes into collective imagination and, at the same time, spoke of the universe as "home for man"? A disciple of Einstein *and* of Bohr, in honor of whom he delivered a heartfelt speech on his pacifist vision,[250] shortly after being a leader of the Matterhorn project? A physicist who went digging into texts from every past age and culture, while flamboyantly proposing his by-any-standard-bold visions of the future? To resort to phrases such as "a man of contradictions" would be superficial and misleading; "multifaceted" risks being an empty word. As we have started to better realize, Wheeler represents a *challenge*, both to the biographical models in vogue for physicists (and more generally for actors in recent science) and to the common conceptual linearity of reconstruction of scientific thought, because of his multiplicity of contacts, routes, sources and inspirations, as well as the heuristic complexity of his attempts. Only then, having (for what is possible) a sort of synoptic view of his activities, can we establish a fruitful confrontation between a scientific journey and other spheres of human activity, without any simplistic slogan or schematizing.

Obviously, in this chapter we do not plan to deal (anew or again) with all the above-said aspects of Wheeler's life: nevertheless, we are going to retrace an important thread of his activities and ideas, which is also an interpretative key to the understanding of that deep research dimension which always accompanied him, going beyond the institutionalized world of academia and laboratories. We are going to try to capture this dimension through the figure of the "seeker", according to the nomenclature and the description provided by Wheeler himself (Wheeler 1979e; 1980c). On the one hand, some – such as (Kragh 1987) – have underlined (or even "accused" him of) a religious component in his ideas and proposals, but these are, as we will show, quite inadequate interpretations. On the other hand, referring, *sic et*

250That was when Bohr was awarded the 1957 Atoms for Peace Award. The text of Wheeler's speech was published a few years later, after Bohr's passing (Wheeler 1963c).

simpliciter, to Wheeler's commitment to the Unitarian Church (Wright 2014) could have misleading results as well, to say the least.

This being said, we are going to try to understand once again Wheeler *iuxta propria principia* and, in order to do so, the present chapter is structured as follows. In the next section, we are going to sketch what is meant by "seeker" and make a few caveats about the various sources invoked by him, as well as about the religious overtones that have been perceived or criticized by some. In section 3, we are going to take another look at the path that led Wheeler from his early-1950s lawful conception of nature to his mid-1970s vision of universal lawlessness. In section 4, we are going to highlight the lessons that Wheeler believed to have learned thanks to those two decades of research, and how a new phase of his career opened up in a way that resonates with the notion of seeker that we have introduced – in the sense of a research that transcends institutional and disciplinary boundaries – and that led him to confront himself, even more than before, with a variety of thinkers, both his contemporaries and from past ages. In section 5, we are going to consider an overview of Wheeler's renewed meditations, starting from the early 1970s, on the foundations of quantum physics, the role of the observer and anthropic-like viewpoints. In section 6 we are going to see his interest in biological issues and mention his little-known dialogue with Ilya Prigogine. In the conclusions, we are going to come full circle back to the broader considerations introduced in section 2.

2. "Seekers of the larger view"

How did Wheeler conceive his scientific vocation and activities?

> Of more concern to us here than the nature of atomic physics and the details of relativity has been the character of the men who brought us these two greatest principles of modern physics. We reflect on the spirit that animated them. We rejoice in the great tradition of "The Search for Eternal Truth" that we inherited from Europe. On that foundation this country builds today's science. […] Animating these men we see the spirit which goes back to a much earlier age and which is described nowhere better than by the great Dutch historian of the Middle Ages, Huizinga. He tells us how similar were the rites of initiation of the knight and the scholar. The knight-to-be, after going through all the stated trials, kept watch beside his armour through the hours of darkness to dawn and then took the pledge to defend right at the cost of life itself… The scholar, having probed one issue deeper

> than anyone before, took a stand on it and defended his thesis against all attacks from a distinguished board of examiners. No one has forgotten how Martin Luther, following in this great tradition, nailed his ninety-five theses to the door of the cathedral. Nobody will forget three great searchers after eternal truth, and the theses that they nailed to the door of the Cathedral of Science.

These words, a remarkable example of Wheeler's peculiarly flamboyant style, are the conclusion of a lecture given at Baker University, Kansas, in 1967 (Wheeler 1967, p. 28). The title, significantly, was *Seekers for Eternal Truth: Planck, Einstein, Bohr* and got published as part of a series of lectures gathered under the aegis of *Authentic Man Encounters God's Word*. If we add a piece of information such as the fact that Wheeler was a member of the Unitarian Church, and if we happen to see a few biblical quotes in his working notebooks, or some mention of "the good Lord", it may seem easy to make the case for John Wheeler as a man of faith, as happened in a work that we have already referenced. Unfortunately, however, this is misleading, superficial, and simply untenable once we read Wheeler's writings – even just the published ones – with more attention. As a matter of fact, such a way of dealing with Biblical "textual evidence", so to speak, could be easily ridiculed by remarking on how Wheeler also mentioned Confucius (Misner, Wheeler 1957, p. 525) and the Upanishads (*ibidem*, p. 536) or Allah (Wheeler 1982a, p. 563): does that mean that he converted in turn, when not at the same time, to Confucianism, Hinduism, and Islam? As for "the good Lord", clearly, Wheeler often used to refer half-ironically to some of Einstein's famous witticisms, as we have already seen in the '73 letter to Paul Cohen. In any case, even more importantly, let us listen to what Wheeler unequivocally says in his autobiography (Wheeler 2000, p. 153):

> Although I don't consider myself religious, churchgoing has been important to me during much of my life. There is something comforting about colleagueship based on shared values, and a good sermon stimulates my thinking - making me perhaps a better, more caring person. There are many modes of thinking about the world around us and our place in it. I like to consider all the angles from which we might gain perspective on our amazing universe and the nature of existence.

Besides the emphasis on colleagueship, which was a crucial component of Wheeler's way of conceiving and living his scientific activity as well (Wheeler 1966), this quote should make clear how we have to frame his

belonging to a "religious" community.[251] Furthermore, thanks to the last two sentences, we also gain a better interpretive framework to account for the variety of religious texts or experiences he used to refer to. As we have already anticipated in Chapter 1, it is important, in this regard, to realize that the "Unitarians" Wheeler was part of have little in common (except for the name) with the Unitarians Isaac Newton somehow belonged to, for instance. Wheeler's perspective is not concerned at all with a denial of the dogma of the Holy Trinity: rather, it is close to the Universalist Unitarians, with their emphasis on community, on rational inquiry, on the plurality of religious traditions and texts, all worth listening to.[252] Wheeler's ideas have no strictly Christian inspiration, nor any "Tao of physics" attitude. This has to be kept in mind in order to properly understand his quest and its "spiritual" dimension, and not to misinterpret the weight of his multifarious references.

Let us then return to the passage featuring the knight and the scholar: meaningful and powerful, it may nonetheless give rise to other misunderstandings, besides the religious one we have just treated. Again, it would be easy, perhaps with the seeming corroboration of some well-known biographical information (such as Wheeler's military work), to detect a sort of patriotism, accompanied by conservatism, Western-centrism, the use of masculine pronouns and role models. Once again, such a categorization would be superficially simplistic and distorting, and we have already touched upon these issues in Appendix A. But enough with defining Wheeler *via negationis,* for what he was not. As discussed in Chapter 1, that same passage, if contextualized within Wheeler's evolving thought and activities, is actually far more interesting and, at least among recent physicists, unusual. The first aspect is Wheeler's peculiar relation with the past, which did not represent for him an inert and dusty set of traces to be preserved in some archive, but an actual tradition he felt himself belonging to – a feeling that, by all accounts, he was very good at transmitting to his students as well (after all, that quote is about rituals of initiation, is it not?). This can be seen as a monumental use of history, as previously explained, but what is really interesting is that it did not just amount to a rhetorical pathos aimed at spurring people to try and perform some deeds. Wheeler's confrontation with the past was genuine and, very differently from scientistic superstitions about an always-increasing and automated progress that quickly makes everything obsolete in *all* areas, he constantly looked for personalities, ideas and theories that could offer some lesson, or had potentialities still waiting to be fully disclosed. The trivial

251As we shall see in the last sections, during the late phase of Wheeler's thought the notion of community entered even into his theoretical work, as a meaning-conferring community of observers-participators.

252See also what we have said in Chapter 1 about Wheeler's notebook of "Essays".

linearity of conventional disciplinary narratives gets thus shattered by analogies and inspirations provided by authors and scientists – "intracranial colleagues" (Wheeler 1979d) – from different ages and/or fields.

That is clearly a dimension of inquiry that transcends by definition the boundaries and the presentism of institutionalized research, but at the same time it is worth remarking that Wheeler managed to conjugate it with academia as well, in an effective way. We shall refer to this all-embracing dimension of research by using (following Wheeler himself) the word "seeker". He employed such label not only for eminent figures such as Einstein, Bohr, Planck, as we have already seen, or, outside of physics, Hutton, Darwin, Mendeleev (Wheeler 1979e), but also – if not *verbatim*, at least in substance – for contemporaries he deeply respected and in which he could see a deep intertwining of life and original ideas, such as Andrei D. Sakharov (Wheeler 1991a). Against any reduction of science to a set of problem-solving activities, at most "taylorized" with some degree of coordination, but without wider horizons in the background, Wheeler (1979e, p. 397) further characterizes the figure of the seeker in terms of a "triology of actions": "to rise to the larger view - and from that vantage point recognize what is missing, and fill the gap" (or, at least, attempt to do it). We may very well say that many of the transdisciplinary dialogues Wheeler tried to establish, especially from the 1970s on (for reasons that we have already discussed between Chapters 3 and 4, and that here we are going to refresh at the end of section 5), are attempts at building together or establishing a comparison between "larger views".

As already alluded to, one does not reach this stature just by the standard training of a given field, nor by simply performing – however efficiently – the tasks of a given job, separated from the "rest" of one's life. In the seeker (and in Wheeler's thought), overall, the strive "toward the whole human" (Wheeler 1986c) is simply evident.[253] Wheeler's may sound like naïve categories and the same goes for that "Search for Eternal Truth", since today everybody "knows" that scientific inquiry is always provisional, perfectible, etc. – but the actual naïveté, it seems to me, is once again of those who react automatically to a single expression, which gets decontextualized and thus loses its specific connotations. After all, we can safely assume that someone of the caliber of Wheeler knew about those commonplaces as well: it is perhaps better to avoid repeating them yet another time and, instead, to try and listen more subtly to

253"Join the two cultures into a single vibrant culture. Meld science and politics, in the highest sense of the word politics. Fuse the searching spirit of science with sensitivity to other humans, near and far. Make ourselves as fully at home with the world of values, loyalties and traditions as with the question-raising and question-setting ways of science and technology. Become, in brief, whole humans" (Wheeler 1986c, p. 7). To be compared with the conclusions of the present chapter, *infra*.

what he actually meant to convey. That is a way, also for the historian (or, more in general, the reader), to actually relate with the full-rounded complexity of a human being, instead of dealing with a strawman. We may also anticipate that the "exploitation" of the religious instinct of man reproached by Kragh (1987) to Wheeler cannot be treated without further contextual elements, which are going to appear especially in Sections 5-6. Keeping this in mind, these prolegomena seem necessary to properly understand what may have induced some people to develop perplexities, or reservations, about Wheeler's views, which, precisely because of their ambition and vastness, had touched upon topics resonant with "theological" matters (the scare quotes are actually his, as we shall see).

3. Far from the particle crowd: Wheeler's first "conversion"

At the beginning of the 1950s, in Princeton, Wheeler, turning forty, was enjoying a well-established career as a nuclear physicist and, more in general, as a well-connected figure among American physicists. He could boast his late-1930s work with Bohr on nuclear fission, crucial for subsequent developments during the war, and in the following decade, besides his active role in military issues, he had contributed, together with his student Feynman, to prepare the ground for the genesis of quantum electrodynamics (Blum, Brill 2020). Still, that was not enough for him: his ambitious attempts at building an all-encompassing picture of nature, based on a particle ontology that intended to get rid of the notion of field ("Everything is particles" was the slogan), seemed to be languishing; and new experimental results brought new challenges. In particular, the discovery of the pion in 1947 marked the beginning of the so-called "particle zoo", that is the proliferation of purportedly "elementary" particles which physicists had to account for. As much as that period may appear, in hindsight, an age of discovery, it could also be called a phase of *krisis*, in the true etymological sense of the word: many physicists had to take a pause in front of this new situation and carefully *judge* how to proceed, which strategy to adopt (Furlan, Gaudenzi 2021).[254] A number of them chose a way of theorizing which was very much dependent on the latest overflow of experimental results and limited to phenomenological or *ad hoc* modifications. With this, what Wheeler would call, with a note of contempt, the "pion industry" (Wheeler 2000, p. 172) was born. Needless to say, such a way of proceeding did not appeal to him at all, and so he started to

254As von Neumann put it in 1955, "Emphasis on methodology seems most often to arise when there are symptoms of trouble, when a realization of difficulties makes necessary a re-examination of some position inherited from the past" (von Neumann 1963, p. 491).

carve his own path "far from the particle crowd", to re-adapt the title of Thomas Hardy's novel.

What were the first steps of this "conversion", which started the second phase of Wheeler's long career? If we consider that he switched from "Everything is particles" to "Everything is fields", we may assume that he had a radical change of mind on the road to Damascus, a sort of gestalt switch. Its deep reorientation of research notwithstanding, the "conversion" was rather a gradual passage, as examined in (Blum, Brill 2020). First of all, partly in explicit opposition to the *modus operandi* of the "pion industry", Wheeler clearly stated his heuristic methodology, daring conservatism. We have already discussed how this meant dusting off Einstein's legacy with Bohr's methodology: such was the task Wheeler assigned himself, while facing the new challenges of his time. Even at this point we can notice a movement backwards in time in order to better move forward and, by personally opening a path, cut through the confused tangle of new issues. We could call it an example of "on ko chi shin", of "interrogating the old to understand the new",[255] and it is not a coincidence that the *summa* of this phase of Wheeler's activities, written with one of his most important collaborators and students (Misner, Wheeler 1957), opens with a Confucian quote as epigraph, "I transmit but I do not create; I am sincerely fond of the ancient". Although Wheeler used the masks of his two mentors, we can readily spot some original traits of his program, that would occupy him until the beginning of the 1970s.

First of all, the name: "geometrodynamics". Wheeler would make use of it (at least when not explicitly preceded by "quantum") as synonymous of general relativity, and interchange it with phrases such as "Einstein's vision": particularly eloquent, in this regard, is (Wheeler 1968b). However, as much as he was undoubtedly building on Einstein's legacy, that vision was actually Wheeler's. As a matter of fact, he rejected the late Einstein's unified field approach on technical grounds (Misner, Wheeler 1957) and, for sure, he never shared Einstein's resistance against quantum physics, on the contrary. Wheeler's attempt at putting together Einstein and Bohr was not limited to adopting a methodology under the aegis of one in order to develop the ideas of the other. From the mid-1950s on, a central notion of Wheeler's program was "quantum foam", that is the "boiling" aspect, due to quantum fluctuations, that, at extremely small scales, Wheeler's imagination ascribed to space itself, no longer "smooth as marble" like in general relativity (Wheeler 1957). In this

255It is worth adding that in 1953, during his first trip to Japan, Wheeler perceived a few affinities between that culture and his own attitude and, as part of a conference on how to deal with the new situation in physics and the new particles, i.e. in order to illustrate his "daring conservative" approach, he staged a dialogue between Sugawara no Michizane, the great Heian poet and statesman, faithful to his principles, and Takamori Saigo, samurai and man of action (Blum, Brill 2020; Furlan, Gaudenzi 2021).

sense, the geometrodynamical program had at its basis not only the aspiration towards a quantum theory of gravity, but a guiding idea that already was *in actu* a fusion of general relativistic and quantum aspects.

We have already remarked how today it is customary to refer to "quantum foam" as a widely shared expectation of quantum gravity theories, even in a reified way, but, when Wheeler introduced it, he had something more ambitious in mind: starting with empty space or pure geometry, but endowed with a quantum fluctuating character, Wheeler tried to sketch a pangeometric view for all of physics. There is no need to repeat again all the scheme, starting with the quantum geometry of the vacuum; its fluctuations would form wormholes, which also meant scattered microcharges; a "cloud" of such microcharges would then be what is commonly held as a particle, whose other properties, such as mass and spin, would be accounted for by other geometrical ideas. From there everything else would be constructed as well: no wonder that Wheeler exhumed Kepler's *Ubi materia, ibi geometria* (Wheeler 1990, p. 324)!

Even considering this as a purely visionary attempt, success is not exactly the first word that comes to mind when looking at these early attempts (mass without mass, charge without charge, spin without spin) *per se*. The important point, however, as suggested in Chapter 2, is precisely that they should not be considered *per se*: the work done by Wheeler's circle on geons and wormholes may have not been a major breakthrough in terms of understanding of some relevant physical entity, but the tools that were thus developed, besides contributing to elucidating some aspects of general relativity, ended up being promptly exaptated, in a few years, in order to understand what we now call "black holes". While Wheeler, already in the early 1950s, had identified the extreme phases of gravitational collapse as an important issue to research, his early confrontation with Oppenheimer, Snyder and Volkoff's pioneering results of the late 1930s led him to struggle against them, until around 1961-62 he was finally convinced of their soundness. However, as underscored in the referenced papers, it would be simplistic, if not wrong, to consider this process as a "delay" due to an idiosyncratic blunder. The questions Wheeler posed and the way he framed them saw his active involvement even when he was opposing resistance; and when new geometric insights, as well as computer calculations (in turn exaptated, at least in part, from the military-aimed technology developed a few years earlier within the Matterhorn project), convinced him to abandon his reservations, that was not an event that stroke him from the outside, so to speak, but one that he had been nurturing for years within his own circle, thanks to the "larger view" of the seeker.

At that point, once Wheeler accepted that nothing could prevent

massive-enough stars from collapsing to what came to be known as "black hole", he saw in that a further chance to invoke the need of a quantum theory of gravitation, capable of removing the infinities that affected the classical framework when dealing with such extreme situations. Quantum foam became, in a sense, the "patch" at extremely short distances from those problematic singularities. In this way, gravitational collapse was the process responsible for linking the large scales of stars (or even of the whole universe) to the extremely small scales where quantum foam dominates. Always fascinated by correspondences between micro- and macrocosm, Wheeler, with his quantum foam, far from merely introducing some phenomenon confined to the smallest scales, had *de facto* pierced the deterministic heart of Einstein's vision, to the point of envisioning the extreme phases of the universe as dominated by a foam-like behavior. It was time, then, to push even more for a quantum version of Wheeler's pangeometric view. In the mid-1960s, thus, we find him busy trying to sketch a mathematical arena, "superspace", for his quantum geometrodynamics (Wheeler 1968c). The basic ideas of superspace are quite simple, as we have already discussed, and also entailed a sort of "multiverse" perspective that resonated with the calculation over possible worlds made by Leibniz's God. But within superspace itself one meets the limits of this pseudo-divine vision: when the universe comes close to its initial (Big Bang) or final (Big Crunch) singularity, the quantum interference of other stories or possibilities becomes dominant, and the usual time ordering (in a sense, the notion itself of a single story or trajectory) no longer holds, thus revealing its non-fundamental character. Questions such as "What happens next? What happened earlier?" become thus meaningless.

In those extreme phases, the universe enters into a "black box" (Misner et al. 1973, p. 1213), so to speak, that one day would perhaps be better described by a full-fledged future version of quantum geometrodynamics, possibly thanks to the study of what Wheeler considered the miniature version of cosmic singularities, black holes. The only aspect that mattered for Wheeler, at this point, was that, out of the "black box", the universe emerges (as if in a "reprocessing") with different fundamental values, assigned by an (unknown) random process which, supposedly, is intrinsically quantum.[256] This allowed Wheeler to articulate the cyclic cosmological view he was endorsing in that period.[257] It also offered him a sort of machinery capable, in a

256Here we can already see that, for Wheeler, there is no room for some classical level or mechanism at the bottom: see *infra,* sections 5-6.

257For Wheeler's cosmological tenets and their evolution, see again (Blum, Furlan 2022, Section 3). While his assumptions about a closed universe can be explained in the light of "internalistic" reasons, there were other curious factors that shaped his expectations and guiding picture, such as a series of schlieren photographs of the phases of expansion and contraction of underwater explosions. The already mentioned interest for cyclic cosmologies

purely naturalistic way, of accounting for the seeming fine-tuned character of the universal constants' fundamental values, as to allow the emergence of life. The latter was indeed a topic that his Princeton colleague Robert Dicke was emphasizing in those same years. The hopes of such a peculiar intertwinement of quantum geometrodynamics, anthropic reasoning and cyclic cosmology are perhaps nowhere expressed more clearly than in a letter by Wheeler to Sakharov, dated 10 July 1970:[258]

> You, like me, believe, I judge, that problems of cosmology and elementary particle physics have a deep inner connection. In this connection I believe the concept of superspace gives a new perspective on the problem, in that it offers an arena in which space undergoes many cycles of expansion and recontraction. One is open to believe that in each such cycle the baryon number has a different value and even the masses of the elementary particles have new values. […] They would seem rather to be of the character of initial conditions, "accidental" to the particular cycle of expansion and recontraction under study. This is in full accord with the fascinating views of Brandon Carter that our own cycle of the universe is distinguished in this, that the time scale and the values of the physical constants are such, as to let life arise, such as we know it, on one planet in the universe. Happily much can be done to develop these considerations in a quantitative way, before we are forced to reach a judgment on this most difficult question, which recalls the proposal of Leibniz, that "this is the best of all possible worlds"! I find not the least reason to question this outlook in the issues brought before me these days as I serve on the president's committee on arms control and disarmament. We have more conflicting evidence on man's place in the universe, and more tie between these once "theological" questions and physics, today than ever before!

Now, even setting aside the cyclic picture and related speculations, with their obvious problems from the viewpoint of empirical science, the quantum geometrodynamical approach would have had plenty of work to do. At that point, however, as we shall see in the next section, the call of the seeker and his dissatisfaction showed up again, and Wheeler chose a much more radical and unconventional move: he abandoned that formalism for quantum geometrodynamics that he had envisioned and contributed to structure.

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of other cultures is to be placed in this context as well.

258John A. Wheeler Papers, American Philosophical Sociery Library, Philadelphia, box 24.

4. Transcending laws: the black hole catastrophe

The tone of Wheeler's letter to Sakharov should not excessively mislead us: it is fair to assume that, to a good extent, it was born out of his excitement to exchange ideas with another remarkable figure and original thinker, whom he had met two years earlier in Tbilisi (as in the case of Zel'dovich). As a matter of fact, the turn of the decade was for Wheeler another moment of crisis. Already at the beginning of 1967, right after some sketches concerning superspace, we can read in his notebooks a passage we have already quoted at the beginning of Chapter 3: "Why is everyone so silent? Why does it have to be me who says this? Story *crying* to be told. Why so long. Silent, on a peak in Darien - the only charitable explanation. *Have* to touch on this question".[259] The "peak in Darien" is a reference to the sonnet *On First Looking into Chapman's Homer* by John Keats (or better, it was meant as a quote, since the last line is: "Silent, upon a peak in Darien").[260] The one to remain silent is Hernán Cortés (historically speaking, he should be replaced by Vasco Núñez de Balboa), who, in Panama, has just reached a peak before his men and, from there, he gazes for the first time at the immensities of the Pacific Ocean. Now, 1967 is the year in which Wheeler would start to popularize "black holes" with this name; however – and here is a difference in the midst of the various parallelisms with Zel'dovich (Furlan 2021) – Wheeler's main concern at that point was not to investigate them "just" astrophysically (that was, in a sense, a task for his group), but to explore what he considered their ultimate conceptual implications. He climbed the peak, sought "the larger view", saw an entirely new scenario, and tried to make use of that in order to guide his collaborators. It is important to realize that Wheeler did not just shift the notion of black hole to the center of attention: he was, in a sense, the Giordano Bruno of this new view, radicalizing it and enthusiastically shattering old metaphysical structures,[261] but at the same time restlessly perceiving his loneliness at the mountain top.[262]

259Relativity Notebook 14, p. 140.

260Curiously enough, Julian Schwinger, little more than one year earlier, used the same reference to conclude his speech for the Nobel prize that he shared with Tomonaga and Wheeler's pupil Feynman (Schwinger 1966).

261That Wheeler himself was somehow flirting with the figure of Giordano Bruno can be perhaps surmised from a quote in (Misner et al. 1973, p. 755), where his thought is not just mentioned as an important stage for the history of cosmology, but where we can also find a passage from *De l'infinito, universo e mondi*, which is a quite meaningful choice *per se*. No less significant are the contents of this quote, dealing with the paradox of the boundary of the universe (see section 5 here), and the emphasis on an all-pervasive "nothing" or "void", that seems somehow to allude, or better wink, at the quantum vacuum out of which Wheeler had been trying to build everything.

262Here too we can recall Oort's reaction to one of Wheeler's talks, as we mentioned in

The end of the 1960s and the very beginning of the 1970s are thus characterized for Wheeler by the thrilling new opportunities that seemed at hand, as well as by the dramatic dimension of solitary research, which was also marking the limits of his previous vision. The imagery evoked above would recur, for instance, in early 1971: "Why stand timidly at threshold of this new domain of thought? Why not walk boldly in and exploit its richness? Is it only Columbus who shall see the gold of Mexico?"[263] That threshold was represented, needless to say, by the issue that had come to dominate Wheeler's interests: gravitational collapse and the black hole. On the one hand, the latter had further convinced Wheeler of the need for a quantum geometrodynamics, where quantum foam was supposed to play a crucial role; on the other, the superspace arena was turning out to be inadequate, in terms of its mathematical potentialities, to express topological transitions and, thus, quantum foam (Wheeler 1968c; Blum, Furlan 2022). To put it simply, the formalism of geometrodynamics seemed too static to account for dynamic changes in topology, which were crucial in order to have that teeming making and unmaking of "handles" in quantum foam; handles which are responsible for "charge without charge" and all the subsequent construction envisioned by Wheeler's pangeometric view. Before such a difficulty, Wheeler's move, *pace* any cautionary set of rules on "how science really works", was to abandon not his guiding idea – quantum foam – but the formalism of quantum geometrodynamics he had contributed outlining! He could have kept festering on a quantum gravity program for many years to come, while playing with the variants that could be produced through some variations of its mathematical syntax, but that would not have satisfied the *élan* of his research, his craving for a powerful guiding view.[264]

Moving on, however, Wheeler did not certainly leave his focus on black holes behind. To him, as we know well, they represented the best window on quantum gravity and on the origin and destiny of the universe. While his collaborators were making progress on a question that had marked Wheeler's struggle with gravitational collapse from the very beginning (that is, the fate of matter getting involved in the catastrophe), his speculations started to directly address the notion of physical law. Baryonic or leptonic matter irreversibly falling into a black hole, Wheeler reasoned, could no longer be distinguished, if not for the three features that, according to the "no hair theorem", characterize a black hole: mass, charge, angular momentum (Chapter 3; Blum,

Chapter 4.

263Relativity Notebook 18, p. 124.

264We may very well frame this observation within the category of the "seeker". That *élan*, in a sense, grows out of the "daring" part of daring conservatism, which is also projected towards the future and not just cherishing the past. In some cases, however, it may be not so trivial to balance it with the conservative part.

Furlan 2022, §1). Because of such indistinguishability, the laws of conservation of baryonic and leptonic numbers were challenged. In Wheeler's view, it was something different from a mere "violation" of a conservation law: the law itself, in that situation, was losing any meaning or, as he put it (Wheeler 1973), was "transcended", since there seemed to be no way, not even in principle, to check what it was supposed to regulate. There were, then, extreme-enough situations in which an otherwise valid law simply vanished. Wheeler was thus suggested to abandon the way of conceiving physical laws as given from eternity to eternity and, in some sense, imposed from above: he now rather aimed at immanentizing them within the universe and its story. This got intertwined with his reflections about time: black holes, together with the cosmological singularities (Big Bang, Big Crunch), mark the "frontiers" or the "gates of time" (Wheeler 1978, p. 41), where the transcendence of laws gets displayed. Not just of some law, but the transcendence of all laws, in the case of the cosmological singularities involving the whole universe (Misner et al. 1973, p. 1215): perhaps, then, the specific laws that govern our cosmos got somehow chosen and "frozen" at the moment of the Big Bang.

To what was such a choice due, however? Wheeler's answer in the late 1960s is the "blackboxed" quantum process which is supposedly responsible, in the superspace arena, for the different values that, from cycle to cycle, fundamental constants may assume. The latter, then, are not just numerical values embedded in a mathematical structure of laws – *vice versa*, the idea is to derive laws from fundamental properties of the universe, in a sort of relationalist way which mixed Mach's principle, Dirac's large number hypothesis and Sciama's partly analogous ideas (Blum, Furlan 2022, §3).[265] Even if one, for the sake of the argument, accepts this highly speculative (and, of course, problematic) picture, the quantum process responsible for such fundamental changes, its randomness notwithstanding, seems somehow hinting at some sort of meta-law role for quantum physics, which would just displace the problem of re-thinking the notion of physical law and its contingency.[266] In a sense, Wheeler would try, during the mid-1970s, two options in parallel: one, more "conventional", aims indeed at looking for a

265For the delicate connection to Leibniz and to a sort of optimization calculus made on possible worlds, mentioned *en passant* in Sakharov's letter as well, we redirect to Chapter 4, where we have seen how Wheeler in a sense spoke of all this as "Theophysics".

266That was indeed an objection that was moved by Steven Weinberg, who wrote that Wheeler seemed to him "to be merely pushing back the problem of the final laws. Wheeler's world without law still needs metalaws to tell us how our observations impose regularities on nature, among which metalaws is quantum mechanics itself. [...] I expect that all attempts to do without fundamental laws of nature, if successful at all, simply result in the introduction of metalaws that describe how what we now call laws came about" (Weinberg 1993, p. 186). See also (Blum, Furlan 2022, p. 307).

deeper level, with its own laws; the other, more radical, intends to question the lawfulness itself of the universe. Let us start with the former.

In Wheeler's eyes, the ultimate prediction of Einstein's relativity, black holes, seemed to unveil "mutability", viz. laws being transcended, hence the title of the speech, *From Relativity to Mutability*, in which Wheeler summarized his two decades of geometrodynamical research and announced its insufficiency (Wheeler 1973). Pronounced in 1972, at the Trieste symposium for Dirac's 70th birthday and dedicated to "the physicist's conception of nature", it was indeed an ambitious overview for an ambitious event, in front of a most illustrious *parterre*. As we shall mention in a few pages, that was also an important chance to establish relations between different grand views and "seekers", we could say, from various subfields. That moment may symbolically be taken to represent the beginning of Wheeler's second "conversion". In fact slower and more intricate than the previous one, this would lead him to the third phase of his long career, "it from bit". First of all, geometrodynamics had shown its limitations, as Wheeler explicitly admits in the speech; however, such a confession should not be taken as the recognition of a mistake or the admittance that the theory had received a fatal blow. On the contrary, it was the theory itself to point out, scoring its last success, where its pillars of Hercules were situated. Daring conservatism, as applied to Einstein's vision, seemed to have petered out: its principles had been squeezed and they had revealed that they needed something more. In other words, the geometrodynamical framework could not aspire any longer, in Wheeler's eyes, to have the last word: something deeper, a "pregeometrical" level had to be found. That also meant that the long-sought "fiery marriage" between quantum physics and general relativity was no longer a marriage between equals: after that crisis,[267] "the quantum", as Wheeler started to call it until the last days of his life, started to unequivocally appear as deeper.

All this can also be read as follows. Daring conservatism had pushed a classical view to its limits and revealed that, in the end, there could be no compromise with a fundamentally quantum world. The latter had to be embraced more radically, instead of being conceived along the lines of a classical theory, somehow mimicking it, with a recipe of substitutions that provides its quantum version. It was therefore necessary to meditate anew on the lessons of Niels Bohr. As much as Bohr had been a hero of daring conservatism – a method with a complete trust in the law – these new

267A curious addition to the dimension of the "seeker": as we have seen in Chapter 1, in a letter dated 29 September 1967, Wheeler, orphan of Bohr, addressed another of the founding fathers of quantum mechanics, Max Born, promising almost a pilgrimage to pay him a visit and ask him which one, between relativity and quantum physics, he deemed "the deepest".

reflections, centered on the role of the observer, would bring Wheeler to glimpse even a fundamentally lawless universe, and thus to attempt the second and more radical option we were alluding to. This deserves its own section, which is the next one. Here we may just conclude by remarking on a conceptual knot which has arguably a longer story than that of modern physics, since it ultimately deals with notions of origin and creation of the universe: the intertwinement of time as a linear succession and of a cosmic order obeying to higher laws. In his superspace, Wheeler witnessed the crisis of the former, or at the very least its non-fundamentality; further developments of the same program led him to doubt the notion of physical law itself, as well as other cosmic cycles. This sounds like a "theological" ground, as Wheeler himself put it in the letter to Sakharov[268] – after all, the immediately related question is: Who or what is responsible for the origin and features of the universe we live in? What is its *causa prima*? Wheeler's first move, essentially naturalistic, was to appeal to quantum randomness as a patch – that is, to deny a first cause and de-problematize the initial singularity by evoking many cycles. His second move, as we shall see, leans instead towards an *autoktisis*, a self-posing of the universe as *causa sui,* via a conscious fragment of itself, the observer.

5. Merlin, the observer-participator, and spontaneous transdisciplinarity

The crisis of quantum geometrodynamics brought an important shift also at the methodological level. Daring conservatism, while persisting in Wheeler's mind as a background attitude, was extinguishing its task as heuristic

268In this context, the following passage, which at first may sound historically superficial and quite dull (were it not that it appears in a rich paper dedicated to cosmology, astrophysics and quantum gravity!), reveals further connotations, which we will meet again in our next section: "One cannot touch thus peripherally on "theology" without recalling the great debates of long ago. One cannot forget that they eventually opened the door to modern science, which demands that we communicate with one another in understandable words, free of all mysticism. When the Bishop of Paris ruled in 1227 that it is wrong to deny God's power to create as many worlds as He pleases, he did not stop controversy; he augmented it. A hundred years later, "one of the most devastatingly critical thinkers of all ages," William of Ockham, stressed that "God's will remained the final arbiter; but just because it could not be circumscribed or defined it was necessary to look to what could be known ... by measurement and observation ... as the foundation of practical knowledge." Gordon Leff goes on to remind us that, "As a result, physics, mechanics, mathematical calculations and geometry all reached a new flowering during the 14th and 15th centuries."" (Wheeler 1968b, pp. 273-274). The reference to the Bishop of Paris, Étienne Tempier, has actually the wrong historical date: it should be 1277. Wheeler got it right in (Misner et al. 1973, p. 753), but in that case it was the name that was misspelled – as if Wheeler's ambiguous engagement with ideas about "other worlds" kept leaving some residue.

methodology and, in order to start a new "cycle" of it, one had first to identify new principles to which it could be applied. As discussed in Chapter 4, at this point we can see Wheeler searching for the actual core of quantum physics beneath the various shapes that, like Merlin the shapeshifter (Wheeler 1975), it can assume. Thus, "How come the quantum?" (Wheeler 1986a) became the refrain that would accompany Wheeler even into the new millennium (Wheeler 2001). Contrary to recent debates on the "interpretations" of quantum mechanics, he had no interest to cling to a position and fight the others. As much as his devotion for Bohr kept him close to the Copenhagen "orthodoxy", even a cursory look at his career reveals his ties to other formalisms and interpretations: Feynman and Everett had been his students; more recent proponents of QBism appeal themselves to Wheeler; Wigner was a quite close friend of his; and Wheeler himself is known for ideas, such as the "observer-participator", which were radicalized (or ontologized) in such a way that it is doubtful whether Bohr would have recognized his positions in them. As happened in Einstein's case, Wheeler's development of Bohr's vision had very much his own mark. It is not irrelevant that Wheeler's embracing of the quantum in its variety of manifestations occurred (and perhaps could only occur) a few years after Bohr's demise in 1962. In this embracing, however, if one takes a look at the table of Merlin's (or the quantum's) different shapes (Wheeler 1975), it is not so difficult to notice that there are some exclusions, highlighted even more by the quite odd fact that Wheeler somehow puts on equal footing Heisenberg's matrix mechanics and the Birkhoff-von Neumann attempt at grounding quantum mechanics in a quantum logic, for instance. The excluded – or directly ignored – views are those nostalgic of a classical deterministic level, postulating or hoping that the latter would be found again beneath quantum physics. Wheeler's direction was clearly the opposite: he had tried to push to the limit a classical vision, "Einstein's", and then he had realized that one had to dig deeper, in order to understand the quantum and pregeometry. In any case, what is important to realize is that Wheeler did not take part in the game of "interpretations", simply because he was aiming beyond that: there was no point in arguing which static position, at present, was right or wrong as if that could be the final word, since he was heuristically looking for hints towards a deeper understanding. His quantum ecumenism is inseparable from this strive, and arguably the excluded perspectives simply did not seem to him to point in a productive direction. As he put it (Wheeler 1978, p. 4) with his unique style (invoking even Jacob Burckhardt):

> It is no use to warn our colleague of the grip of determinism, nor to compare it for him with "the hold of astrology on the Renaissance mind; neither education nor enlightenment [Jacob Burckhardt insisted] could

> do anything against this delusion... because it was supported by the authority of the ancients and satisfied passionate fantasies and the fervent wish to know and determine the future". He reads more physics and comes back convinced that the plan of the world is still determinism.

If Wheeler's struggle with "How come the quantum?" was destined to last until the end of his long life, there is nonetheless, between the late 1960s and the first half of the 1970s, some clear thread that dominates his meditations on quantum physics: the role of the observer. If it was typical of modern physics, until the advent of quantum mechanics, to leave the observer out of the picture, or at least to assume in principle the possibility of removing any such "intrusive" traits in the objective image of nature drawn by science, such mindset persisted even in more recent decades. We could say that Wheeler himself, his acceptance of quantum physics notwithstanding, while developing Einstein's view had kept a "naturalistic" attitude, without dedicating much reflection to the role of the observer. One of the questions that brought the topic to his attention, however, was his attempt at considering a wave function of the whole universe, in his sketch of quantum geometrodynamics. A dichotomy *à la* Copenhagen between the observer (together with the experimental set-up) and the observed system, cannot be applied *sic et simpliciter* when the system under observation is the universe itself – where would the observer stand, then? Old philosophical and theological paradoxes resurface. This was definitely one of the factors that led Wheeler to try and play with other facets of the quantum (Blum, Furlan 2022, §3). Still, Wheeler's problem was not just related to the external observer and its role in making the wave function collapse, turning one of the possibilities into an actuality. As we have already mentioned, the metaphysical framework of the classical view was, in his eyes, falling apart due to the lessons of the black hole. The laws of physics themselves were, in a sense, crushed and brought down from their hyperuranian immutability; the search for the "mechanism of the world" seemed to fail over and over again. The observer, at this point, could no longer be conceived as somebody safely staying – undisturbed and not disturbing – behind a thick wall of glass, looking at the autonomous working of a universe-clock. "There may be no such thing as 'the glittering central mechanism of the universe' to be seen behind a glass wall at the end of the trail" (Wheeler 1973, p. 203). Such was the announcement that accompanied the transcendence of laws and the limits of geometrodynamics.

Ontologizing the role of the observer, Wheeler included the latter *within* the observed system/universe: the glass was broken.[269] The observer was thus

269See also the eloquent drawing in (Wheeler 1980a, p. 355).

a "participator" in the constant making of the universe itself, a no-longer-alienated part of the Whole that, in a sense, thus gets to know itself. This did not just mean that the observer had a role in a sort of *creatio continua*: since the observer's influence manifests itself even in the effects that the chosen experimental set-up could have on photons which have traveled for billions of light-years (that is, were emitted billions of years in advance), the whole universe, considered in its history, is holistically intertwined. If we add the fact that in those same years Wheeler, in dialogue with Robert Dicke and Brandon Carter, was trying to explain how come universal constants seem fine-tuned as to allow for the origin of life, then it is perhaps less surprising that he attempted even an "anthropic" form of reasoning, shortly before the "anthropic principle" got its name in 1973 (ironically, during the celebration for the 500th birthday of Copernicus). Indeed, at least if we take "Copernican" according to the meaning that prevailed in recent cosmology, the speech that Wheeler delivered for that anniversary sounds anti-Copernican even from the title: *The Universe as Home for Man* (Wheeler 1974; 1975). That, however, was only the beginning: the observer participator soon became invested with a cosmogonic role (Patton, Wheeler 1975; Wheeler 1977). In other words, the universe comes into being thanks to the observer that within the universe itself, at some point in time, looks back and confers actuality to what gets observed.[270] Only a universe whose features are favorable to life at some point of its history can thus exist – as *causa sui*, as we were saying. Since the usual time ordering had been shown illusory by quantum geometrodynamics, the paradox of this circular causality had a way out: cosmogony was decided *before* time – or, if we prefer, its conditions got "frozen", all together, at the Big Bang, as if only a set of life-bearing features could coagulate from possibility to existence.

The difference with respect to Wheeler's previous view is that now all the other cycles can just be "Ockham-shaved" away: all the superspace machinery gets in a sense replaced by the observer, endowed with a cosmogonic role. Even the laws of physics, at this point, could be considered as secondary (frozen at the Big Bang, which is however a Big Bang that needs the conditions on the observer in order to occur), hence the question: *Is Physics Legislated by Cosmogony?* (Patton, Wheeler 1975).

> "Collapse is dissolution. There is not one law of physics that does not require spacetime for its statement. With the collapse of the universe, the framework falls down for every thing ever called a law. At the end, so far as we can see today, there is no law left except the "law of

270Famous is the diagram (Patton, Wheeler 1975, p. 565) of a capital U with an eye on the left top looking back at the right top, as we have already said in Chapter 5.

> mutability": there is nothing that does not change. And as at the end, so it must be at the big-bang beginning. There is dissolution at one end of time, "coming into being" at the other. [...] Mutability implies adjustability. Ask then this question: Is the "initial adjustment of the structure of the universe" made in such a way as to render possible the existence of the knower? If so, this is a testable prediction, in the sense that it exposes itself in principle to destruction in a dozen ways. To make the test, examine the effect of a change in the original adjustment and see if it would rule out life" (Wheeler 1974, p. 688).

The intricate, paradoxical, beyond-time-ordering relation between "genesis and observership" (Wheeler 1977) is ultimately responsible for the cosmic order: laws are just subsequent. Of course, it is easy to object that the conditions – whatever they might be – concerning the appearance of the observer seem in turn to imply a set of laws, but in this way one just dismisses Wheeler's *tentative* suggestions and does not understand the conceptual challenge he was trying to face and conceptualize, or the new ideas he was striving to develop. At least from a historical point of view, that is not something we can afford to nonchalantly do. It is understandable that such ideas raised perplexities, such as those expressed in (Kragh 1987), but, since nobody is compelling us to subscribe to them and we have now gained some historical distance, we can actually make more interesting observations. Importantly enough, Wheeler himself was not satisfied with these *suggestions* (we should emphasize again this character of theirs).[271] He was by then in his mid-sixties and he could have enjoyed his retirement and fame, while speculating at ease or even settling for similarly comforting views, which could be hardly attacked from an empirical point of view and easily disseminated to a wider audience. That, however, was not an option for a seeker, who was actually yearning to expose his ideas to falsification or, as he would more strongly put it, "destruction" (Wheeler 1974, p. 688; Wheeler 1990, p. 319) – a destruction aimed at opening a new path, or at least a glimpse, before his eyes.

We should notice that sticking to radical positions of observer-centered lawlessness would have had the risk of preventing Wheeler from making science in the first place: not just because they had already introduced a good deal (possibly an excessive one) of "metaphysical" speculations, but also in the subtler sense that such lawlessness could undermine at its basis the search for natural laws, or at least the usual meaning associated with this search. Indeed, with the stimuli of his new Texas *milieu* and his on-going struggle

271This is underscored in various places, from (Patton, Wheeler 1975) to (Wheeler 1994c, p. 186).

with the quantum, Wheeler would move, already by the end of the 1970s, to a sort of "grey zone" (Blum, Furlan 2022, p. 317) between his former daring-conservative lawfulness and the lawlessness he had briefly glimpsed. Thus, "law without law" (Wheeler 1978) made its appearance: statistical regularities of large numbers of events now appear as the quintessence of what we call "laws", while single events, in a sense, keep something of that fundamental lawlessness or "freedom" that Wheeler had pushed himself to consider.[272] Thanks also to the development of computers, this did actually result in a partially new way of considering the search for natural laws, now conceived as regularities emerging on a screen from large-number simulations (Wheeler 1983b). In the backdrop of all this, as much as Wheeler had abandoned a chiseled and lawfully organized cosmic order, he did not simply unleash a menacing and meaning-depriving chaos. Wheeler kept emphasizing his warm faith in the harmony and understandability of the universe, according to his "Leibniz-Einstein" tradition. We may also add his constant faith in the *unity* of nature: regardless of the plurality of ideas and approaches that Wheeler considered after the *impasse* of the attempted unification of general relativity and quantum mechanics, he never seemed to doubt that the answer to the question "How come the quantum?" would provide a unitary principle capable of explaining the universe and be also an answer to the question "How come existence?" or, to echo philosophers from the previous centuries, "Why something instead of nothing?".

At this point, we could then say that the two post-geometrodynamics options we mentioned in the previous section – the search for laws but with a different meaning or form and some sort of lawlessness – were reconciled anew after a bifurcation that lasted for a few years, without ever losing their interplay. Clearly, it would be simplistic to assume that this synthesis was built only on the thread we have just followed. In absence of a proper compass like

272Another lesson that Wheeler drew from those cosmological speculations is the role – perhaps not cosmogonic, but still to be taken into account – of the observer as an interpretant in a sense close to Charles Sanders Peirce's. In (Patton, Wheeler 1975, pp. 593-595) we can actually find a florilegium of Peircean quotes; other themes (such as tychism), which do display some affinity, can be detected in the reflections of the late Wheeler, as some readers will perhaps perceive even in the next few pages. A separate work should be dedicated to this fascinating topic. Here we may just mention that, from the end of the 1970s on, Wheeler tried to "semiotize" in a minimalistic way the process of quantum measurement, looking for a way to capture its basic scheme without making extra-assumptions about the interpretant, the role of consciousness, and so on (Wheeler 1981; 1990). On the one hand, that was a process of de-anthropomorphization of the observer, as we have already commented with regard to monadology. On the other hand, the cosmic role of the observer would ultimately be "spread" or assigned to meaning-making communities (that is also in line with pragmatism) of "observers-participators" across past, present and future (Wheeler 1990). See Chapter 7 as well.

daring conservatism once was, the search for clues about a "pregeometrical" level and its laws brought Wheeler, from the very beginning of the phase opened by his talk in Trieste, to try and establish dialogues with other disciplines, not to leave any stone unturned. The 1973 letter to Paul Cohen that we have quoted in Chapter 4 is a nice example of that, as well as of the spirit of research of the seeker: "I have no special axe to grind. I am simply in search of deeper understanding". In tentative dialogues such as this,[273] we can see the sprouts of an interdisciplinarity, or even better of a transdisciplinarity, which emerges spontaneously out of the subject matter of research, out of the issues themselves. It is perhaps a lesson to be emphasized, not only for its obvious links to the notion of the seeker that trespasses boundaries, but also in contrast with a widespread way of conceiving (or analyzing) interdisciplinarity in purely exterior terms, as a result of top-down planning which usually ends up representing little more than trite slogans. As Wheeler wrote in that same letter, after all, "the good Lord, I'm afraid, didn't have the benefits of the modern university business office, with precise allocations of so much to physics, so much to mathematics, and so much to philosophy". To put it even more drastically: "Collapse and mutability make unprecedented demands on imagination and judgment. Now more than ever one is certain that no approach to physics that deals only with physics will ever explain physics" (Wheeler 1973, p. 244). Of course, not all the dialogues Wheeler tried to establish turned out to be fertile, or productive in equal measure; a good number of them, as far as they are of great interest (at the very least historically), are still waiting to be investigated, and variety of topics – from biochemistry to geology, from biophysics to informatics, from modern logic to ancient philosophy – is quite impressive. Now we are just going to examine one of them.

6. At the watershed of physics, chemistry and biology

Who or what was Wheeler's observer? And how to get an observer in the first place? Is there not some implicit and problematic teleology in the jump from life-allowing conditions to the actual appearance of an observer, especially if Darwinian ideas are accepted or even enthusiastically invoked? All these issues, that we left unanswered (or better: unasked) in the previous section, occupied Wheeler's mind as well. Even if there is no clear resolution, these questions were nonetheless maieutically very active in directing Wheeler's search for new contacts and ideas. Already in a note dated 10 June 1971, quite

273On the copy of the letter in Wheeler's archives there is written that they actually met. However, not much seemed to come out of it, in this case at least.

significantly and laconically titled "Program",[274] we can find a reference to a recent work by Wheeler's friend and colleague Eugene Wigner, *Physics and the Explanation of Life* (Wigner 1970). We are going to better contextualize this in the next chapter, but it is clear that the problem of life was indeed gaining Wheeler's attention more and more, not just because of Dicke's and his own ideas about life-permitting values of natural constants, but also because of the rising importance of the observer in his reflections on quantum mechanics. Wheeler significantly ends that page with "Crash through in one great plunge to the glittering central mechanism of the world" – only to soon give up the very idea of a "central mechanism", as we have already seen. Wheeler's interest was caught at the intersections of fundamental physics, chemistry, biology, and cosmology: thus, when he happened to hear some ambitious talk on possible scenarios for the origin of life, at the same event in Trieste (1972) where he proclaimed the transcendence of laws and the limits of geometrodynamics, he paid close attention. He was particularly impressed by Manfred Eigen's proposal of the hypercycle (Chapter 7; Blum, Furlan 2022, §4), which intended to show the viability of explaining the origin of life through the laws of physics, held up with an attitude quite similar to daring conservatism. The constructive role of fluctuations, somehow gradually encapsulated in more complex structures, was definitely another analogy that Wheeler must have perceived with his own grand view. At the same event, he also listened to Ilya Prigogine speaking about time and dissipative structures; as a matter of fact, Wheeler would quote both Eigen and Prigogine in a synthesis of his 1970s ideas (Wheeler 1978): the text of the Varenna lectures in which he enunciated "law without law".

Actually, in Trieste, Prigogine gave not just a talk, but two (Prigogine 1973a; 1973b). One dealt with his work with Léon Rosenfeld, Bohr's former assistant, on the foundations of quantum mechanics and, at least as a "philosophical" topic, it resonated with Wheeler's renewed meditation on Bohr's lesson. The other concerned the issues that would make him known even to a larger public, as the title itself (*Time, Irreversibility and Structure*) reveals. The latter talk was the one explicitly quoted by Wheeler a few years later in the Varenna lectures (and Prigogine was also there). In the meanwhile, Wheeler had retired from Princeton and moved to Texas, where Prigogine too was partly based, and by the end of that decade they had clearly established a dialogue (Blum, Furlan 2022, §4). Curiously enough, given the fame of these two personalities, such an exchange, as suggestive as that can sound, has not previously received any attention. This is complicated by what we may call "Prigoginean ecdotics": namely, not only the various editions, but also the translations of the text that made Prigogine known outside of the circles of

274Relativity Notebook 18, p. 219.

specialists, *La Nouvelle Alliance*, have meaningful differences. For instance, from the original edition in French (Prigogine, Stengers 1979), one could not make guesses about Prigogine's contacts with Wheeler, whose observer participator appears instead in the German edition soon thereafter (Prigogine, Stengers 1981); this, of course, may also be used to infer that their dialogue truly sparked at the end of the 1970s. Nonetheless, a further problem is that Prigogine's thought not only has not received, up to now, some serious historical and technical attention to its development, but also seems to have become prisoner of its own slogans and catchphrases. The circle of these worn-out repetitions can hopefully be broken by highlighting interesting relations with other figures such as Wheeler, whose career moved in areas quite distinguished from Prigogine's and thus makes their comparison more stimulating. Here, however, we just intend to emphasize how, besides a few conceptual nuclei of common interest (such as the role of the observer, time, life in the universe), both Wheeler and Prigogine began to develop, from those years on, grand views for a larger public, often extrapolating in a bold way (when not recklessly, someone could say) results or hints that they had reached or glimpsed in their previous career.

Both passionate about the history of physics, during the 1970s they independently assembled quasi-historical narratives that underline, *inter alia*, (1) the fundamental role of Darwin's intuitions about the interplay of chance and selection, then the somehow paradigmatic role of (2) statistical mechanics, whose lesson was finally made even more evident and important by (3) quantum mechanics (Wheeler 1978; Prigogine, Stengers 1979).[275] The *fil rouge* was provided, of course, by fluctuations.[276] If the world picture of classical physics, with its determinism and its omission of the observer, had thus been found inadequate and insufficient, Prigogine's work on dissipative structures, in a sense enlarging Boltzmann's legacy in statistical mechanics outside of equilibrium, had offered positive hints for the new vision that was being unveiled. Each of those complex structures, self-organized in (local) defiance of the second law of thermodynamics, had a characteristic lifetime within which its complexity was built and ultimately dissolved: no geometrization of time, nor any further consideration that regards it as a mere parameter that "flows", therefore, could do justice to the creative role that,

275Not that this was *per se* an entirely new narrative, nor just a selective retelling without any solid historical ground: see e.g. Schrödinger in (Elkana 1992).

276In view of the aforementioned narrative, that also meant, somehow, to generalize Darwin's ideas (or a few of them) to the whole universe, not unlike Wheeler was claiming to do (Patton, Wheeler 1975; Wheeler 1978; Blum, Furlan 2022, §4): a claim that belonged to Peirce's tychism, too. Indeed, some interest in Peirce is another common trait between the two: Prigogine, for instance, would even write the preface to an anthology of Peirce's writings edited by Helmut Pape (Peirce 1990).

with an explicitly Bergsonian inspiration, time assumes in Prigogine's new view. Mankind's creativity is thus not an accident that developed meaninglessly in the middle of barren immensities. It may be worth remembering, just to suggest a further cultural coordinate, that in 1970 Jacques Monod had published his famous *Le Hasard et la Nécessité* (Monod 1970), against which Prigogine would react by the end of that decade with the already mentioned *La Nouvelle Alliance*; Wheeler too, with his observer participator and his anthropic considerations, was, although not explicitly, reacting to that kind of vision. Both Prigogine and Wheeler thus seem concerned with building a new *Weltanschauung*, suggested, according to them, by the most recent developments of science: a worldview in which mankind is not just an accident in the midst of desert and meaningless immensities. The universe is our home and, in order to properly realize that, we need to get rid of the "obsolete" view that science is some abstract (in the sense of being referred to an observer "behind the glass") form of knowledge of ahistorical and static structures, realizing on the contrary that we are deeply involved, as participators, in a meaning-making exchange with nature.

It is also important to realize a significant difference between Wheeler's ambitions in the 1970s and Prigogine's: while the latter was trying to reconcile physics and life on a local scale, Wheeler's cosmogonic observer attempted something even bolder (and more problematic), that is to reconcile them directly on a global scale, considering the universe *in toto* (Blum, Furlan 2022).[277] Nonetheless, the resonances with the "harmonic" view of Wheeler's late years, as briefly sketched in the previous section, are evident. Still, it would be wrong to assume that he spent the last decades of his career evoking mirages for a larger public, or ossifying himself in this kind of positions. On the contrary, the *Unruhe* of the seeker still pushed him beyond any temporarily attained conviction. As we have already mentioned, in the last phase of his career Wheeler kept juxtaposing the close and fertile interaction with younger collaborators to his solitary, even idiosyncratic visionary attempts. In Texas, working on quantum foundations and trying to follow the trail of "Merlin the shapeshifter" until the end, Wheeler's ideas got in a sense milder, after the most radical phase of lawlessness, even if the statistical view of laws that he then adopted kept something of that radical lawlessness he had previously envisioned. After all, it is not surprising that, in a universe where laws can be "transcended", there is always some *residue* which eludes them.

277A stimulating topic for further research in this direction might be the intellectual exchange that, in those same years but not only, Wheeler had with Fred Hoyle, all their differences notwithstanding (about the Big Bang in the first place!), especially in consideration of the latter's ideas on panspermia and cosmic intelligence. Their correspondence is partly preserved in Wheeler's archives in Philadelphia, in various boxes; in Box 12, for instance, there are some hints about these issues, including a mention of Eigen's name.

7. The seeker and the community

> All the great works grasp the man in his entirety, and the man is no longer anything but the servant of the work, that monster in need of nourishment. Scientifically speaking, we can speak of a veritable parasitism of the work with respect to man. And the work's call is a bit like the call of the child who wakes his deeply sleeping mother. She is immediately aware that he needs her. Everyone knows the work's call because everyone has had to answer to it. It awakens us at night to make us feel the time passing by, the severely limited time that remains to us for all that remains for us to do. It is that which made Caesar cry, thinking that at his age, Alexander was dead. It is that which makes the sculptor go down to his workshop in the middle of the night to give the still moist lump of clay the three strokes of the chisel of which it was still in need. […] [I]t is essential to our problem that we feel the fact that the work to-be-made implicates us. And that is the way in which we feel it. I say that it implicates us: we are implicated by it. We feel ourselves to be implicated. And this is the very experience of the work's call.

These words by Étienne Souriau (2015, p. 235), first published in 1956, more or less when Wheeler was busy conceiving and outlining his pangeometric view and had thus already heard the "call" of geometrodynamics, seem particularly fit to describe the vocation of the "seeker". At first sight, this can be taken as a sort of romantic category, perhaps a descendant of Newton's solitary travels of the mind as famously evoked by Wordsworth in *The Prelude*. However, "strange seas of Thought" or not, we have repeatedly remarked upon the convivial dimension of Wheeler's research and *modus operandi*; and, all the dramatic events of the 20th century that he crossed *do* call for specific insights into their interplay with his activities. Right after the tensions or seeming contradictions that we underlined at the beginning of this chapter, hearing that someone like Wheeler, who had been involved in "mundane" (scil.: military) affairs that a number of people would find questionable, was speaking about "the universe as home for man" could have just sounded as the sugary rhetoric of a *persona* – indeed, a mask – that was addressing a public enchanted by the success and promises of science. It may still sound like that, in part, but we have gained some further insight.

Wheeler never lost sight of broader historical horizons, in an age that declared the death of grand narratives, and he tried to trespass any disciplinary boundary and actively merge distant ideas, in an age which was assuming,

sometimes facetiously, that similar mixtures between "old" subject areas were just the *status quo* of a languishing condition. Wheeler the seeker crossed all that, but was never bogged down, nor did he quit the profound dedication of an entire life: he rather liked to recall three lines from Dante (*Purgatorio*, XIV, 148-150), "Heaven wheels above you / Displaying to you her eternal glories / And still your eyes are on the ground" (e.g., Misner et al. 1973, p. 1196) – a *memento* to rise and seek the larger view. Thus, the "universe as home for man" (Wheeler 1975; 1994c), with all the swarming of ideas around it, is not simply the comforting phrase of an eminent senior scientist, or a sort of suffused and reassuring "religiosity" *ad usum delphini*. Dogmatically propagating the responses of the oracles of science would have been rather out of character for someone like Wheeler, who had turned asking questions and proposing tentative ideas into the hallmark of his scientific activity. The "universe as home" was not the (para)scientific verdict that we can sit quietly in our cosmic living room, so to speak: *that* would have been very anti-Copernican, indeed. If anything, it meant recognizing one's role as an observer-participator even within the community that, together with the generations that came before and those that are coming after (Wheeler 1968b; 1990), is always looking for – and actually capable of creating – meaning in the universe. The vision that the seeker brings to this community does not imply a passive acceptance, under the sign of a sort of paternalism of science. Let us recall the strive "toward the whole human" (Wheeler 1986c): Wheeler's new ideas about the world, as brought by a physicist to non-specialists, seem to be implying a sort of *effort* on the latter's part as well, rather than a more or less incompetent and enchanted subscription to their contents, or a trivial repetition (Wheeler 1975, p. 268). Is this not, then, also a sort of "spiritual exercise", in the sense Pierre Hadot (1981) has egregiously illustrated for ancient thought? That is to say: it is important to know *enough* of the natural order to adopt a change of perspective and look at our existence from a much broader point of view, thus getting rid of false concerns and obsolete limiting paradigms, as well as finding some form of belonging, some role within what we conceive as the universe.[278] Does this not resonate with the meaning that a restless seeker *must* have tried to give to the expression "at home in the universe"? It only seems fitting to conclude our re-evocation of Wheeler's path with a few lines that he dedicated to Copernicus, halfway between a prayer and a tribute (Wheeler 1975, p. 292):

Copernicus, you were watchman of your day

278Such an exercise, by the way, clearly displays some affinity, in terms of general outlook, with that same Spinoza whom Wheeler, somehow confusedly, was trying to investigate in order to better understand Einstein's references to him, as we discussed in Chapter 1.

And told us of the course
That this planet swings around the sun.
Give penetration to the keen eyes
Of the fellowship of science
That now keep watch for all mankind
On what there is ahead of peril and promise.

7. The Modern Maestro of Matter

In this chapter, starting from the examination and contextualization of a little known contribution by Wheeler, quite late (1988), we are going to take a look back at his whole career – its first years included – and make use of all the threads highlighted in the previous pages to show how his reflections about exotic forms of matter and his broader framework of "law without law" and "it from bit" went hand-in-hand to an unsuspected extent. We are thus going to reach a new, deeper view of Wheeler's last synthesis and appreciate how some of his peculiarities of doing physics were finally encapsulated in his own physics and epistemology.

Willst Du ins Unendliche schreiten,
Geh nur im Endlichen nach allen Seiten.
– Goethe, *Gott, Gemüt und Welt*

1. Introduction: the promises of the nanoscale?

In this second group of chapters, we have seen how Wheeler developed his ideas in creative "dialogue" with thinkers of the past (Chapter 4), but without losing sights of a concrete and engineering-like *savoir-faire* (Chapter 5). "Thinkers" and "things", as Wheeler had summarized the strands of Einstein's creativity (Wheeler 1979d). We have also examined how these aspects were held together in the figure of the seeker (Chapter 6), which also inherited some features once ascribed to religion. It is easy to imagine how a mixture of these elements can give different results and be potentially explosive. To finally put in focus some of its peculiarities, it may be interesting to compare and contrast it with partly similar – *prima facie* – combinations of scientific promises, grand narratives and almost religious expectations for the future, such as those that, in the 1980s, contributed to the hyped establishment of the field of nanotechnology.

Among the eminent names of 20th-century physics, it is usually Feynman who gets mentioned with respect to the promises of the nanoscale, even in a sensationalized way.[279] Much less known is the fact that also his mentor Wheeler entertained some reflection – of a quite different kind – on similar topics.[280] Indeed, within the vast Wheelerian bibliography, there is a

279See (Toumey 2005; 2008) for a more nuanced and critical story of Feynman's impact, leaving aside a sort of intellectual "apostolic succession" in the genealogy of nanotechnology.
280At the current state of exploration of Wheeler's and Feynman's archives, it is not known whether they ever had conversations around these matters, or whether Wheeler directly knew some version of Feynman's famous considerations, such as (Feynman 1961; 1993).

late paper, laconically and emblematically titled *Nanosecond Matter* (Wheeler 1988c), which stands out almost as an aerolite in the midst of a field. Why is that? As we have seen, Wheeler's career and interests are usually divided according to a trichotomy that he himself suggested: a first phase, from the beginning to the early 1950s, dedicated to nuclear (and subnuclear) physics; a second period, from the 1950s until the early 1970s, which represents the adventures of his geometrodynamics, or, more conventionally, his engagement with general relativity and related issues; and the final phase, usually put under the aegis of "it from bit" and characterized by Wheeler's interest in quantum foundations and information. At first sight, *Nanosecond Matter* would seem a piece of work matching, in terms of contents, the first period, but chronologically belonging to the third. This, in some sense, is indisputable, but, as we shall see, there is much more than what meets the eye and, in the end, also the characterization of Wheeler's overall trajectory – and his way of pursuing ideas – will appear in a quite different light.

By examining the content of *Nanosecond Matter*, therefore, we are going to first provide a proper contextualization of Wheeler's considerations (Section 2) and then outline the much wider framework (or even "philosophical outlook") that he was sketching in those years, starting from a discussion of the nature of physical laws and ultimately reaching a perspective on the fundamental role of information (Section 3). Intertwining it with all that, Wheeler paid more and more attention not only to quantum foundations, but also to the the frontiers between physics, chemistry, and biology: another hardly appreciated aspect that is going to enrich the insights gained in the previous two sections. In particular, we are going to discuss part of his interactions with Eugene Wigner and their differences, but also remark on his little known affinity with Manfred Eigen (Sections 4.1-4.2). At that point, we are going to be in an unexpectedly favorable position to grasp some further aspects of Wheeler's last phase, that of "it from bit" (Section 4.3). As a conclusion, some more general historical-critical lessons will be suggested (Section 5): as we know, Wheeler's case is highly idiosyncratic and, at least in relation to the history of fields such as nanotechnology, admittedly quite marginal, but here the intent is to make use of his peculiarities to better highlight some features of more general interest, which, in turn, will help us to clarify the meaning of the broad vision proposed by Wheeler during his last decades.

In this final chapter, we are not just going to build on all the previous ones, but we are going to look back at his whole career, attempting to put ourselves from Wheeler's viewpoint even more than usual. We are going to emphasize also the personal aspect of some relationships and of the recurrence of some ideas. At this point we should be prepared to follow various threads at

once, as quite typical of Wheeler's own papers, where many points represent an *aperçu* from which several possible directions of further research radiate.

2. Nanosecond matter, mu-mesic atoms, polyelectrons: in the workshop of the modern Maestro

2.1 Polyelectrons

An obvious question, first of all: what is that “nanosecond matter” mentioned in the title of Wheeler’s paper? As can be easily noticed, the nano- prefix is not explicitly referred to a spatial scale, like when we usually talk about nanotechnologies, but to a temporal one. This does not trivially mean that Wheeler was just considering relatively fast (or short-lived) processes in ordinary matter: he was rather dealing with some "exotic" configurations of matter, in order to appreciate which it is necessary to focus on a temporal nanoscale. In his own words: “Nanosecond matter as discussed here is of two kinds. One is superlight hydrogen […]. The other is mu-mesic matter, built of mu-mesic atoms: atoms in which not merely one electron but all the electrons have been replaced by mu-mesons” (Wheeler 1988c, p.101). By “superlight hydrogen” Wheeler meant the hydrogen-like atom commonly referred to as positronium (Ps): instead of being a bound system consisting of a proton and an electron, the constituents are a positron and an electron. It is therefore an instance of the so-called "onia", bound states of a particle and its antiparticle. Even intuitively, the system the positronium consists of makes it unstable and short-lived. The story of Wheeler's engagement with this topic goes back to the 1940s. As recounted by his collaborator and biographer Kenneth Ford (2009, p. 31),

> Also during the war years, Wheeler responded to a competition of the New York Academy of Sciences and submitted a paper entitled “Polyelectrons”, which won the prize and was published in 1946. In it, he worked out the theory of positronium and also calculated the properties of a positronium ion (two electrons and a positron), an entity that was finally detected in 1981 by Allen Mills, who, some 20 years earlier, had completed his junior paper and senior thesis at Princeton under Wheeler’s guidance. The polyelectron paper was, Wheeler confessed, much more modest than the grand vision he had harbored for some years that perhaps the universe in its totality is made only of electrons, positrons, and photons.

The first theoretical prediction of the positronium is usually credited to Stjepan Mohorovičić in 1934: he called it "electrum" (Kragh 1990; Mohorovičić 1934). What is interesting to note here was the astrophysical context in which it was first considered, as evident already from the title ("Möglichkeit neuer Elemente und ihre Bedeutung für die Astrophysik"): we will return to that. What Wheeler, a decade later, was up to, however, was quite different. Even in the late 1980s, just a few years before Kragh's historical note, Wheeler (1988c) does not seem to be aware of Mohorovičić's work, or possibly did not take him seriously (since he was not providing a quantum treatment of the issue; plus, Mohorovičić was an anti-relativist). Of course, Wheeler claims no exclusive priority for himself and mentions (as he had already done in the 1946 paper) Arthur E. Ruark and even some unpublished paper by Lev Landau (Wheeler 1988c, p. 126). The positronium would be experimentally discovered in 1951; clearly, Wheeler had been working on that topic on a theoretical basis, but he had discussed experimental testing, too.[281] Nonetheless, behind all that there was also a highly speculative background, which does not appear immediately from the text of the paper. Back then (Blum and Brill 2020), he was trying to develop a minimalistic particle ontology, as summarized by his slogan "everything is particles"; he also entertained the idea that "everything is electron".[282] As bizarre as that may sound, it should not be taken – after what we have been saying in Chapter 4 – as a monadology-like world within the world[283] or as a mere form of radical (and somewhat arbitrary) Ockhamism, singling out a single fundamental "ingredient" to be employed for a brutal *Aufbau* of everything, block after block. The theoretical virtues that were involved, even the aesthetics, went beyond that: "I was so enchanted with the electron, with its beautiful, exact Dirac theory and its ultimate simplicity, that I couldn't help wondering: Is everything made out of electrons?" (Wheeler 2000, p. 119).[284]

281Kragh, however, notices: "Contrary to the expectations of Mohorovičić, Ruark, and Wheeler, the eventual discovery of positronium did not rely on detection of its spectral lines but on measurements of the annihilation rate as a function of gas pressure. It was with such measurements that preliminary evidence for positronium was reported in 1949. Two years later Martin Deutsch could report to have found 'some definite proof of the abundant formation of positronium, the bound electron-positron system analogous to the hydrogen atom'" (Kragh 1990, p. 197).

282Or even a single electron, going back and forth in time: see the recollection in (Feynman 1966).

283Like Valery Y. Bryusov when asking, in his 1922 poem "The world of electron": "What if these things we call electrons / Are worlds with continents and seas?"

284We may add that nowadays, in order to deal (approximately) with two or more massive fermions interacting electromagnetically, one typically resorts to the Breit equation, which in turn builds on the Dirac equation. On a personal but not irrelevant note, Gregory Breit, in New York, was the first mentor Wheeler had after his doctorate. Wheeler had chosen him over

This is an eloquent example of what Zel'dovich would call “the chrestomatic example of the Dirac theory of a relativistic electron” (Zel'dovich 1993b, p. 642). Such a primordial, fundamental fascination would stick with Wheeler even after he abandoned his “everything is particles” program: a similar attitude would receive the name of daring conservatism (Blum, Brill 2020; Furlan 2021, 2022). Bringing an idea (or a mathematical tool) to its extreme consequences was a trait of his *modus investigandi* even before Wheeler gave that name to his heuristic methodology: it is not surprising that, in his 1946 paper, he also ventured into the consideration of more complex (three-particle) systems than positronium.[285] Following his *rêverie* "everything is electron", Wheeler was thus envisioning a form of short-lived matter made up by the delicate and unstable – but certainly suggestive – balance of particles and antiparticles. His prize-winning paper, of course, was much soberer in its aims and exposition. Still, it did not lack ambition: the reference to cosmic rays and the hope that polyelectrons could provide some clue (at least by analogy) about mesonic structure are evident throughout the paper, which was therefore trying to tackle, from a peculiar angle, some recognized issues that were at the forefront of research (Wheeler 1946).[286]

Now, why did Wheeler go back to that topic in the late 1980s? Toward the end of this section we will say something more about the details of that specific occasion, but we can already suggest a few more general considerations. As already mentioned by Ford, in 1981 Wheeler's former student Allen Mills[287] obtained a related experimental result, observing the positronium negative ion; Wheeler does recall it (Wheeler 1988c, p. 126). In that same year, a very different kind of paper (Page, McKee 1981) discussed

Oppenheimer: “Although I scarcely knew Breit at the time, I had formed a good opinion of him from hearing him speak at Physical Society meetings. I resonated with his style. Like me, he seemed to be always puzzling and was not afraid to let his puzzlement show” (Wheeler 2000, p. 106). Luckily for us, Wheeler was not afraid to show his puzzlement even in his writings (not just in his private notebooks – and Breit too kept notebooks, now among his papers at Yale), throughout his life: not only, as we know well, a precious source for historians or anyone interested in the topics he dealt with, but also an important message for a different image of science, as we shall discuss at the end of this chapter.

285Dipositronium (Ps2) was only far more recently obtained in the laboratory (Cassidy, Mills 2007), due to the difficulty of combining two “atoms” of positronium together.

286As a further corroboration, if we take a look at the announcement of the winners of the prize (more precisely, the 1945 A. Cressy Morrison Prize), bestowed by the New York Academy of Sciences, we can read that, apparently, the manuscript sent by Wheeler had the title (even more explicit, in this regard) of “Electromesons” (New York Academy of Sciences 1946, p. 155).

287His senior thesis in 1962, as we have seen in Chapter 2, helped Wheeler abandon his earlier reservations about the physical relevance of the early pioneering results on gravitation collapse leading to black holes (Wheeler 2000, p. 295).

the relevance of positronium as the dominant form of "atomic" matter in the far future of the universe, assuming that proton decay occurs. Wheeler, by then an authority in matters of general relativity and relativistic cosmology, had long been thinking about the future of the universe and the role of black holes (discussed also by Page and McKee) in that scenario.[288] On this topic, just a few years after the paper on nanosecond matter, we assist, in a sense, to Wheeler's exaptation of its content concerning polyelectrons: in a sort of juxtaposition that partially superposes the two earlier phases of his own career, he invites the reader to "compare the death of a small black hole by evaporation with the dematerialization of a droplet of liquid positronium in a blizzard of individual e^+e^- annihilations" (Wheeler 1998, p. 178) – and there he quotes the *Nanosecond Matter* paper. The result of this "comparison" is left open-ended, as often happens when Wheeler suggests or evokes some analogy or guiding idea, but it reveals that kind of deep intertwinement between geometry and matter, or between general relativity and quantum physics, which Wheeler had been trying to unravel for decades. We may also notice that A.D. Sakharov (1986), with whom Wheeler loved to exchange bold ideas (see Chapter 6),[289] had published, shortly before *Nanosecond Matter*, a paper on the evaporation of mini black holes. Regardless of an actual connection, this shows how, more in general, Wheeler felt quite close to the "cosmoparticle" way of thinking of some of his illustrious Russian colleagues, among which (besides the already mentioned Sakharov) Gamow and Zel'dovich (Bonolis, Furlan 2024; Furlan, Bonolis 2024). Besides thinking about the astrophysical and cosmological implications of particle physics and vice versa, this attempt at tying together the extremely large and the extremely small always remained a penchant of Wheeler's speculations, as hinted also by the epigraph I have chosen for this chapter. After all, in the very first paragraphs dedicated to positronium in the *Nanosecond Matter* paper, Wheeler (1988c, p. 102) asks (even if just to add that he would not provide a treatment there): "Does astrophysics supply any natural means to make superlight hydrogen?" Wheeler would remember his paper in relation to astrophysics also in an interview with Ford:

288In Wheeler's archives there is indeed the copy of a paper by Page and McKee, *The Future of the Universe*, published a couple of years later, in 1983 (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 111), as well as two folders of correspondence and various files related to Don Page (box 56), dated 1981-1987.

289"I've forgotten how much later it was that I had the pleasure of meeting the two leaders of the Soviet H-bomb project, Yakov Borisovich Zeldovich, and Andrei Sakharov. We never discussed the gadget at all. We were interested in questions of principle in physics and questions of peace in the world" (Wheeler 1996b).

> "'Nanosecond Matter' is a discussion, among other things, of the properties of a fluid made of molecules of super-light hydrogen, one positron and one electron. There are many positrons and electrons in the space around some powerful astronomical emitters of gamma rays. It would be lovely to discover a mechanism by which that stuff can be, and is sometimes, expanded suddenly and cools and condenses to give a liquid, just the way one can liquefy hydrogen by sudden cooling" (Wheeler 1994b).[290]

Last but not least, in the early 1980s Wheeler had included his paper on polyelectrons in the anthology he edited with Zurek, *Quantum Theory and Measurement* (Wheeler, Zurek 1983). Given the title, that may already seem a surprising choice, but it gets almost bizarre if we look at the section in which he decided to put it, *"Hidden Variables" vs "Phenomenon" and Complementarity* (p. 351), right before some of David Bohm's pages on the Einstein-Podolsky-Rosen paradox. The reason for this is not made explicit there, but, as explained in (Wheeler 1979i; 1986a), it is related to the experimental perspectives that Wheeler had proposed towards the end of his 1946 paper, as possible ways to test the previously discussed ideas (this is indeed the part anthologized in 1983). More specifically, the issue at stake was not just the experimental investigation of polyelectrons: discussing the

290Speaking of gamma rays and "cosmoparticle" perspectives, we may recall that already in 1934 Wheeler, together with Breit, built on Dirac's theory of the interaction between radiation and matter and considered the possibility, given some conditions, of light turning into matter, by making two photons collide to create an electron and a positron (Breit, Wheeler 1934). The relevance of the Breit-Wheeler process probably concerns the early phases of the universe, but also gamma-ray bursts. Wheeler's work in the first part of his career ended up transcending boundaries also in this case. During the centennial symposium in honor of Breit, the almost 90-year old Wheeler thus recalled it: "'Wouldn't you help me check these calculations on the Dirac electron?' he asked me one day. Naturally I was honored to, even though I had to start out as a beginner. Breit explained to me the algebra of the Dirac matrices, of which only later was I to learn the romantic Irish history. And I had to become acquainted with Dirac's bold idea to take all the negative energy states of the electron to be filled. Breit realized right from the beginning that the states of the electron in the vacuum are so free-moving that no single photon could raise an electron to a positive energy state. It would take two photons, which meant for us a second-order calculation. Breit had done it and I checked it out. So we came to a formula for the effective cross-section of the collision of two photons to produce a positron-electron pair. Looking for an application, we found ourselves driven to what seemed astrophysical conditions, hard to observe. Would that we could have foreseen the fantastic photon flux obtainable more then half a century later at the Stanford Linear Accelerator. With it my Princeton colleague Kirk McDonald, working in 1997 with partners from Stanford University, the University of Rochester, the University of Tennessee, and Princeton, directly observed numerous instances of the production of an electron pair out of the vacuum" (Wheeler 2001, p. 113).

implications of his treatment and their spectroscopic testing difficulties, Wheeler quickly abandoned his specific case and stressed the importance of "looking at the problem of the test of pair theory in a broader light" (Wheeler, Zurek 1983, p. 354). The irradiation of a suitable gas, as he proposed, is of no particular concern here, but, after that, another possible experiment he discussed involves polarization: "by far the dominating type of annihilation is that in which the positron combines with an electron whose spin forms a singlet state with respect to the spin of the positron". If we consider the two photons resulting from the annihilation process,[291] "[a]ccording to the pair theory, if one of these photons is linearly polarized in one plane, then the photon which goes off in the opposite direction with equal momentum is linearly polarized in the perpendicular plane" (p. 354). Then Wheeler, on the basis of all that, discussed an experimental arrangement to measure such polarizations. At the top of the next page (of the anthology) we can read, by way of indexing: "Polarization correlations". That makes Wheeler's intentions clear. Nowadays that he is famous for his "delayed choice experiment", it is almost impossible not to perceive in that page - that Wheeler wanted to show to readers almost forty years later - the first steps that would lead him to a bolder *Gedankenexperiment* with a similar set-up. We should also mention (as we shall repeat more at length in the last sections) that Wheeler, especially after moving to Texas in the second half of the 1970s, became much more attentive to a discussion of the foundations of quantum mechanics in the light of similar experiments. Hence the revisiting of that aspect of his old paper in that new context.

Therefore, while it may seem that Wheeler, in 1988, was just dusting off an aged work of his where he had considered the constitution of matter and its possible alternatives, and then providing an overview of superlight hydrogen's properties, he was actually looking at all that from a much richer and interesting perspective, not least thanks to the experience he had gained by crossing various subfields of physics.

2.2 Mu-mesic matter

What about "mu-mesic atoms"? That is a misnomer, probably kept by Wheeler for old times' sake, when the muon was still thought to be a meson. If the "superlight hydrogen" could be conceptually obtained by replacing the proton with a positron, mu-mesic atoms have instead their electrons replaced by muons.[292] To quote a recent research paper,

291 That is also the inverse of the Breit-Wheeler process we have been mentioning.

292 As we know by now, resorting to analogies is one of Wheeler's typical moves.

> "Muons are a fascinating probe to study nuclear properties. Muonic atoms can easily be formed by stopping negative muons inside a material. The muon is subsequently captured by the nucleus and, due to its much higher mass compared to the electron, orbits the nucleus at very small distances. During this atomic capture process, the muon emits characteristic X-rays during its cascade down to the ground state. The energies of these X-rays reveal the muonic energy level scheme, from which properties like the nuclear charge radius or its quadrupole moment can be extracted" (Knecht et al. 2020).

As a matter of fact, an older paper by Wheeler has precisely the title *Mu mesons as nuclear probe particle* (Wheeler 1953); in 1988 he did not fail to mention it, in a footnote at the very beginning of the section dedicated to mu-mesic-matter, together with three other papers he had written in the late 1940s (Wheeler 1988c, p. 125). Obviously, the 77-year-old Wheeler was not in need of self-advertising when he was mentioning those old works of his and, as also shown by other references he makes in the paper, he could have chosen to redirect the reader to more recent and more pertinent works. I would rather suggest that there is almost an emotional aspect to that list of papers, going back once again to four decades earlier. As in the case of the positronium, his early results and ideas (or simply interests) accompanied him in the other areas of physics he would explore.[293]

No longer unexpectedly for the reader – by now – Wheeler, right after introducing mu-mesic matter, offers once again a joint perspective of exotic forms of matter and their astrophysical relevance. Not just for the obvious reason that muons were first detected in cosmic rays, but for some rather specific situation – at which point another friend of Wheeler's, Gamow, makes an appearance:

> "George Gamow's URCA process taught us that a collapsing star can be a copious source of neutrinos. Subsequent work has made it clear that the material of the star itself may present a substantial opacity in the way of these electron neutrinos, so that they build up to a high pressure. At a sufficient energy an electron neutrino is capable of reversing the normal

293Besides the role of muons as probe, muonic atoms are interesting also for quantum electrodynamics (since we have been mentioning Wheeler and Feynman…): muons, as much as they are still leptons, are about two hundred times heavier than electrons, and thus they make Bohr's orbits closer to the nucleus and QED corrections more relevant. For a survey about the formation of muonic matter, see e.g. chapter 4 of (Nagamine 2003).

process of radioactive decay of a free mu-meson into an electron" (Wheeler 1988c, p. 108).

This, in other words, "offers a means to convert ordinary matter in bulk to all-mu-mesic matter" (*ibidem*).[294] We are certainly familiar with Wheeler's ability to make his messages effective thanks to original and occasionally ironic pictures: here too, just in the following page, we can see, in a sort of pressure chamber, a cartoon-like human figure who is being turned into a much smaller version (made of mu-mesic-matter) due to the increase in neutrino pressure (Fig. 5). The caption says: "With sufficient increase of the neutrino pressure, all the electrons of all the atoms are converted to mu-mesons. The new all-mu-meson atoms are two-hundred times smaller than the original atoms" (Wheeler 1988c, p. 109).

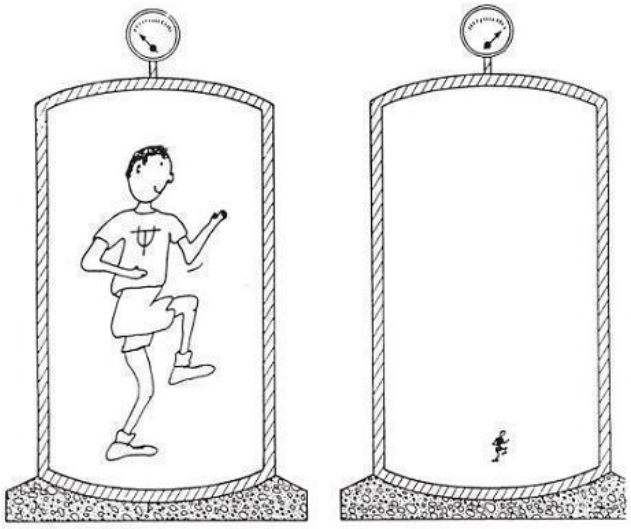

Fig. 5. The shrinking in size of muonic matter. Source: (Wheeler 1988c, p. 109).

Right after that, Wheeler devotes a section to imagining a new periodic table for muonic matter. Although there is no explicit illustration, here too the pictorial character – as a visible picture of order and organization – is obvious. We may recall that Wheeler, at the end of 1969, in occasion of the centenary of Mendeleev's periodic table, wrote a very original and curious synthesis of his own vision, accompanied by a quasi-historical narrative that presents Mendeleev as "the prophet of the quantum" (Wheeler 1971b). In partial

294Even if Wheeler's name is not typically associated with neutrinos, even after the first phase of his career they did stimulate a number of his reflections during the 1950s, from the "zero mass hypothesis", in his attempt – starting from fields without mass (e.g. Blum, Brill 2020) – to get rid of the proliferating new particles to his (not unrelated) geometrodynamical considerations about the interaction between neutrinos and gravitational fields (e.g. Brill, Wheeler 1957).

defense of this oddity, we may add that it was made up for an event, taking place in Turin and Rome, in view of which illustrious physicists had been asked to share their expectations about the future of physics and the on-going exploration and ordering of subatomic particles, possibly in analogy with what Mendeleev had done for atoms. To Wheeler, the ordering of the periodic table was the tangible manifestation and gradual unrolling of what he was starting to simply call "the quantum" – the core principle (still to be properly identified and understood) of quantum physics, that he would put at the basis of everything that exists. Of course, this brief digression is more at an illustrative and personal-associative level, but Wheeler's 1988 exercise of imagining a new periodic table for muonic matter is not a mere theoretical virtuosity. We just need to take a look at the following passage:

> "A proper working out of the new periodic table would require us to modify existing elaborate computer programs, include the effect of nuclear bloat, determine for each all mu-mesic atom the self consistent field and the order of level filling, and treat the coupling of the outermost states in enough detail to specify the chemical valence" (Wheeler 1988c, p. 110).

The periodic table-like organization should be ready for practical purposes, so to speak. The reference to computer programs is quite meaningful: after we all, we have already commented upon Wheeler's far-sighted use of computers,. By the 1980s, they represented for his reflections much more than a mere calculating device, as we shall see in Section 4.

Speaking of "practical" purposes, Wheeler then deals with ascertaining the possibility of nuclear fusion (yes) and fission (no) in muonic matter. It is a question that he had considered already in the 1940s, in yet another work of his (Wheeler 1947). We may add that he was not the only one exploring such questions: Sir Charles Frank, in that same year, theoretically treated muon-catalyzed fusion (Frank 1947), while, in the Soviet Union, Wheeler's future H-bomb counterparts Sakharov and Zel'dovich would soon deal with the same topic as well (Sakharov 1948; Zel'dovich 1954). If these papers were concerned with fusion, Wheeler, who, as we know, had so much contributed to the understanding of fission in his work with Bohr (Bohr, Wheeler 1939), considered instead muon-induced fission. To put it briefly, a muon-catalyzed fusion is a viable option because the shrinking in size of the muonic atoms brings the nuclei much closer; in the case of fission, instead, the energy barrier to split the atom becomes too large. Recalling this result, Wheeler (1988c, p. 119) uses the latter negative conclusion from another angle: assuming we have to deactivate a bomb, by bombarding it with neutrinos can we turn its matter

into muonic atoms, thus preventing it from undergoing fission? In principle it seems an ingenious stunt, but the required neutrino pressure makes it impractical.[295]

2.3 Remembrance of things past?

After the overview of the properties of mu-mesic matter, then, in the opening of the conclusion of the paper who has been following Wheeler's trends of thought in the previous pages will find some quite unanticipated remark:

> "Life as we know it is confined to a narrow range of temperature and pressure. Conditions normally available on earth span limited possibilities. On both accounts it is easy to overlook the enormous variety of strange forms of matter that invite study" (Wheeler 1988c, p. 119).

What Wheeler meant is clear *per se*, of course, but the appearance of these sentences is sudden, to say the least, and apparently quite unrelated even to the overtones of the paper, or to the angle of the previous considerations. For now, let us consider it as a hint that there is something more going on below the level of visibility: we will provide some context for this reference to life in the next sections. Before that, however, our outline of the paper would be incomplete without mentioning the occasion for which it was prepared, as well as a peculiar conceptual character that gets evoked within it.

As already said, just by taking a look at Wheeler's bibliography, *Nanosecond Matter* does look like an occasional piece: it is not too difficult to find out, in fact, that the occasion was a *Festschrift* for his friend Edward Teller's 80th birthday. Their relationship dated back to the 1930s, due to their common engagement with nuclear physics – they also became co-authors (Teller, Wheeler 1938) – and later, with its military applications.[296] The title

295In Wheeler's own words: "it is interesting to see that a mu-mesic environment simplifies the ignition of a condensed-matter thermonuclear device (because it raises the density eight-million-fold) and yet entirely deactivates every ^{235}U and ^{239}Pu bomb (because it raises the barrier against fission by many MeV)" (Wheeler 1988c, p. 118).

296The relationship between Teller and Wheeler has not received specific attention yet. Besides redirecting to their respective autobiographical memoirs (Wheeler 2000; Teller 2001), we may just highlight how they both highly respected some common acquaintance, such as Niels Bohr or Enrico Fermi; had common friends, such as Eugene Wigner; shared in various degree some personal dislike, such as towards Robert Oppenheimer; and decided to push for the development of thermonuclear weapons due to what they perceived as the Soviet threat. Of course, the few names just mentioned are already enough to conjure up a peculiar unity of theoretical and practical issues.

given to the *Festschrift* was, quite significantly, *Energy in Physics, War and Peace* (Mark, Wood 1988). There was, in other words, a clear reference to applied dimensions – as expected, given Teller's activities. Nonetheless, Wheeler's paper, as we have seen, may be said to have just some applied physics connotations, rather than engaging with practical applications "at hand". In his own words (Wheeler 1994a):

> "For example, the idea of everything made out of positive and negative electrons. There was a paper that I wrote [later] on so-called poly-electrons, objects made out of positive and negative elections, that was a reflection of that earlier interest. But these were objects which really had nothing to do with nuclear physics; they are more like fancy forms of molecular physics.
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> I published a paper on this super-light hydrogen in a Teller Festschrift a few years ago. One thinks of how gases are cooled by allowing them to expand through a nozzle and I think of the domain around some stars today where all our evidence makes us feel there are lots of positive and negative electrons around. If only one could dream up some set of circumstances there that would give the equivalent of the nozzle exhaust, which would cool off a lot of this stuff in order to condense. I'm sure that if one wanted to do something on a Manhattan Project scale, one could make the stuff liquid positronium [laughs]. But so what? What would you do with it? It would blow up" (Wheeler 1994a).

Teller and Wheeler certainly shared a passion for explosions – hence, in the paper, the slightly odd (as some sort of innuendo between "insiders") discussion of nuclear fusion and fission, and of defusing bombs.

Having now in mind that Wheeler was speaking at a celebration in honor of Teller, we may notice in the footnotes how he mentions not only some of Teller's works, but also how his own trajectory intersected Teller's. That sort of emotional aspect that I underscored in the case of Wheeler's list of his old papers about muons becomes not only clearer (and, in the same footnote, Wheeler also recalls the paper that Teller co-authored with Fermi), but allows us also to spot other elements of personal reminiscence among the (admittedly not systematic) bibliographic references, such as a few works of their common friend Wigner.[297] And yet, in spite of all these distinguished names,, the one

297On a more personal level for Wheeler, who really seems caught up in remembrance of things past, we may notice, since we have mentioned Gregory Breit (his first postdoc mentor), some reference (Wheeler 1988c, p. 106) also to his Ph.D. advisor, Karl Herzfeld. Discussing whether cold superlight hydrogen could behave as a conductor at high pressure, Wheeler

who remains etched in memory and occupies the scene in *Nanosecond Matter*, with one entry at the beginning and one at the end, is neither Teller nor the reminiscent Wheeler.

> "Where can one find a customer for nanosecond matter? Look for a creative genius, an animator of hundreds of ideas and projects, maestro of all the known forms of matter, for whom 92 elements, or even 106, are not enough. Find the man who has moved beyond specifying gold for radiation shield, beryllium for conductor of radiation, foam for damping agent, someone for whom it is no longer enough to do engineering on tritium with its 17.7 year mean life, or bottle neutrons with their 17.0 minute mean life. For this fast worker, a substance can surely be counted as "matter" if the bonding electrons - or mesons - live long enough to make 100,000 revolutions" (Wheeler 1988c, p. 101).

> "We have introduced and examined here – but only in the most cursory and approximate way – two strange forms of matter, all-mu-mesic atoms and super light hydrogen. They are small symbols of the great garden of richness on which the modern matter maestro may meditate" (Wheeler 1988c, p. 119).[298]

Was this an exaggerated, flamboyant tribute to Teller? Unlikely, although it is quite tempting to imagine this "maestro" using the periodic table as a keyboard, perhaps as a musical keyboard, like the piano that Teller was so fond of. It is even more unlikely, due both to the circumstances and to his personality, that Wheeler was speaking about himself (although "animator of hundreds of ideas and projects" would certainly be a befitting description).[299]

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quotes "On atomic properties which make an element a metal" (Herzfeld 1927) and, right after that, Wigner's paper on the possibility of a "metallic" modification of hydrogen (Wigner, Huntington 1935).

298The last sentence may remind someone of a more recent title by Françoise Brochard-Wyart (2019), surveying forms of soft matter. That Wheeler just speaks of "symbols" is even more suggestive and intriguing, but the archetypal connotations of the garden is going to become more explicit in the last sections, when we are going to discussing his view of *The Universe as Home for Man* (Wheeler 1974; 1975).

299As he once said in an interview, "[i]n my office I keep a two-inch white box for every project that I plan to do someday. When I do the project and publish the paper, I bind up the working materials of that project for my records. The number of new projects that I add each year exceeds the number that I accomplish. So now there are about 150 such two-inch boxes in my office - misery for my poor secretary. To me each is a precious tie to the world. So it is hard for me to think of myself ever being tired of the world. You remember Dr. Samuel Johnson's words, 'When a man is tired of London, he is tired of life'. What he said about London applies to everything in my life" (Goodman 1981, p. 80).

Rather, we could say that the maestro is an enhanced projection of a few aspects common to both of them and, more generally, of a certain way of approaching the scientific enterprise. He seems to belong to the family of gods and demons that are featured in Wheeler's published and unpublished writings; interestingly enough, this demi-god, or just more-than-human being, reflects in a sense a shift in what Wheeler had been thematizing in his epistemological meditations between the 1970s and 1980s. To grasp the range of thought and action of the modern maestro, then, we have to examine some of Wheeler's multifarious reflections of those years.

3. Law without law: from the relativistic cosmos to the foundations of microphysics and the role of the observer

3.1 Lawlessness and the exorcism of demons

There is no law except the law that there is no law. Add the cosmogonic observer-participator – namely someone who, looking back in time or billions of light years away, actively shapes the history of the universe. At first glance, it is not easy to believe that the 77-year old who was still rattling off properties of nuclear matter (and beyond) is the same scientist that, just a few years before, was proclaiming those radical, staggering, highly speculative perspectives. Even more so: does a fundamental lawlessness not undermine the very possibility, or at the least the usual meaning, of scientific research? Indeed, as has been argued elsewhere in the reconstruction of the story of "how John Wheeler lost his faith in the law" (Blum, Furlan 2022), Wheeler's extreme positions, soon after their enunciation in the mid-late 1970s, entered *de facto* a sort of "grey zone" between the search for the eternal laws responsible for cosmic order and a radical lawlessness: a search for statistical regularities is still possible. Or better, that is the nature of physical laws: "No prediction lends itself to a more critical test than this, that every law of physics, pushed to the extreme, will be found to be statistical and approximate, not mathematically perfect and precise" (Wheeler, Zurek 1983, p. 210).

Nonetheless, the framework that Wheeler would develop under the name of "law without law", which during the 1980s flowed into "it from bit", is not without ambiguities or inner tensions – but that is also due to its richness of ideas and its evocative power, capable of inspiring, as we shall see, a variety of approaches. When Christopher Fuchs (2016), for instance, writes that it was precisely because of that vagueness that "law without law" could be so fruitful, he is not just making a paradoxical statement. Faced with the task of historically interpreting Wheeler's thought, then, we also find ourselves in a

sort of "grey zone". On the one hand, assuming a too stiff coherence in Wheeler's positions (especially regarding the late period, but this, in different measure, holds for his whole thinking life) leads nowhere, or only to over-simplistic and quite poor distorsions. On the other hand, if we refuse to take one-sided approaches and we try instead to get an overall picture of what Wheeler was up to in a certain period, it is possible to follow his parallel trends of thought, track their development and transformations (and occasional interference), find an inner logic in his manyfold attempts and suggestions. In this section and the next, then, rather than remarking on the seemingly unsolvable differences between Wheeler the prophet of lawlessness and Wheeler the author of "Nanosecond Matter", we will try to use the latter work to provide some constraint on the "vagueness" of the former, as well as using the former to better contextualize the latter.[300] This being said, there is no space here to recapitulate the long story that led Wheeler to question the very notion of physical law (and we have already given a reference to the interested reader); a few crucial passages can nonetheless be helpful.

In the spring of 1967 a bright breeze of classical metaphysics still blew through Wheeler's reflections. As he contemplated the "superspace" arena of his quantum geometrodynamics, he was meditating on the cyclical nature of the universe, the mechanism responsible for its features, their possible alternatives, and so on: no wonder he was beginning to be fascinated by the Leibnizian Creator and his calculus over possible worlds, as we have seen in Chapter 4. Wheeler even used, in his private notes, a curious – but somewhat telling – expression: "Theophysics".[301] Aspiring to a contemplation *sub specie aeternitatis*, akin to the one sought by his mentor Einstein when he wanted to know God's thoughts (Wheeler 1979i, p. 807), Wheeler had long been

300It could surely be objected that a contribution to a *Festschrift* celebrating the 80th birthday of a friend met half a century earlier and written by someone of advanced age, who was actually approaching his own 80th birthday, is not the best place where we could expect to find new and unconventional ideas, somehow representative of what Wheeler was up to. On the contrary: as already said for the Mendeleev's centenary, Wheeler regarded anniversaries and celebrations as a good chance to try and establish bold connections or dialogues, possibly divining the *Nachleben* of the ideas, results, and projects of who was being celebrated. This *élan* towards the future is clearly highlighted, in the present case, by the projectuality of the modern maestro. While writing "Nanosecond Matter", Wheeler was definitely drawing upon the memories of a lifetime (which were made evident by this commentary, but to the typical reader of a physics paper they could easily pass entirely unnoticed); nevertheless, as we have discussed at length, resorting to the past and transfiguring it in the light of new situations is a typical trait of Wheeler's *modus operandi* (and *cogitandi*). "Nanosecond Matter" may be atypical when compared with someone else's papers, but in the respects just mentioned it is typically Wheelerian. Its uniqueness lies only in its content with reference to those years: it is thus meaningful to use it as a resource in order to get further insights on Wheeler's reflections.

301Relativity Notebook 14, p. 172.

entertaining the ultimate idea of eliminating all "free parameters" and arbitrariness from physical theory: the dream of a purely rationalistic *theoria* in its etymological sense, a pure *vision*. It is the vision usually reserved for gods or demons – from Laplace's to one of the smiling gods that appears in Wheeler's notebooks.[302]

Progress in his quantum geometrodynamics then started lacking, some of its difficulties seemed insurmountable: at the beginning of 1970 we can find in Wheeler's notebook a series of quotes by Michael Polanyi;[303] it is not too difficult to identify the source with *Knowing and Being* (1969). One of these quotes appears, in the light of everything we have been saying, particularly meaningful:[304]

> "The idea, which comes to us from Galileo and Gassendi, that all manner of things must ultimately be understood in terms of matter in motion is refuted. The spectacle of physical matter forming the basic tangible ground of the universe is found to be almost empty of meaning. The universal topography of atomic particles (with their velocities and forces) which, according to Laplace, offers us a universal knowledge of all things is seen to contain hardly any knowledge that is of interest".

Thus, the billiard metaphor, where – implicitly or explicitly – Laplace's demon is king, just turns out to be inadequate, uninteresting, to be abandoned;[305] not only that, but, keeping in mind the title of Polanyi's book and some of his famous ideas about the personal and tacit nature of knowledge, it seems as if Wheeler, by isolating the quote above, was indeed moving towards the idea of an observer-participator which somehow *embodies* knowledge, in a sense that the ideal of Laplace's demon does not account for, or even prevents from properly considering. It is not just about an irremediably finite perspective: the implicit metaphysics of subject and object of scientific knowledge gets challenged, as we shall see at length. That, however, also raises the question of the meaning of that "embodiment": is it really about our biological body, possibly extended by prosthesis? Or is it about experimental setups? Wheeler's own answer changed over the years, as

302Relativity Notebook 4, p. 39. See Chapter 3.

303While many today would think of Polanyi as a philosopher (and not exactly of the kind that is mainstream in philosophy of physics), for Wheeler probably he was first of all Wigner's mentor and co-author of the formula that gave him insights on how to develop his own work on fission (Wheeler 2000, p. 25).

304Relativity Notebook 17, p. 21.

305Even thinking within the framework of his geometrodynamics, Wheeler had started to realize that the Laplacean paradigm was insufficient, because it did not have within itself the initial conditions of the world. Cf. Chapter 6.

we are going to examine, but for sure we are not dealing with the pure vision of a Laplacean demon any longer, not even in principle. Finally, if we take a look at Wheeler's reflections just a few years later, in 1977, in the Varenna lectures in which he announced "law without law", we can see how he imagined, in very assertive terms, a sort of dialogue with a colleague who still hoped to restore a classical worldview beneath the quantum level:

> "Now and then we meet a colleague in another realm of thought who still thinks physics is in possession of this plan. He cites the words of Laplace and reiterates the Laplacean vision as he understands it: the laws are definite, the initial coordinates and momenta are definite, and therefore the future is definite. The universe is a machine. No, we have to tell him; that is a cracked paradigm" (Wheeler 1978, p. 4).

And Laplace's demon is thus dismissed once and for all: not just as an emblem of determinism, but more radically as the epitome of an idea of knowledge (even if unattainable). However, this was not merely a negative result. The observer-participator had in the meanwhile come in, literally crashing the glass behind which the world was previously supposed to work undisturbed according to its laws. "There may be no such thing as 'the glittering central mechanism of the universe' to be seen behind a glass wall at the end of the trail" (Wheeler 1973, p. 203). In the new view of the universe that Wheeler was developing, there was no space for the superior point of view of gods or demons – that is the background on which the modern maestro appears.

3.2 A further step into the unknown: the staircase of physics

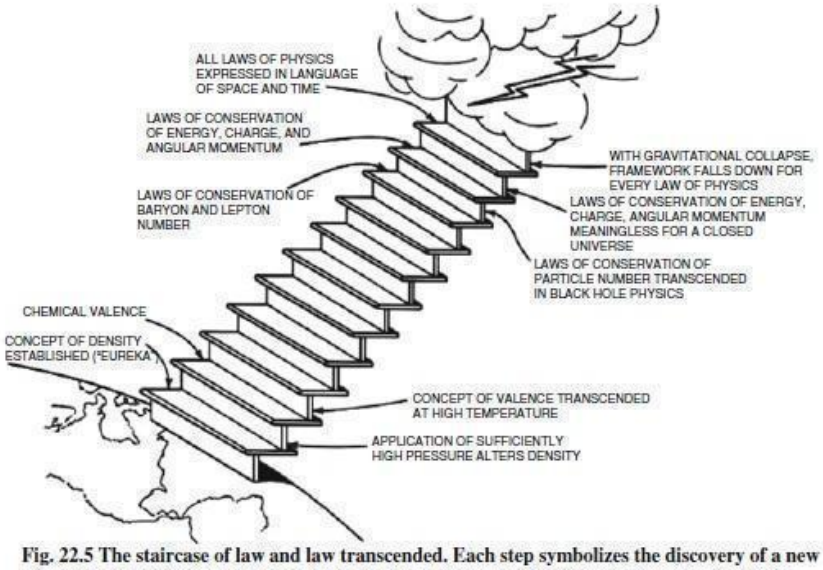

Fig. 22.5 The staircase of law and law transcended. Each step symbolizes the discovery of a new regularity or constancy of nature; each riser, the discovery of a technical means or a natural condition so extreme as to overcome or transcend that regularity.

Fig. 6. Wheeler's staircase of physics. Source: (Wheeler 1975, p. 282).

To better understand the passages just outlined and Wheeler's ideas and expectations, from the mid-1970s on, about the status of the discipline and its future developments, we may iconically resort to his "staircase of physics" (e.g. Wheeler 1975, p. 282). As can be seen from the picture (Fig. 6), Wheeler believed that, after his insights into how in black holes space and time seem to end or lose any meaning, and (some of) the laws of nature seem to be transcended or lose their validity, the task at hand was then to look for some deeper idea capable of explaining "how come the quantum" and dealing with space, time, and laws as something derivative. Looking more closely, the staircase of physics, while visually impactful – typical of Wheeler's communicative style, as we have already said – and effective in conveying the heuristic direction that he was pointing out, is not that self-evident in its assumptions. Are the steps supposed to represent ontological levels, separated by what Wheeler called "transcendence"? Or do they constitute a sort of ideal trajectory of the human mind's process of discovery of nature? Probably, the most effective way to think about it, also in the light of Wheeler's successive developments,[306] is to consider, almost in a historical-epistemological way, each single step (in its "horizontal" dimension) as a set of conceptual and experimental practices that define and constrain our exploration of nature.[307]

306As a matter of fact, the staircase returns in later years, when Wheeler's ideas had partially changed. Iconologically speaking, the picture itself seems to be inspired by a long tradition, not unlike other examples that can be found in Wheeler's repertoire: see Appendix B.

307The closest description to this, also with an emphasis on what we do and not just on what we think, can be found in (Wheeler 1979i, pp. 813-814): the illustration "symbolizes

The riser is met when such preconditions and assumptions, of which people are typically not entirely aware (such as a "constant" of nature not being constant), break down and turn out to be insufficient:[308] we then have a crisis that is also an opportunity to reach a new step, whose characterization can be properly restricted to recover the previous ones.[309] It is certainly not a coincidence that, in those same years, Wheeler, renewing his meditations on Bohr's lessons, was starting to pay more and more attention to the role of the experimental setup, the importance of preparing the experiment, the "preconditions" of physical phenomena, their conceptual implications – to echo Bohr's and Wheeler's own "Socratic" inquiries, the different ways of asking questions to nature, so to speak. But it is also clear that the "summary" of the development of physics, as condensed in the simple picture of the staircase of physics, is future-oriented, heuristically loaded, and dependent on Wheeler's own path and on his thoughts about the crisis of geometrodynamics: once we realize this, rather than a staircase, it seems a quite personalized springboard or stepping stone.

Wheeler's first attempts to take this step involved a bold rethinking of the role of the observer. In his eyes, laws had revealed themselves not to be absolute; the search for a central mechanism of the world, safely behind a glass, had turned out to be an illusion; the observer could no longer be omitted from the picture.[310] At first with a radical (or rough) "ontologization" of Bohr's

mutability, the staircase of law and law transcended. That day when Archimedes rushed from his bath crying 'Eureka' may serve to symbolize the first precision measurements of a property of matter: density. Later, however, one learned to apply to matter so high a pressure that one could bring about a discernible change in density. With that development density lost any claim it might have had as a 'conserved quantity'. At a later stage, valence acquired immense usefulness in predicting the outcome of chemical reactions. However, still further down the road one learned to achieve temperatures so high that chemical valence in any normal sense of the term lost all application". It is suggestive to realize how Wheeler's aspiration to a theory without any free parameters or "constants" of nature added by hand (in a sense, a purely rationalistic dream) assumes here a gradualistic, partly experimental, and historical character.

308This is clearly modeled on the way he was considering the shortcomings of his geometrodynamical program: general relativity was no longer enough, but at the same time it was the theory itself that had pointed out a specific situation, the black hole, where one could get insights to take the next step.

309It is also interesting to notice that Hegel's notion of *Aufhebung* may have played a role (we will shortly return to Wheeler and idealism). The overall picture of the staircase – which, in its last step, leads to the dismissal of its laws as fundamental – might be vaguely inspired by the famous ladder that Wittgenstein evoked at the end of his *Tractatus*: Wheeler was expressing some interest for him in those years, as can also be seen for instance his later interactions with Hao Wang (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, boxes 31, 68, 125).

310"Physics gives rise [...] to light, pressure, and sound. They provide means of communication, of the importance of which Niels Bohr notes, '... every analysis of the conditions of human knowledge must rest on considerations of the character and scope of our

positions, Wheeler introduced, as we have already seen, the observer-participator and extended their role even to a cosmological, or better cosmogonic, scale (Wheeler 1974; Patton, Wheeler 1975; Wheeler 1977). Without the observer and their act of measurement,[311] no universe. One could be reminded of a Fichtean overturning of "operari sequitur esse"' into "esse sequitur operari", that is, in this case, the being of the universe itself following from the observer's operations, as much as it was the universe to give rise to the observer (a strange loop that Wheeler considered to be structured outside of time – since his geometrodynamical research had convinced him that time was not fundamental anyway).[312] In 1973, during the celebrations for the 500th year from the birth of Copernicus, Wheeler had clearly expressed what we may now call anthropic considerations (an "anthropic principle" even some weeks *ante litteram*, although he had been in dialogue with his Princeton colleague Robert Dicke and with Brandon Carter[313] for years).[314] As he put it, "[i]t is not that there is a universe and then one has his choice whether he will or will not put man or mind in it. It is that in some sense the universe

means of communication'. Physics is also the foundation of chemistry and biology, out of which arise communicators" (Wheeler 1986a, p. 304).

311In the next section we are going to better discuss this last "and".

312"The quantum principle shows that there is a sense in which what the observer will do in the future defines what happens in the past – even in a past so remote that life did not then exist" (Wheeler 1977, p. 3). The quite perplexing phrasing is simply meant to say that an important aspect of that "quantum principle" Wheeler was trying to identify is the cosmological role of the observer-participator., with its cosmological or cosmogonic implications as well Wheeler's positions about time were even more radical, however: "Small effects? Accidents? Accidents like mutations, or like the rainstorms that wear away mountains? Blind accidents? We have to be careful with that word 'blind accident'. 'Blind' implies blind towards future consequences. It suggests a happening that is rooted in the past and heedless of the future. Such a conception implies that an order in time is already in being. The direct opposite is lesson number one of our survey of 'Frontiers of Time'"' (Wheeler 1978, p. 42). Even if this "result", according to him, was a consequence of geometrodynamics and gravitational collapse, we may recall that Wheeler had been playing with ideas about the future's retro-effects (or what commonly would be conceived as such) at least since the 1940s, while developing the so-called Wheeler-Feynman absorber theory (Feynman 1966).

313See (Misner et al. 1973, pp. 1216-7).

314This also led Wheeler to attempt some curious hybridization between the study of biological life and the self-referential capabilities of modern logic. I shall return to this in some forthcoming work. For now, besides some passages such as those in (Wheeler 1974), the reader interested in the aforementioned "loop" can find some clarifications in (Blum and Furlan 2022). The fact that Wheeler was adding problems to problems, paradoxes to paradoxes, may leave us perplexed, but it was actually a method of some sort: "Two paradoxes are better than one; they may even suggest a solution" (Teller 1991, p. 135). A lesson that, apparently, both he and Teller had taken from Bohr. "We need two paradoxes. Only then can we play off one against the other to locate the new point" (Wheeler 1980, p. 341). In a sense, they were trying to create a field of conceptual tensions: see Appendix B.

absolutely could not exist without mind in it somewhere, at some time" (Gingerich 1975, p. 584). It would be easy, at this point, to label Wheeler as an "idealist", who no longer believed in the autonomy of nature, and rather saw it as a quite malleable substance for the observer participator – since, after all, he had just presented "the universe as home for man" (Wheeler 1974).

At this point, we may already start making some considerations. The very structure of the staircase of physics is such that previously established knowledge is not thrown away: doubting the existence of fundamental, absolute laws does not amount, in Wheeler's case, to forget or declare invalid all the "bulk" of physics. This means that, when dealing with lower steps, the previous "naturalistic" way of approaching the question does not suddenly lose its validity, since laws are not suddenly deprived of their stability. On the contrary, any supposed "deeper" perspective which is conceptually different should be able to account for the robustness and effectiveness (*wirklichkeit*, we may say, mindful of the same root of "work" – and of course playing with the Hegelian expression) of those fields of inquiry. This should have been even far too obvious for someone with a scientific career such as Wheeler's. While the influence of idealist thinkers on him certainly deserves more attention,[315] putting him in a Procrustes bed like that is totally misleading and

315Depending on how one wants to stick labels here and there, if Berkeley is listed as an "idealist", then we can remark that Wheeler does engage with his "esse est percipi" in some intuitive and post-quantum mechanics version, possibly mediated by Popper's reading (e.g. Wheeler 1977). This is due to obvious reasons, given Wheeler's speculations about the cosmogonic observer-participator and so on. In this regard, as a sort of counterpart to Berkeley's famous falling tree, we may incidentally note that what David Deutsch (1997, pp. 86-8) calls "Dr. Johnson's criterion" is already present in e.g. (Wheeler 1980, p. 359): "If the concept of a participatory universe seems to make the world a never-never land, we can recall Samuel Johnson's remark on kicking the stone. Whatever the theory of reality, the pain in the toe made the stone real enough to him. In recent decades we have judged solid matter no less solid for being made up of electrons, nuclei, and mostly emptiness. It will make the stone no less real to regard it as entirely emptiness". However, what we are referring to is actually post-Kantian idealism and continuators: we can then say that Schelling, Hegel, and Croce make their appearance in not irrelevant (but certainly fragmentary) ways, still to be explored (e.g. Wheeler 1977, p. 32). As usual when Wheeler invokes some philosopher, there is more than one hermeneutical *caveat* to be kept in mind (Furlan 2020b). What at first sight may seem like name-dropping, or a second-hand reference (as often is), actually hides some more interesting and deeper intertwinement with issues Wheeler had been thinking about for years: if not philologically correct, these become nonetheless original episodes in the reception of those figures and, once one has realized what their names stand for in Wheeler's notes, they can actually provide insights on his ideas as well. Once again, it was about drawing upon philosophical ideas for heuristic, rather than systematic, purposes, even if the fact should not be underestimated that Wheeler was apparently able to convince his philosophically versed German colleague H.-J. Treder that he was a refined "*Kenner*" of German idealism (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia: boxes 30, 67). By "heuristics" here I do not only mean what in the first place helped to suggest an idea

little more than lip service. What we may assess here, however, is that, borrowing a Kantian (and Fichtean) famous distinction, the last step of the staircase of physics marks for Wheeler an important – and unappreciated – change in philosophical attitude: if his physical outlook before that was "dogmatic", that is typically naturalistic, with given laws and entities, and the observer was out of the picture (or just considered as something emerging way down the river of complex structures, so to speak),[316] now it became "critical", in the sense that it could not avoid a confrontation with the role of the observer from the very beginning.[317] In a first moment, Wheeler seems to give a quite gross ontological charge to all this,[318] but gradually his positions got more refined: what was left was the question about the preconditions of our

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to Wheeler: in the previous cases it was rather about some partial resonance with what he had already been thinking. This brought him to highlight those references, trying to establish a dialogue with different perspectives and to cultivate further developments. (And that is also why a theoretical comparison may be interestingly and meaningfully done even when it is not strictly necessary to tell the story of Wheeler's reflections). He was mainly looking for philosophical ideas that could break away from received ways of thinking, powerful guiding visions for the scientist as well: see the end of the Introduction.

316That is why we have spoken of "classical metaphysics" with reference to his 1967 (more-than-)cosmological speculations in quantum geometrodynamics.

317Wheeler himself did not seem aware of this distinction, but the appreciation he expressed for Kant in the years that followed and the emphasis on preconditions is worth attention. "It is one position to say that Kant is all wrong. It is quite another to say that he is right in general conception, wrong in detail. If he could publish evidence in 1754 arguing for a slow change in the axial rotation of the earth, and in 1755 calculate how fast the Milky Way must rotate to withstand gravity, perhaps he had as good a nose for physics as anyone today. Few conceptions are grander than Kant's idea that space and time are preconditions for a knowable world" (Wheeler 1983a, pp. 25-26). "How interesting it would be if one armed with modern insights would undertake afresh the program of Kant's *Kritik* (Kant, 1781)" (Wheeler 1982a, p. 559).

318Was it really like that, though? Even the most "preposterous" idea of the cosmogonic observer-participator is expressed in a paper (Patton, Wheeler 1975) which has some very Kantian words by Einstein: "... time and space are modes by which we think and not conditions in which we live". In any case, there were certainly a couple of factors that favored (and still favor) misunderstandings of Wheeler's positions. One is the continuity of his way of expressing himself, always giving the impression that he was still building (in some sense, he was) on his previous vision of geometry and spacetime. The other is the prevalent "dogmatic" (in the already mentioned sense) attitude among people working on those topics: given that, if you keep using the same words but you are now meaning them in a "critical" fashion, it is best not to leave it to the perspicacity of others, especially if you are also following various ideas in parallel. Similar comments, however, would not be fair to Wheeler, since they somehow presuppose a philosophical "conversion" that had been carefully thought out in advance. That was not the case, clearly, and what we can see is Wheeler struggling with concepts and words to express his new insights. This is also the reason why his intellectual experience is much more interesting, in several respects, than that of a physicist just adopting a given philosophical attitude.

observations and physical knowledge, as we have already said. Likewise, his "anthropic" speculations should not be taken as the invocation of a sort of metaphysical principle that would just settle the issue – they were rather a move which was quite typical in Wheeler's heuristics, that of inverting *explanans* and *explanandum* and exploring the range of possibilities from that other point of view, as if it were an inverse problem.[319]

With this in mind, let us go back to the conclusion of *Nanosecond Matter*: we can now read that reference to life-permitting regimes as a manifestation of Wheeler's interest for the preconditions of life.[320] It is no coincidence that, in (Wheeler 1994b), he mentions his preface to the famous book by Barrow and Tipler (1986) immediately before speaking of *Nanosecond Matter*. However, in the conclusion of the paper, as we have seen, it is also clear that, after the reference to life, Wheeler, with a "decentralization" that this time someone could perceive as more akin to Copernicus (or better: to what the Copernican revolution stands for in recent times), wanted to explore other regimes as well. According to what we have seen thanks to the staircase of physics, this exploration was presumably conceived along the lines of the "usual" *modus operandi* of science, regardless of one's fundamental conception about physical laws,[321] but it would not be exhausted by that. This is not a particularly deep interpretative gain *per se*, but, having identified Wheeler's focus and some of his interests, with their peculiar interconnection, we are now in the position to dig in a direction which is not usually associated with him. Having then partially clarified how Wheeler's modern maestro could make its appearance without being made either incapacitated or overpowered by the background of lawlessness, we can indulge a bit longer at the frontiers between biology and physics, and see how Wheeler's ideas may end up having something to say about the

319"Man muss immer umkehren", we may say according to Jacobi's dictum. See also (Patton and Wheeler 1975) for a similar operation with the relativistic metric, its reasons and constraints. Nonetheless, Wheeler (1986b) would recognize that the anthropic principle "superficially looks like a tautology": he rather sees it as "an attractive working hypothesis". Not least because of many misunderstandings, in later years he would be even more cautious: "I think I was a little too enthusiastic about the anthropic principle, and I would give a more qualified statement about the idea now" (Wheeler 1994b).

320With reference to this topic, we may also mention some exchanges he had with Fred Hoyle: see e.g. John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 12.

321As already pointed out, the staircase of physics was modeled on the blueprint of the crisis of Wheeler's own geometrodynamics: in a sense, it is his *main* narrative condensed in a picture. However, a staircase, step by step, is, needless to say, far too "linear" to account for Wheeler's parallel pursuit of various options: who knows if some further exploration of "nanosecond matter" could contribute, more or less directly, to a better identification of the riser?

nature/technology divide and the way it gets challenged – a topic often debated within the context of bionanotechnologies, for instance.

4. At the watersheds of life and consciousness

4.1 Wheeler and Wigner

It is helpful to take a look at the views that another eminent figure, personally quite close to Wheeler, was developing in Princeton: the already mentioned Eugene Wigner.[322] In Wheeler's notebooks,[323] it is possible to notice how in June 1971 – by then the crisis of geometrodynamics seemed at some level irreparable – he was reading a paper by Wigner (1970), *Physics and the Explanation of Life*. We also know that, in nearby years, Wheeler would read other works, quoted also in the "manifesto" of law without law (Wheeler 1978), such as *Are we machines?* (Wigner 1969).[324] In all these papers there is a refrain that we shall now examine.

Even though Wigner did not resort to his own staircase of physics, he was also entertaining the idea that some radical step was needed, capable of recovering the bulk of current physical knowledge just as a limiting case of some sort. While also concerned with the lessons of quantum mechanics, Wigner was looking in a different direction from Wheeler, still taken by his geometrodynamics and black holes: the role of living beings and, more specifically, of consciousness. In the papers we have mentioned above, Wigner kept pushing the idea that physics, as had been practiced and conceptualized until then, was related to specific regimes which were inadequate to deal with life and consciousness. As is well known, he ascribed a crucial role to the latter in his views on quantum mechanics. Although their positions mostly remained well distinct, as we shall see in a moment, Wheeler seems to have been genuinely intrigued by these ideas and even asked Wigner whether his lessons on quantum mechanics could be recorded, so that he could listen to them carefully.[325] If we cannot speak of a commonality of ideas, we

322"In later years, I have had no more valued colleague and friend than Eugene Wigner. My admiration for his talent and good sense is boundless. We also turned out to be soul mates in our thinking about defense issues and public service. His death in 1995 was a great personal loss for me" (Wheeler 2000, p. 105).

323Relativity Notebook 18, p. 219.

324Just checking the name "Wigner" in the list of Wheeler's archival papers can give an idea of the extent of their interaction. Nonetheless, it could be stimulating to "triangulate" this dialogue considering the already mentioned Polanyi as well, given the topics and the interest that Wheeler manifested in his notes. For an examination of the Wigner-Polanyi correspondence around those years – more precisely between 1961 and 1971 – see (Jha 2011).

325John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia,

can definitely speak of a commonality of issues: the role of the observer in quantum mechanics but also – something that has been almost entirely neglected – the biological aspect of the observer. While Wigner strongly believed that the current laws of physics needed conceptual innovation in order to tackle life and consciousness, Wheeler seemed more sympathetic – according to the attitude of his daring conservatism – to first try and see up to which point today's laws could bring us towards the understanding of life and its emergence. Hence his interest in the work of Manfred Eigen (such as the hypercycle), whom he heard at the great Trieste symposium for the 70th birthday of Wigner's brother-in-law, Dirac. In Wheeler's archives (Blum, Furlan 2022, §4) we can see that, a couple of years later, there is a letter in which he invited Eigen to stop by in Princeton, so that they could go on with their discussions and have a sort of Trieste reunion with Wigner too – and that was quite meaningful to say, given that in Trieste there had been dozens of well-established physicists.

Wheeler's interest in Eigen's (and Prigogine's)[326] ideas about the formation of complex structures, and possibly life, manifests again an ambiguity that we have already commented upon: Wheeler was calling for some radical rethinking of the conceptual basis of physics, but at the same time, rather than intervening on some specific law (as Wigner was suggesting), he kept the "old" *modus investigandi* and, before adding anything new (with the risk of "free novelties"), he wanted to squeeze the current principles and their possibilities up to their extreme limit.[327] A similar tension

box 32.

326See Chapter 6.

327Was Wheeler, then, a radical reductionist? In the next subsection we will see even more explicit statements, but I do not believe that the use of such categories here is particularly useful. We would not understand many other aspects of Wheeler's thought, for instance, or why he repeatedly expressed interest and approval for Anderson's "More is different" (1972): see e.g. (Wheeler 1982a; 1986a; 1990). (We may add, incidentally, that (Wheeler 1986a) is a contribution to a conference dedicated to Wigner, "Techniques and Ideas in Quantum Measurement Theory", held by the New York Academy of Sciences on January 21-24, 1986). In any case, this reference to Anderson is not meant to suggest that his attitude and positions are transparently clear or unrelated to external factors as well – for all these aspects, we redirect to (Muñoz 2023). In his famous "manifesto" there is, however, a passage that may allow us to develop some further considerations: "The main fallacy in this kind of thinking is that the reductionist hypothesis does not by any means imply a 'constructionist' one: The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe. In fact, the more the elementary particle physicists tell us about the nature of the fundamental laws the less relevance they seem to have to the very real problems of the rest of science, much less to those of society" (Anderson 1972, p. 393). Perhaps all too often it is forgotten that figures such as Wheeler, Eigen, or Anderson were actively involved not only in building bridges between different levels but also in exploring and preparing the river banks, so to speak, making new research in areas as-yet

is pointed out by Max Delbrück in an April 1975 letter to Wheeler,[328] after he read the latter's paper about the cosmogonic observer (Patton, Wheeler 1975). Delbrück's objection is more strictly related to a "orthodox" Darwinian framework, namely the apparent irreconcilability between the necessary presence of an observer and the randomness of the Darwinian process by which this same observer is supposed to emerge. On a methodological level, we can see again the tension between Wheeler's "critical" turn, with its necessity of dealing with the observer *ab initio*, and his "naturalistic" investigation of the physical processes *more solito*. Still, it is not just about methodology, especially in this phase of Wheeler's speculations, when a certain way of framing the observer-participator, or even their cosmogonic role, with the mind being hinted at as the flower of creation (Wheeler 1974), does indeed suggest that, in the early-mid 1970s, Wheeler was entertaining or exploring possibilities quite close to Wigner's positions about consciousness. From another angle, this has been also remarked in secondary literature about quantum foundations: Freire (2014, p. 165), for instance, discusses some of Wheeler's and Wigner's affinities during that period, and rightly calls the attention to some letters that Wheeler sent to Aage Bohr in order to know whether his father, in his last years, had expressed similar ideas about consciousness. In a few paragraphs we will add something important about this "inquiry"; for now it is important to realize that yes, Wheeler's and Wigner's ideas about consciousness probably reached their minimal distance during that period, but, quite differently from the narrative of the community

unexplored and not well-defined. In other words, the "constructionist" side is missing. By that I do not mean an armchair opinion (like, say, there are constructivists in the philosophy of mathematics), but I intend to highlight the importance of recognizing a heuristic impetus, often not taken into account at all, and its guiding view. *Daring constructivism*, we may say. There is a difference between the commitment to a "naturalistic" methodology and to a "naturalistic" ontology, rigidly conceived. The following passages by Wheeler and Eigen further resonate with Anderson's, all their differences notwithstanding: "No one in chemistry or biology feels himself cheated because the relevant physical laws are already known. There is challenge enough, and to spare, in unravelling fresh regularities and in finding new ways to put together old building blocks. So too in physics. And with each passing decade we understand the principles better because we have applied them to more issues. We believe in them all the more firmly because they have never let us down" (Wheeler 1968d, p. 168). "[T]he ladder from the dust of stars to life and intelligence is a 'Wittgenstein ladder': of which we have to dispose once we have reached the steps that represent the chemical complexity of even the most primitive stages of life. Living matter does not recall any principles of a 'theory of everything': as little as our brains are inherently reminiscent of quantum gravity" (Eigen 2013, p. 122). (We could have certainly found some earlier quote by Eigen, but this one also shows some connection with Wheeler's thought, and enriches our previous suggestion about Wittgenstein's ladder).

328Max Delbrück Papers, California Institute of Technology Archives and Special Collections: box 24, folder 10.

nowadays concerned with the debate around quantum interpretations, both Wheeler and Wigner were facing these issues with a strong heuristic charge and a much broader outlook, as has been outlined in these last few pages.[329]

4.2 Bohr's stick, thinking machines, bionanotechnologies

At this point, what we can surely say is that, by the time Wheeler enunciates "law without law" in Varenna (1977), his and Wigner's positions are very much apart. There are a few passages worth quoting at length:

> We know that in that empty courtyard many a game cannot be a game until a line has been drawn – it does not matter where – to separate one side from the other. I know that no Gaussian flux integral can be a flux integral until the 2-surface over which it runs - bumpy and rippled though we make it and deform it as we will - has been extended to closure. But how much arbitrariness is there in the this [sic!] more ethereal kind of demarcation, the line between 'system' and 'observing device'? Much arbitrariness! Bohr stresses that the stick we hold can itself be an object of investigation, as when we run our fingers over its surface. The same stick, when grasped firmly and used to explore something else, becomes an extension of the observer or - when we depersonalize - a part of the measuring equipment. As we withdraw the stick from the one role, and recast it in the other role, we transpose the line of demarcation from one end of it to the other. The distinction between the probed and the probe, so evident at this scale of the everyday, is the without-which-nothing of every elementary phenomenon, of every 'closed' quantum process" (Wheeler 1978, pp. 18-19).

329Even the "Interlude: Wheeler's Perennial Concern with the Quantum" (Freire 2014, pp. 317-8), although it offers a list of correct facts, ends up being quite misleading, because of the way they are presented and because of what is omitted. Granted, Wheeler's case is not easily assimilable to the narrative of the community of philosophers and historians of physics concerned with the interpretation debate; nor is the dialogue between Wheeler and Wigner a discussion over the "interpretations" of quantum mechanics (although in part it can be abstractly reenacted as such, for sure), but a heuristic attempt aimed at enlarging and rethinking the whole of physics, while paying particular attention to biology as well. Even in his phase of quantum ecumenism (e.g. Wheeler 1974), so to speak, Wheeler was considering various interpretations *and* formalisms of quantum physics only because he was looking for hints capable of suggesting a deeper understanding than *all* those positions. He did not want to debate the right way of lying down on a step of the staircase of physics, but to take the next one.

That is certainly a quite original way of discussing Heisenberg's cut, but the example of Bohr's stick has implications which go well beyond that. Following Holton (1988), the source is often indicated in a retrospective essay by Oskar Klein (1967). Actually, also Dirac (1967) – perhaps not exactly the most expected source – speaks about it. As for Wheeler, he directly refers to Bohr's "Atomic theory and the description of nature" (Bohr 1934, p. 99).[330] With some variation, it is an example that has quite a story. Descartes makes use of it in his "Dioptrique", even if, obviously, with other questions in mind; it was nonetheless taken up, discussed and transformed by Merleau-Ponty, whose "blind cane" in the "Phénoménologie de la perception" (Merleau-Ponty 1945) is nowadays, at least among philosophers, a *locus classicus*. This, of course, can quite easily be framed within the context of phenomenology and Husserl's discussion of the distinction between *Leib* and *Körper* – the lived, active body and the body as inert material – and it is also interesting to notice that *via* Husserl it occasionally made his way to physics once again (Hut 2001). Still, it would be misleading to suggest that phenomenology has a sort of prerogative:[331] there does not seem to be any trace that Bohr's example was influenced by that philosophical current, for instance. His basic idea, nevertheless, is certainly similar to Merleau-Ponty's: depending on the way one grasps the stick (more or less firmly), the extension of the perceptive body-system varies – the line separating subject and object is thus not fixed, in analogy with quantum mechanical situations or, in Wheeler's example, with what came to be known as "Heisenberg's cut" between experimental apparatus and observed system. While for someone caring only for the technical aspects of quantum mechanics all this may sound like an unwarranted conflation, neither Bohr nor Wheeler would be of that advice. As Holton (1988, p. 171) once remarked, "on studying Bohr's writings one realizes by and by that his uses of apparently 'extraneous' examples or analogies of this sort are more than mere pedagogic devices". After that, he quotes (*ibidem*) the conclusions of Bohr's "Quantum Physics and Philosophy": "We are not dealing with more or less vague analogies, but with clear examples of logical relations which, in

330If we check the reference, we can find the following passage: "One need only remember here the sensation, often cited by psychologists, which every one has experienced when attempting to orient himself in a dark room by feeling with a stick. When the stick is held loosely, it appears to the sense of touch to be an object. When, however, it is held firmly, we lose the sensation that it is a foreign body, and the impression of touch becomes immediately localized at the point where the stick is touching the body under investigation".

331Here we certainly do not intend to try and offer a story or genealogy of these reflections, but arguably one of the factors that, during those decades, disseminated them across Europe, among thinkers as different as Pavel Florensky and Walter Benjamin and the ones we have mentioned, was the more or less mediated reception of Ernst Kapp's ideas about tools as "projections of organs" (Kapp 1877).

different contexts, are met with in wider fields". May we, at this point, even speak of "extended cognition"? It is definitely not a coincidence that cognitive archaeologist Malafouris (2008) has picked up the example of the stick once again.[332]

Of course, these are just a few examples about the various possible contextual connotations (the "wider fields" mentioned above) that the "stick" can assume – and clearly, if Bohr says something like that in the late 1920s and Wheeler repeats it in the late 1970s, the "wider fields" are going to be quite different in the two cases, given the different scientific, technological, and cultural surroundings. In order to better understand what Wheeler was thinking about, then, let us see how he goes on (Wheeler 1978, pp. 19-20):

> "Wigner argues that an observation is only then an observation when it becomes part of "the consciousness of the observer" and points to "the impressions which the observer receives as the basic entities between which quantum mechanics postulates correlations." For Bohr the central point is not "consciousness," not even an "observer," but an experimental device - grain of silver bromide, Geiger counter, retina of the eye - capable of an "irreversible act of amplification. This act brings the measuring process to a "close." Only then, he emphasized, is one person able "to describe the result of the measurement to another in plain language. [...] I would have felt very uncomfortable if Bohr had used the term "consciousness" in defining the elemental act of observation. I would not have known what he meant. However, I am beginning to understand and accept the terms he actually adopts, "brought to a close by an irreversible act of amplification" and "communicable in plain

332With reference to this trend, Iliopoulos (2019) also discusses its relation with Peirce's philosophy. Peirce does not speak of sticks in this regard, but his famous example of the inkstand may suggest some analogy. Nonetheless, it is also important to avoid lumping phenomenological and Peircean resonances together. As Viola (2016, p. 265) notes, "[w]e might, therefore, be tempted to follow a distinction that has become customary in today's debate, and suggest that Peirce's emphasis on the 'external' nature of mind, as a precursor of the *extended mind* hypothesis, is indeed contrary to a strong *embodied* theory in Merleau-Ponty's sense. Peirce, in effect, does not focus on our ability to 'interiorize' the inkstand into our own bodily schema". We have seen how Wheeler, while reading Polanyi, must have meditated upon some loose notion of embodiment, but his concern was quite alien to the interiorization of exosomatic tools into a bodily schema. Rather, the reason to invoke Peirce here is that, as we shall soon mention, Wheeler's interest in his thought during that phase may have helped him to make the issue of the observer soberer and in a sense "semiotize" (or, to quote from Wheeler's long passage, "depersonalize") it. Moreover, Wheeler's "monadology", with its enlarged notion of what can act quantum mechanically as a probe or observer (another topic that we will soon discuss), seems, at least from this point of view, quite resonant with Peirce's notion that matter is a sort of effete mind.

> language." What was his position on consciousness? We have asked Jørgen Kalckar, who collaborated with Bohr in his last months, and he has kindly replied, "During work on the preparation of some lecture, to define the phenomenon of consciousness, Bohr used a phrase somewhat like this: a behaviour so complex that an adequate account would require references to the organism's 'self-awareness.' I objected jokingly that with this definition he would soon have to ascribe a consciousness to the highly developed electronic computers. This did not worry Bohr. 'I am absolutely prepared,' said he, 'to talk of the spiritual life of an electronic computer; to state that it is reflecting or that it is in a bad mood…The question whether the machine *really* feels or ponders, or whether it merely looks as though it did, is of course absolutely meaningless.'"

If anything, here we can see why Wheeler used to consider Bohr as the prime example of bringing ideas to their extreme consequences. It should be quite obvious, hopefully, that here we do not intend to make Bohr or Wheeler "transhumanists".[333] After all, in a footnote to this same passage, Wheeler

333Rather than going "beyond" the human, Wheeler wanted to reach "the whole human" (Wheeler 1986c); this is linked to his notion of the "seeker", whose research transcends institutional boundaries (Chapter 6). Even if personalities such as Frank J. Tipler have been in contact with or inspired by Wheeler, one should be very cautious in assuming the latter's endorsement of ideas such as the "physics of immortality" and whatnot. In an interview for a book about "Death and the Creative Life" (for which Wigner too, incidentally, was interviewed), Wheeler put it like this: "I.: Some expect everything of science-even to be able, one day, to banish death. Would you banish death if you could? J.W.: Taking a responsibility for the trees at my children's summer place makes me aware of how a great old spreading tree kills the future for promising new young trees which are too close to it. Death is essential for renewal. We know that the world is renewed from underneath" (Goodman 1981, p. 80). "I also feel that life without death is meaningless. It's like a picture without a frame. Death gives value to life. More than that, without death there is no life" (*ibidem*, p. 78). "The dream world of that fantastic play by J.P. Sartre, *Les jeux sont faits*, is enough to persuade one that all the preciousness and meaning of life would be drained away if one could go on living forever" (*ibidem*, p. 81). Aside from this kind of considerations, he clearly stated: "I.: What about our expectations of science eventually being able to abolish death? J.W.: I don't think we will ever realize that expectation" (*ibidem*, p. 81). Still, it is quite interesting to notice how his change of cosmological views (from the naturalistic mechanism of quantum geometrodynamics, with its cycles of the "reprocessed" universe, to a single cosmos) is accompanied by moral considerations and other reflections. In his notebooks, for instance, he wonders about the effects of his ideas about observer-participancy in the Vietnam war (Blum, Furlan 2022, p. 316), while in another interview he echoes the previous comments by explicitly tying them to cosmology, speaking of the perspective of "a one-life-only in a one-life-only universe" (Wheeler 1979f). And for sure Wheeler, after that cosmological turn, did meditate on the possibility of life inheriting "the vastness of space" (Wheeler 1988d, p. 125), as we shall see in a more extended quote; another topic discussed by people such as Tipler, but also a friend of Wheeler's such as Freeman Dyson (1979).

specifies that Kalckar "adds that he cannot guarantee to have correct wording, and that Bohr's reply, as so often, was a joke with a definite "point" – hence to be taken seriously, but not *quite* seriously" (Wheeler 1978, p. 194). And Wheeler himself, in the text, adds, shortly after the above passage, that "I am happy not to have to delve today into the term 'consciousness'" (p. 21).

And yet, in that very same page, he is also quite explicit about his attitude or expectations:

> "How can we possibly accept such a difference of principle?
> Do we not believe that brain function itself will someday be explained entirely in terms of physical chemistry and electrochemical potentials? What escape is there from the reasoning of von Neumann and Bohr and many active present day investigators? When one of the three discoverers of the mechanism of superconductivity today gives us, chapter by chapter and verse by verse, an entirely cellular account of the mechanism of memory, who can dismiss it? When a distinguished computer expert and student of the structure of society details, one by one, the distinctions proposed in times past between "consciousness" and the computer, and painstakingly analyzes each down to nothingness; what case can anyone possibly maintain for *any* distinction of principle between the computer and the brain?"

Besides thinking of von Neumann's "The Computer and the Brain" (1958), obviously,[334] Wheeler was referring to George E. Pugh, a quite versatile physicist who would soon publish "The Biological Origin of Human Values" (Pugh 1977), where he, inspired by computers, considered the human brain as a biological decision system.[335] As for "one of the discoverers of the

334In (Wheeler 2000, *passim*) we can find quite a number of references to von Neumann. Wheeler was on a similar wavelength as him (as Wigner and Teller) when it came to national defense and military matters. In those various remarks, however, besides revealing Wheeler's deep respect for von Neumann's mathematical mastery, there does not seem to be as much of a personal element as in the cases of Wigner and Teller.

335We may surmise that Wheeler, rather than interpreting that as the "reduction" of the brain to a computer, was considering such kind of modeling as a way to get insights on deeper and in some sense structural communalities: "Steady enlargement of number-processing capacity, from the abacus to today's computer, has brought a stepwise evolution of computer architecture. It has also forced a specialization in function within the computer - forseen by von Neumann (1958) - that recalls the limbs, sensors, and organs of an animal or particles, fields, and space-time of the universe. 'More is different' has long been a guiding theme of many-body physics. It is spectacularly appropriate for any complex form of life and any complex computer" (Wheeler 1982a, p. 570). A partly similar attitude can be found in the work on the brain by Peter Putnam, as we shall mention in a moment. Furthermore, Wheeler would thus "generalize" his previous considerations (again in conjunction with Anderson's

mechanism of superconductivity", it was Leon Cooper, who had turned his interests to memory and the human brain (Cooper 1995). To comment more generally upon the passage just quoted, we may also add that Wheeler, once he moved to Texas after retiring from Princeton in 1976, established a dialogue with a curious figure, Patrick Gunkel, who was *inter alia* an early advocate for robots' rights and pursued a sort of artificial intelligence version of the *ars combinatoria*, which he called "ideonomy" (Furlan 2020b). Or, in more scientific terms, another of Wheeler's versatile interlocutors, Eduardo Caianiello, had long been developing his work on neural networks and "thinking machines" (e.g. Caianiello 1961).[336] Wheeler's former student Peter Putnam had also been expressing his ideas about the brain since the early 1960, in an "Outline of a Functional Model of the Nervous System".[337] The range of Wheeler's engagement with Wigner's "Are we machines?" (which is referenced in the same text we are now discussing) can arguably become clearer when put within this larger constellation.

We can actually take another step into the "wider fields". Wheeler's passage just reported, if applied – *mutatis mutandis* – to life and its origins (thus denying in principle forms of vitalism or dualism),[338] would clearly echo what, shortly thereafter, Henri Atlan would proclaim in his well-known "Entre le cristal et la fumée: essai sur l'organisation du vivant" (Atlan 1979). This is just to mention a paradigmatic example: there does not seem to have been contacts between the two. However, we have already said about Wheeler's sympathy for Eigen's views[339] and, in this case, there is much more to add even

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slogan, curiously enough): "From the wheels-upon-wheels-upon-wheels evolution of computer programming dig out, systematize and display every feature that illuminates the level-upon-level-upon-level structure of physics" (Wheeler 1990, p. 322).

336The word "machines", in this case, does not imply a mechanistic viewpoint. As has been underscored (Termini 2017), Caianiello's innovation over the famous McCulloch-Pitts model (and derived results) was the introduction of physical tools in dealing with neural networks, instead of considering them in merely logical terms. In this sense, the inspiration of his work was quite similar to what we will see about Wheeler's hesitancy to invoke information theory, in the light of his attempt to find a physical interpretation of "meaning". It is worth reflecting on the fact that Wheeler approaches his considerations on "the computer and the universe" (Wheeler 1982a) while moving *away* from the Laplacian paradigm.

337John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 114.

338Wheeler, furthermore, references – very optimistically – Oparin: "Less than four years after the Nov. 24, 1859 publication of *The Origin of Species*, Charles Darwin (1863) wrote to Joseph Dalton Hooker, 'It is mere rubbish, thinking at present of the origin of life; one might as well think of the origin of matter'. Today, thanks not least to Darwin himself, we possess an attractive and actively investigated scenario [Oparin (1938)] for the origin of life. Will we ever know anything about the still deeper issue, what is the origin of matter?" (Wheeler 1977, p. 3).

339The following "transformation" of the passage quoted in the previous footnote is telling

at a personal level, as much as their relationship still needs to be properly and extensively explored. As a matter of fact, we may surely add that, even after their already mentioned exchanges during the 1970s, there were further stimulating interactions.[340] One only needs to take a cursory look at the explicit mentions of Wheeler's ideas in Eigen's vast synthesis (Eigen 2013) to realize the extent to which, after impressing each other with their talks at the Dirac symposium in Trieste, they kept an active interest in the other's vision.[341] As an even more concrete and later example, in Wheeler's archives[342] it is possible to find an invitation to Klosters for the 1995 winter seminar of the *Max-Planck-Institut für biophysikalische Chemie* (where Eigen had long been a director), where Wheeler illustrated his "it from bit". Now, it is rather well-known that Eigen, of course also due to his fields of research, was actively closer than Wheeler to bionanotechnologies and their possibilities, and was also the co-founder of two biotechnology companies, Direvo Biosystems and Evotec AG (Jäckle et al. 2018; McCaskill 2018). Wheeler too, nonetheless, already in 1961, while addressing the *Colegio de Ingenieros de Venezuela* for its centenary, ventured into a series of *predicciones* for the next decade, in which he included a dramatic development of biological engineering and, in the wake of the understanding of DNA structure, the control of life processes by intervening at that scale (Wheeler 1962b). These were not just conceived as a series of "applications", as may be misunderstood according to an

enough: "Charles Darwin, in replying to a letter from his friend Joseph Dalton Hooker, wrote, 'It is mere rubbish, thinking at present of the origin of life; one might as well think of the origin of matter'. Today, thanks not least to Darwin himself, we do understand (at least in broad outline) the origin and mechanism of life. Large numbers are absolutely central to that explanation, as we see nowhere more spectacularly than in the functioning of the 'life machine' of Manfred Eigen" (Wheeler 1986a, p. 314).

340It may not be entirely coincidental that, in the early phase of Eigen's career (1953), one of his breakthroughs was to show the possibility of measuring the rate of ultrafast chemical processes that took place within nanoseconds (Eigen 1972). By "not entirely coincidental" I do not mean that Wheeler, while evoking the modern maestro and nanosecond matter, was implicitly referring to Eigen: rather, that seems to have been like a common frontier to explore.

341It is interesting to note – just as a sign of a quite deep resonance – that, at the end of his 1967 Nobel lecture, Eigen seems almost to prefigure his meeting with Wheeler's key interests and ideas: "We are just beginning to understand how molecular reaction systems have found a way to 'organize themselves'. We know that processes of this nature ultimately led to the life cycle, and that (for the time being?) Man with his central nervous system, i.e. his memory, his mind, and his soul, stands at the end of this development and feels compelled to understand this development. For this purpose he must penetrate into the smallest units of time and space, which also requires new ideas to make these familiar concepts from physics of service in understanding what has, right into our century, appeared to be beyond the confines of space and time" (Eigen 1972, pp. 200-1).

342John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 150.

excessively "theoreticistic" picture of science that Wheeler arguably did not share. Eigen himself, in a series of retrospective interviews in the late '90s, spoke for instance of the way his research was led by the idea of "using nanotechnology to do evolutionary experiments" (Eigen 1997), thus hinting also at a conceptual feedback and an opening of new perspectives thanks to these technologies. In short, to put it simply, we can certainly emphasize Wheeler's and Eigen's tenet that a *lato sensu* Darwinian interplay between randomness and self-organizing structures, as well as the role of "information", were going to provide crucial elements for a new grand view of scientific knowledge.[343] In turn, the understanding of assemblage and information exchange at small scales would open new possibilities to intervene directly. We do not intend to collapse Wheeler's and Eigen's views on Drexler's famous "prophecy" of molecular engines and so on (Drexler 1986), but it is certainly interesting to relate these various perspectives, coming from very different angles. When Eigen (1997), recollecting his ideas, asks: "Now, why not using again nature's technology?", it is difficult not to perceive *in nuce* that same sort of partial technologization of nature, or naturalization of technology, which is present no less radically also in Wheeler's thought from the late 1970s on, as we have already hinted at and we will now see better. After all, these last few paragraphs, from the point of view of the history of science, may only represent some relatively interesting opinion, since it would be far-fetched to claim that Wheeler had an impact on these specific issues. Bringing them to light was useful for the purposes of the present paper, so that we could better identify an underlying attitude of his, some broader reflections he entertained, some dichotomies that were challenged, and what the framework of "law without law", with its statistical-only regularities, could encompass, but now we can also examine how all that gets mirrored in Wheeler's suggestions when it comes to fields where his ideas have been much more relevant and impactful.

5. Towards "it from bit": monads and information

If we open Leibniz's *Monadologie* and take a look at paragraph 17, we can find his famous windmill argument (Leibniz 2014, p. 17):

> "And if we suppose that there were a machine whose structure makes it think, feel, and have perception, we could imagine it increased in size while keeping the same proportions, so that one could enter it as one

343For all that they both resorted to the metaphor of "game", as we have partly already seen and will mention again.

> does with a mill. If we were then to go around inside it, we would see only parts pushing one another, and never anything which would explain a perception".

Where to find a boundary between life and inert matter? From what we have discussed in the previous pages, it is legitimate to expect that there is no such boundary in Wheeler's view. Nonetheless, recalling what we have said about the heuristic awareness of those scientists, we may also exclude a "So what?" reaction, mindful of the surprises and unexpected discoveries that would be waiting along the path. After all, the "mechanicalization" of nature that Leibniz was contrasting had been declared dead by Wheeler himself with his dismissal of Laplace's demon as well as of a central "mechanism" of the world. Still, there is some irony in the fact that Wheeler, in order to develop his views, took inspiration from Leibniz's monadology.

In order to see again, but now in this new context, how come Leibniz's figure (perhaps it would be better to say: Wheeler's Leibniz) is a sort of ferryman that can guide us from Wheeler's early 1970s reflections until "it from bit", let us take a look at a relatively bizarre passage from the last, visionary chapter of *Gravitation* (Misner et al. 1973, p. 1215):

> "That one geological stratum has one many-miles long slope, with marvelous linearity of structure, and another stratum has another slope, is either an everyday triteness, taken as for granted by every passerby, or a miracle, until one understands the mechanism. That an electron here has the same mass as an electron there is also a triviality or a miracle. It is a triviality in quantum electrodynamics because it is assumed rather than derived. However, it is a miracle on any view that regards the universe as being from time to time reprocessed ." How can electrons at different times and places in the present cycle of the universe have the same mass if the spectrum of particle masses differs between one cycle of the universe and another?
>
> Inspect the interior of a particle of one type, and magnify it up enormously, and in that interior see one view of the whole universe [compare the concept of monad of Leibniz (1714), "The monads have no window through which anything can enter or depart"]; and do likewise for another particle of the same type. Are particles of the same pattern identical in any one cycle of the universe because they give identically patterned views of the same universe? No acceptable explanation for the miraculous identity of particles of the same type has ever been put forward. That identity must be regarded, not as a triviality, but as a central mystery of physics".

Let us now look again at this passage from Wheeler's "The Computer and the Universe", almost a decade later (Wheeler 1982a, p. 560):

> "One who comes from an older time and is accustomed to the picture of the universe as a machine built out of "atoms" is not only baffled but put off when he reads Leibniz and Leibniz's conception of the ultimate building unit, the monad (Leibniz, 1962):
> '1. The Monad, of which we will speak here, is nothing else than a simple substance, which goes to make up composites; by simple, we mean without parts.
> 2. There must be simple substances because there are composites; for a composite is nothing else than a collection or aggregation of simple substances.
> 3. Now where there are no constituent parts there is possible neither extension, nor form, nor divisibility. These Monads are the true Atoms of nature, and, in fact, the Elements of things.
> …
> 7. There is also no way of explaining how a Monad can be altered or changed in its inner being by any other created thing, since there is no possibility of transposition within it . .... The Monads have no windows through which anything may come in or go out.
> ...
> 9. Each Monad ... must be different from every other...'
> These words of Leibniz about the "monad" are more relevant to "quantum phenomenon" than to anything one has ever called an "atom"".[344]

While we already know that the story of how Wheeler developed a passion for Leibniz and transfigured his thought in his own way is complex and rich, we are now in the position of making sense of these two quotes without following all its threads. We can in fact recall that the extended passages discussed in the previous subsection are from Wheeler's lectures in Varenna 1977, midway between these two other quotes. Keeping in mind what we have learned from them, it is perhaps excessive to see already in the 1973 passage some seed of that partial technologization of nature or naturalization of technology

344As stated just before this same passage, by "quantum phenomenon" Wheeler, echoing Bohr, meant that "[n]o elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon" (Wheeler 1982a, p. 560). In the light of Wheeler's "critical" turn, we may notice the resemblance to Kant's notion of phenomena, which include the precondition of their observation by us, even if the meaning of "observation" is notoriously insidious and hides important differences as well.

mentioned above: after all, we know that, in those years, Wheeler would also pursue other ideas in parallel, such as the cosmogonic observer-participator (there are some hints already in that same chapter of *Gravitation*). Nonetheless, we can already perceive *in nuce* (or as a stage of maturation) some thought that would make its explicit appearance a few years later. Wheeler is starting from an analogy with geology: Lyell and Darwin would remain a source of inspiration: they are quoted also in the Varenna lectures (Wheeler 1978). They have provided us with a gaze capable of looking at rocks as traces of natural processes, windows on remote times and situations.[345] Wheeler, who was never satisfied with the fundamentality of the so-called elementary particles, especially after the explosion of the particle zoo (Blum, Brill 2020; Furlan, Gaudenzi 2021), certainly did not consider the latter as the "basic building blocks" of the universe; by the 1970s, he was no longer looking at them merely as something derivative, but also as something "historical", so to speak, encapsulating information about the primordial processes that gave them the features we can measure nowadays.

At a superficial glance it may seem as if Wheeler were mistaking, in a very anti-Leibnizian way, Leibniz's monads for material particles, but his reference is subtler and more interesting, as we have already hinted in Chapter 4. That encapsulation of information makes the particles, we could say, petrified monads, in the sense that they can reveal to us a sort of frozen "point of view" on those remote situations. In this passage, Wheeler is still entertaining the "naturalistic" cyclic cosmology of his quantum geometrodynamics, where some mechanism is supposed to assign specific values to particles from cycle to cycle: the one responsible for all of this is not the cosmogonic observer-participator or any form of "consciousness". In order for us to speak about particles we surely need an experimental apparatus, but by the time of the Varenna lectures Wheeler – trying to explain (instead of taking for granted) why our observations of particles always have some limited set of values – was ready to extend the idea of "probe" avoiding in principle any distinction between conscious and inert, organic and inorganic: "the central point is not 'consciousness', not even an 'observer', but an experimental device – grain of silver bromide, Geiger counter, retina of the eye – capable of an "irreversible act of amplification" (Wheeler 1978, p. 19). A probe is not necessarily, then, a tool chosen by us, an "artificial" interference with a "natural" quantum system: rather, it sounds like a relational property, a relative qualification.[346] "Not consciousness but the distinction

345One of Wheeler's brothers was a geologist, we may add, of course without trying to reduce his use of the analogy to that. Here we highlight the "historical" dimension that is analogically implied, but in other cases there is also an emphasis on stratification: see the "geology of the vacuum" in (Furlan, Gaudenzi 2022).

346Needless to say, more recent explanations of this relational aspect owe a great debt

between the probe and the probed as central to the elemental quantum act of observation" is the long and irrevocable title of a paper prepared shortly thereafter (Wheeler 1981). Its occasion was a symposium of the American Association of the Advancement of Science held in Houston in 1979. The topic was "The role of consciousness in the physical world" (Jahn 1981). The keynote spokesmen for physics were precisely Wheeler and Wigner.[347] On the one hand, Wigner's intervention is significantly titled (in the light of what we have previously claimed) "The extension of the area of science" (Wigner 1981). On the other hand, Wheeler's assertive title assumed a further connotation because of a curious "accident": at that symposium Wheeler and Wigner had found themselves in the company of parapsychologists and people speaking about "consciousness" in a very different sense from theirs. Wheeler's reaction was quite strong and, in the proceedings, we can find two appendixes written by him.[348] In Appendix A, "Drive the pseudos out of the workshop of science", Wheeler does not hesitate to state: "The author would be less than frank if he did not confess he wanted to withdraw from this symposium when – too late – he learned that so-called extrasensory perception (SCESP) would be taken up in one of the papers" (Wheeler 1981, p. 99).

In the more discursive Appendix B, "Where there's smoke, there's smoke", we can find again his references to Pugh, Cooper, von Neumann, Bohr. In synthesis, putting anecdotes aside: once Wigner's positions about the role of consciousness were rejected,[349] we can see how in 1977 Wheeler's emphasis on Bohr's definition of phenomenon and the "depersonalization" of the measurement process points precisely in this direction.

The unexpected turn after that is the assimilation of (Wheeler's take on) Bohr's ideas to (Wheeler's reading of) Leibniz's monadology – but *c'est*

towards Wheeler. Some of his ideas, in turn, seem partly reminiscent of issues he had discussed with his student Everett back in the 1950s. See e.g. (Everett 2012, p. 182): "Consider any measuring apparatus interacting with any object system. As a result of the interaction the state of the measuring apparatus is no longer capable of independent definition. It can be defined only *relative* to the state of the object system. In other words, there exists only a correlation between the two states of the two systems".

347A couple of years later, in 1981, at the Nobel Conference XVII at Gustavus Adolphus College (St. Peter, Minnesota), titled "The place of mind in nature" (Elvee 1982), we meet again Wheeler and Wigner: choosing this duo as representatives of physics *lato sensu* was quite meaningful (the other invited speakers were Karl Popper, Richard Rorty, Ragnar Granit, Wolfhart Pannenberg: two philosophers, a neurophysicist, a theologian, and no parapsychologist).

348In Wheeler's archives we can also find five folders collecting "Extrasensory perception, dowsing materials" (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, boxes 73-74).

349That did not mean that they stopped discussing about these issues: see e.g. the acknowledgements in (Wheeler 1990).

Wheeler.[350] Even setting aside his Leibnizian idiosyncrasies, as much as fascinating as they are, there are two points worth highlighting. One is that, by using as a heuristic scaffolding his own "updated" monadology, Wheeler completed that process of depersonalization we have already hinted at: to use a different jargon, we may say that he transferred (or better: extended) the agency in quantum measurement processes from the human observer to what appears as "things".[351] After Wheeler gave his "anthropic" speech for the fifth centenary of Copernicus, we can read in the proceedings the comment of one of the participants (the philosopher Daniel J. Callahan): "In a curious sense, and particularly after hearing Professor Wheeler this morning, I came to feel that, despite all the talk of the Copernican Revolution – which supposedly displaced man from the center of the universe – he was really coming back to say that indeed man is still the center of the universe" (Gingerich 1975, p. 587). This was a (well motivated) misunderstanding. Yes, Wheeler had shifted the center on mankind, but not in a static or exclusive way. After putting forward his model of the cosmogonic observer-participator, with its almost solipsistic flavor,[352] he recognized the plurality of centers – his monadology – and depersonalized the basic quantum processes: overall, the resulting vibe of his participatory universe, at least at that point, is more similar to the enthusiasm that permeates Giordano Bruno's universe, with its center in all places and in no place, teeming with life and activity, than to the hierarchy of a geoanthropocentric cosmos.[353] Wheeler, as usual, did not reject his former

350For further heuristic reasons behind this move, see (Furlan 2020b).

351It would certainly be interesting to confront these ideas with the development of the quantum decoherence view, during the 1980s, also in circles that were close to Wheeler.

352That is certainly not how Wheeler meant it, however: "Solipsism, no; communication, yes" (Wheeler 1988d, p. 127). "What is required in the analysis of genesis is not private judgment, but public judgment – which is to say, science. If judgment is an awareness of all the factors in a situation and an appreciation of their relative importance, science evidently includes that and more: falsifiability. Not only should the individual steps along the way open themselves to detailed analysis. In addition the final overall picture should, in the words of Mendeleev, "expose itself to destruction". It should make predictions that are new and testable. Both analysis and testing are public. Any qualified analyst from anywhere has the democratic right to trace out and verify for himself one by one the logical links in a chain of analysis. Any qualified observer from anywhere has the democratic right to do an experiment, or make an observation, and see for himself whether it agrees with a prediction" (Wheeler 1977, p. 29). Mendeleev makes a quite odd appearance, again; nonetheless, we may notice that Popper is explicitly thanked in the acknowledgements of the paper and that, in (Wheeler 1990, p. 319), the same expression ascribed to Mendeleev is – predictably – associated with Popper.

353Of course, an important disanalogical aspect is that Wheeler's cosmological preference was for a closed rather than infinite universe (Blum, Furlan 2022): there is even the record of a 1978 bet in which Austin Gleeson decided to stake one dollar that the universe is open, while Wheeler wagered one hundred dollars that the universe is closed (John Archibald Wheeler

ideas: he just transformed them. We may say that the "global" cosmogonic observer-participator ended up being a sort of toy model for Wheeler's local elementary "acts of observer-participancy" or monads, which in turn became his "bits", as we will further discuss in a moment.[354]

> "Are life and mind indeed unimportant in the workings of existence? Is life never to inherit the vastness of space because today its dominion is so small? Or is not rather life destined to take possession of all the out-there because the time available for conquest is so large? How easy it is to be overimpressed by the remoteness of the quasars; how tempting to discount as anthropocentric any purported place for life and mind in the construction of the world. Is it not even more anthropocentric to take man's migration by foot and ferry in fifty thousand years as the gauge of where life will get in fifty billion years? The fight against here-centeredness began with the 1543 *De revolutionibus orbium coelestium* of Copernicus. The time-bridging power of the elementary quantum phenomenon warns us today to battle against now-centeredness.
>
> Life and mind: for how much can they be conceived to count in the scheme of existence? Nothing, say the billions of light years of space that lie around us. Everything, say the billions of years of time that lie ahead of us. It cannot matter that man in time to come will have been supplanted by, or will have evolved into, intelligent life of quite other forms. What counts - in the ideal view being explored in this paper - is the rate of asking questions and obtaining answers by elementary quantum phenomena, acts of observers-participancy, exchanges of information" (Wheeler 1988b, pp. 125-6).

That interplay between global and local actually runs quite deep in Wheeler's reflections of those years. In (Blum, Furlan 2022) it was for instance noticed that, Wheeler's interest in and affinities with Eigen and Prigogine notwithstanding, his attempt at conciliating life and the cosmos differs from theirs because it is global (truly!): it was a matter concerning *ab initio* the whole universe and its very existence.[355] Eigen's hypercycle or Prigogine's

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Papers, American Philosophical Society Library, Philadelphia, box 254). That, however, is not really the point here and, in any case, we will perceive some further strong resonance with a Brunian vibe in the concluding quotation of the present paper.

354This puts some quite strong constraints if one wants to speak about Wheeler's "idealism": what kind of idealist would in fact develop a monadology *after* the cosmogonic observer?

355We have already pointed out that Hoyle too can be taken into consideration: his panspermia, in this sense, represents another "global" approach to the question of life in the universe. Again because of this "global" character, moreover, there is the possibility of drawing a curious compare-and-contrast, somewhat illustrative at least on a philosophical

dissipative structures, instead, can be seen more as attempts at showing the local viability of the emergence of life.[356] This oscillations, in a sense, also remind us that, from first exploring the nuclear and subnuclear world, Wheeler was then led to the extremely large – black holes and the destiny of the universe and its laws –, afterwards back to the extremely small – the quantum world and its lessons about the observer – and, from there (even if we have by now noticed that these successions, in Wheeler's case, are always an oversimplification, both due to his "cosmoparticle" perspective and his polytropic pursuit of ideas), he tried once again to build a view of the universe and of our place within it.

The other aspect that we have still to properly underscore, after everything we have said, is that Wheeler's "bits" are quite different from received views about his "it from bit" (or, according to the "updated" slogan,

level, between Evald Ilyekov's "Cosmology of the Spirit" (Ilyenkov 2017), which is also globally postulating the existence of the mind, and Wheeler's participatory universe (and its moral implications, as suggested by a previous footnote here). I will return to this in some other work about the cosmic dimension of such phantasmagoric narratives during the Cold War; moreover, these ideas are not unrelated to the already mentioned Dyson's scenario of eternal intelligence (Dyson 1979).

356Another "filter" through which we could look at this tension between a global and a local approach is semiotics. We have already mentioned how Wheeler's interest in Peirce (Furlan 2022), while certainly not the driving force of his reflections, could have nonetheless helped him to "semiotize" and "depersonalize" the role of the observer (and at least this is a stimulating theoretical confrontation): indeed, in (Patton, Wheeler 1975) we can find a sort of florilegium of Peircean quotes about the role of the "mind" or, in more impersonal terms, of the interpreter. (The semiotic considerations in (Dosch et al. 2005), partly inspired by Peirce, about the plurality of formalisms in quantum field theory do also resonate with what I have above called Wheeler's "quantum ecumenism"). Nonetheless, if we broaden our semiotic references to include Lotman and his notion of "semiosphere", with his global or holistic approach to semiotics (Lotman 1990), Peirce's semiotics appears somehow "atomistic", in the sense that it describes local processes which are then combined to try and construct the global. Wheeler's "semiotization" of quantum measurement processes (the elementary acts of observer-participancy or monads) are indeed, in the sense just outlined, "atomic" and gradually assembled in a combinatorial way, even if all "wired up together". However, Wheeler's former "global" approach does not get entirely lost: his emphasis not just on "information", but also on "meaning" (Wheeler 1990), which is supposed to emerge from the overall "game", makes these semiotic suggestions even more relevant. Although Wheeler, when asking questions about "meaning", mainly references Dagfinn Føllesdal (e.g. Wheeler 1977; 1986a; 1990), here is another possible link to his interest in Wittgenstein's thought; and we have seen the metaphor of the "game" already in the Varenna lectures, as well as in Eigen (and Ruthild Winkler)'s book "Das Spiel", quoted in (Wheeler 1978; 1986a). In any case, with Lotman's distinction in mind and these Wheelerian resonances, it may also be stimulating to go back to what Bohr was quite cryptically saying, in an interview during the last days of his life (Bohr 1962), about his fascination with William James, his "stream of thoughts", the impossibility of an "atomistic" analysis of these thoughts and some analogy (another "wider field"!) that he was perceiving with his own epistemological questions.

"it from qubit"). As we have already said more than once, Wheeler's bits are not "naturalistically" given, *Gegeben* (recall his "critical" turn): they are rather the *result* of a process, more precisely of the simplest quantum measurement process that admits a binary answer. It is possible, in a sense, to put a sort of conceptual cut-off and say: let us start once we already have the binary answer, or bit, and take it as a basic unity.[357] This, however, is a great simplification, or even distortion, of Wheeler's view and philosophical attitude. We may agree with the already quoted comment by Fuchs (2016) when he says that it was precisely because Wheeler's powerful ideas were vague that they proved to be so fruitful and visionary; and perhaps we could suggest that Wheeler's vagueness was not a shrewd move to cover many possibilities, but – in light of the explicitly "maieutic" role he had given himself – it was *meant* to be later articulated and implemented in different ways in more circumstanced proposals: the fact that he could inspire approaches as different as QBism by Fuchs himself or David Deutsch's variations on "it from qubit" (Deutsch 1997) witnesses to that. Nonetheless, this should not prevent us from recognizing that similar positions, even when they are explicitly invoking Wheeler as an inspirator, anticipator or ancestor, are just looking at his complex framework from one side. As a matter of fact, it is instructive to very briefly survey how Wheeler arrived at his ideas about "information". Differently from what one could expect from popular stories of how this notion came to pervade science (e.g. Gleick 2012), Wheeler did not "import" information theory *sic et simpliciter*. If anything, it is quite striking that, in the variety of disciplines and authors quoted by Wheeler in his late papers, Shannon is a regular absence, even if his presence is documented in a well-known volume co-edited by Wheeler (Wheeler, Zurek 1983),[358] as well as in the work of people who, to varying degrees, contributed to the shaping of Wheeler's ideas, such as the latter's students Hugh Everett (Barrett and Byrne 2012, p. 61) and Jakob Bekenstein (Belfer 2014).[359] Once his focus was on

357This may also be due (e.g. as in David Deutsch's case) to a different underlying view of quantum mechanics, such as the Everettian.

358In Wheeler's archives (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 108) there is also an annotated copy of a 1975 paper by Richard D. Moore, "A Physical Definition of Meaning". Wheeler added a date, "Jun 26 1986" (relatively late in the genesis of his ideas, then), while right above the title he wrote down the role he presumably assigned to the paper: "The relation between the Clausius-Shannon identity and meaning". That is quite meaningful (no pun intended), since, as usual, Wheeler was wary of abstract formalisms until he could clearly establish their physical relevance. In the case of information and information theory, as we have already seen, his concern was mainly with the role of "meaning" in the circuit of observer-participancy. It is interesting to note that Manfred Eigen's ideas are referenced in Moore's paper as well.

359Speaking about Bekenstein, information, and black holes, it is also worth noting that, in the "Open Discussion" following the papers by Wheeler and Dyson at the Einstein Centennial

information, Wheeler did actually make reference to one of its standard routes into physics, the thermodynamic one (Wheeler 1988d, p. 109):

> "For a new understanding of how information fits into the scheme of things, we are indebted to no one more than Rolf Landauer. His work, and that of Szilard, Christodoulou, Bekenstein, Hawking, Fredkin, Toffoli, Bennett and others, has created new ties among information as bits, information as negentropy, information as mass-energy, and information as elementary quantum phenomena. The way of thought of information theory, we nevertheless can believe, will be of as much help in the new enterprise - to understand self-synthesis as plan without plan - as it already has been in the task of explaining entropy in terms of the elementary yes, no actions of the famous demon. More than one distinguished investigator - Kelvin, Maxwell, Szilard, Landauer, and Bennett - had to contribute an important idea before the final point became totally clear: The 'thermodynamically costly act, which prevents the demon from breaking the second law, is not (as is often supposed) the measurement by which the demon acquires information about the molecule being sorted, but rather the resetting operation by which this information is destroyed in preparation for making the next measurement'".[360]

It would be misleading, however, to assume that this represented Wheeler's own path towards the relevance of information.[361]

Symposium held in Princeton, Wheeler and Wigner had a quite interesting (and early) exchange about "information" and the destiny of what falls into black holes. After a while, Dirac (acting as chairman) suggested: "This discussion had better be completed in private", but the audience, evidently captivated by the topic, objected (Woolf 1980, pp. 381-383).

360Since we have been speaking of Wheeler's relationship with the Hungarian "Martians", we may just say that, on a personal basis, Szilard was the one he liked the least: "I admired Szilard for his flashes of brilliance and his enthusiasm, but I confess that I was among those who had trouble exercising patience with his eccentricities" (Wheeler 2000, p. 39). Back to the quote, Wheeler's relationship with Landauer would certainly deserve further attention (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, boxes 51, 148, 202). The same paper from which that passage is taken actually ends with the following dedication (Wheeler 1988d, p. 128): "This paper is dedicated to Rolf Landauer on the occasion of his 60th birthday and in special appreciation of an important lecture given by him, 'Computation: A Fundamental Physical View' at the IBM United Kingdom Symposium, Science and Paradox, London, March 1987".

361Interestingly enough, we are now in a position to see how the evolution of Wheeler's thought took him from a first-principles setup to an increasingly statistical emphasis. In a sense, we can easily realize this by thinking of Maxwell's devil: in the case of "everything is electron", indeed even a single electron, perfectly governed by the Dirac equation, we can imagine it (as Wheeler did at one point) going back and forth in time. "Ask a [single]

Rheinberger (2010, pp. 203-214) has shown how the introduction of the notion of "information" in molecular biology, if we take a close look at the work of someone like François Jacob, was actually the result of more or less subtle "hybridizations" trying to merge together notions and practices from different scientific subcultures. These transformations typically get lost in the dominant narratives (both within scientific disciplines and in popularization) that back-project more recent results and just add a few chronological labels or milestones. All this – both the hybridizations and the misleading narratives – are macroscopically evident if one takes a closer, but still cursory, look at Wheeler's case. His ideas about some fundamental binarity (or bit) are the result of various suggestions, coming (but not deductively following!) from earlier topological insights about spin (as "nonclassical two-valuedness", as Wheeler liked to put it echoing Pauli) without spin, that is his hope of explaining spin in geometrodynamical terms (e.g. Misner et al. 1973, p. 1204); but also from propositional calculus (for a while considered by Wheeler as a candidate for "pregeometry", a deeper level than spacetime and thus than geometrodynamics: for a synthesis, see (Misner et al. 1973, pp. 1211-2), from his meditations on the destiny of matter falling into a black hole (as already mentioned with reference to Bekenstein), and even from Leibniz's fascination with binary calculus. All these aspects do make for a very idiosyncratic hybrid. There were also, as already mentioned, some "minimalistic" considerations: once Wheeler convinced himself that quantum processes were at the basis of everything, it was quite natural to think about the simplest case, one admitting a binary answer.[362] In Wheeler's own words (Misner et al. 1973, p. 1208):

> "Among all the principles that one can name out of the world of science, it is difficult to think of one more compelling than simplicity; and among all the simplicities of dynamics and life and movement, none is starker [Werner (1969)] than the binary choice yes-no or true-false. It in no way proves that this choice for a starting principle is correct, but it at

molecule about the flow of time and it will laugh in your face", Wheeler is reported to have said (Barrow et al. 2004, p. 15). By the 1980s, the statistical character of a large number of particles is no longer a mere approximation, but the epitome of law without law. This brings epistemic changes in the way of practicing and conceiving physics as well, as we shall mention in the conclusion of this chapter.

362Similar, in this regard, to Weizsäcker's *Ur-alternativen*. Wheeler and Weizsäcker developed their ideas in a largely independent way (Finkelstein's own ideas may have acted as a bridge), but were actually aware of each other's perspective and privately discussed affinities and differences. Some brief historical mention can be found in (Furlan 2020b), but it is another matter waiting for a specific study.

> least gives one some comfort in the choice, that Pauli's "nonclassical two-valuedness" or "spin" so dominates the world of particle physics".

This is not to say that the analogy with computers did not cross Wheeler's mind, on the contrary: the already quoted "The Computer and the Universe" (Wheeler 1982a) is the clear outcome of that, but it should be clearer (even just because of the intertwinement with monadology) that, besides emphasizing disanalogical aspects as well,[363] Wheeler was not merely suggesting a change of paradigmatic metaphor – from the universe as clock to the universe as computer – nor is his view reducible to more recent narratives such as that by Seth Lloyd (2006) or some reification of "data science". Wheeler's magmatic, multifarious, heuristic use of "information" is also reflected in other "hints" that he associated with "it from bit", such as the Aharonov-Bohm effect, and regarded as "evidence" that "the whole show is wired up together" (Wheeler 1990).[364] This can easily show how much the suggestions disseminated by Wheeler's framework went beyond the community of people that were making explicit reference to "it from bit" or were decently aware of that. For instance, recent work at Utrecht Universiteit (Kempkes et al. 2019) concerning the behavior of electrons in fractal spaces – a nanoscale Sierpiński triangle – suggests interesting properties of "fractal quantum mechanics" (such as global effects *ab initio* due to the "information" of those geometric constraints), which resonate with other examples adduced by Wheeler. However silently, mediately or distortedly, it seems that his "it from bit", or better the framework he envisioned behind this slogan, some trivializations notwithstanding, is far from exhausting its fecundity or, to borrow an expression from Manfred Eigen (1972), its "unused possibilities". The preparation of the nanoscale Sierpiński triangle is just another manifestation of that manipulation of matter at nanoscales – not for merely practical or applicative purposes – that we have been emphasizing.

> "We can ask ourselves if it is not absolutely preposterous to put into a formula anything at first sight so vague as law without law and substance without substance. How can we hope to move forward with no solid ground at all under our feet? Then we remember that Einstein had to perform the same miracle. He had to reexpress all of physics in a new language. His curved space seemed to take all definite structure away

363 We have seen how, in the Varenna lectures, Wheeler was referencing von Neumann, more specifically his lectures "The Computer and the Brain". The title "The Computer and the Universe" (Wheeler 1982a) could perhaps be a nod to that, too. In both cases, we see the examination of analogical and disanalogical aspects, even if, in larger audiences, the "and" of both titles typically became later a much less subtle juxtaposition or even identification.

364 In a sense, we thus find again that "global" aspect of Wheeler's reflections.

from anything we can call solidity. In the end physics, after being moved bodily over onto the new underpinnings, shows itself as clear and useful as ever. We have to demand no less here. We have to move the imposing structure of science over onto the foundation of elementary acts of observer-participancy. No one who has lived through the revolutions made in our time by relativity and quantum mechanics - not least through the work of Einstein himself - can doubt the power of theoretical physics to grapple with this still greater challenge" (Wheeler, Zurek 1983, p. 210).[365]

6. Conclusions

Following Wheeler's trajectory across many fields, we have seen how, in the late decades of his long career, he developed a picture of the scientific enterprise which is very different from what one may expect from the "visionary" theoretical physicist whose legacy keeps shaping – in terms of expectations, questions, guiding ideas – very speculative areas such as quantum gravity. The shift that brought him to pay more and more attention to the role of the apparatus, to the preparation of the experiment, or more generally to the preconditions of physical knowledge, can be seen as metaphorically mirrored by the dismissal of Laplace's demon (or similar conceptual characters) and the appearance of the observer-participator and, then, the "modern maestro of matter". From a kind of science that contemplates to a kind of science that makes, without losing its theoretical breath and some self-reflectivity.[366] The purely rationalistic *theoria* is gone; the dimension of *making* science, as expressed by the two components that constitute the very adjective "scientific" (*scientiam facere*), is brought to the fore. Although this balance between between boldly speculating and pragmatically having one's finger on the pulse, so to speak, is a trait that characterized almost every period of Wheeler's activities, during which he juxtaposed very concrete issues – such as his military work – and his much more ambitious theoretical insights, it is only in his late phase that Wheeler comes to fully integrate both of these aspects into his scientific, or even epistemological, vision. Against the background of all this, as we have discussed, the figure of the modern maestro of matter is evidently not inspired

365Notice once again the optimism and faith in the understandability of the world, regardless of the approximative character of laws.

366We may suggestively juxtapose (Fig. 7), in a sort of montage, the picture used by Wheeler to convey his ideas about the cosmogonic observer-participator and a plate by the engraver Albert Flocon, portraying a hand which is not just in the act of making but also in that of being made.

by some mere bomber, but draws upon much of Wheeler's vast experience. The rich and diversified network of references that Wheeler started weaving around "law without law" shows very well to what extent all the questions we have been mentioning flowed into a peculiar picture of scientific activity.

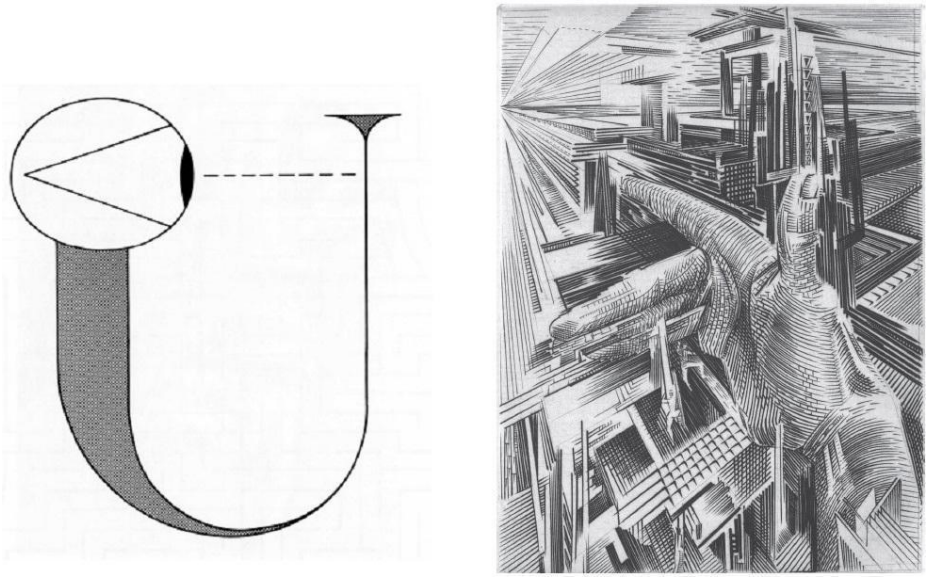

Fig. 7. On the left: the icon of Wheeler's self-referential cosmology, with the eye of the cosmogonic observer-participator looking back in time in the history of the universe (U). On the right: plate "Le trièdre" (12.5 x 9.5 cm) by Albert Flocon. Source: (Wheeler 1980a, p. 362) (left); (Flocon 1952; Rheinberger 2013, p. 365) (right).

What we have highlighted about the relations between Wheeler's more general reflections and the possibilities opened by the manipulation of matter at small scales can certainly be put in closer dialogue with "less unconventional", or more mainstream, developments, such as the rise of nanotechnologies and the expectations around them. Sure, it is very well possible that, assuming there are no major surprises from archival explorations, Wheeler's relevance to fields such as nanotechnology is not destined to go much beyond the issues outlined in the previous pages, even if it is also possible that, while acting as a government military consultant or cooperating with organizations such as the Battelle Memorial Institute, Wheeler heard and discussed many more "futuristic" proposals that, today, we could include among the inspirations or ancestors of nanotechnologies. However, our purpose was certainly not to compile such a list, nor to fall into the rhetoric of the "prophetic" theoretical precursor,[367] nor to sacrifice Wheeler's peculiarities in order to corroborate or

367As we have clarified in the very beginning even for Feynman's case. We have also seen en passant how Wheeler's appeal to great names of the past and the narratives thus suggested were, precisely because of their originality and great buoyancy, much less insidious and passive; but that is also why they can provide a sort of unfiltered version to get insights on the

contest some collectivist theses (e.g. Forman 2007) about technology taking over science during the period of "law without law" and "it from bit" (assuming that the hegemony of "pure" science was not a myth to begin with).[368] I rather intend to suggest that, by training the eye to follow a trajectory such as Wheeler's and adopting for a moment his original (or even eccentric) perspective, received views can be more interestingly problematized, while at the same time new insights and a more complex picture of scientific thought and its working can be gained. Beyond the "factual" dimension, so to speak, of the development and impact of some of Wheeler's ideas, it is appealing to consider his specific case as a sort of benchmark for whoever reflects on recent disciplines that have arisen at the confluence of various fields and were immediately charged with grandiose promises, for a series of reasons.

For instance, Wheeler's exuberant rhetoric is second to none, even in its futuristic *élan* – but his vicissitudes can also suggest us to ask: what happens when this impetus towards the future has not the anchors of something analogous to daring conservatism? On another level: especially since there are studies with titles such as "Advertising nanotechnologies: imagining the invisible" (Campbell et al. 2015), how can we forget that the same Wheeler is a prime example of an effective ability to make others visualize the invisible, both thanks to his verbal and visual rhetoric? Now we are not speaking of the cartoonesque shrunken human figure or the staircase of physics, but of black holes, quantum foam, it from bit, and so on. But what happens when this rhetoric, instead of being recognizably flamboyant and *sui generis*, but also enriched by an actual intertwinement with heuristics, merely repeats or corroborates some widely spread *cliché* and assumptions, and is self-feeding with unrealistic sensationalism? Even without wishing to go into the specifics of their criticism, can we not say that, when physicists such as Robert Laughlin (2005) or Philip W. Anderson (2005) dismissed, with a certain contempt, the promises of nanotechnologies aiming at controlling and disposing of single atoms, they were, in a sense, mocking a Laplacian demon disguised as a nanoengineer? Nothing new for figures such as Wheeler or Eigen, who were well aware of that and were certainly thinking along very different lines, but are we sure that some myopic disciplinary narrative is capable of fully appreciating that?

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mechanisms underlying the creation of such "pedigrees".

368Nonetheless, a proper embedding of Wheeler's reflections in studies about broader tendencies could definitely be the starting point of a compelling study. Kwa (2011), proposing to consider "styles of knowing" also with reference to the "technoscience" supposedly emerged around those decades, may offer some further inspiration: after all, in the light of what we have examined it is hard not to perceive Wheeler's as a peculiar, but not exclusively personal, "style".

Mülberger and Navarro (2017), offering some historical-critical perspective about the promises of recent fields such as nanotechnology, remarked on how also the related historiography not rarely remains caught in the same scheme of those promises: "history was often re-written so as to justify the actual discoveries as the outcome of a previous promise. The strong and long-lasting impact of science in our societies is often interpreted as due to the audacity and the effectiveness of promises that science supposedly delivered successfully" (Mülberger, Navarro 2017, pp. 167-8). In order to break this mold, exceptional and partly eccentric trajectories such as Wheeler's can provide means to enlarge the horizons and to probe more general theses, without falling into the academic game of "case studies", simply meant as examples or counterexamples. It is rather about a tension between a specific case and a sort of middle view – a tension which is supposed to result in new questions, new angles, or further nuances. If the typical *divide et impera* of the scientific way of facing questions can usually boast its effectiveness, imitating it historiographically does not sound like a brilliant idea. As Canguilhem (1968) used to repeat, the object of the history of the sciences is not the same object of the sciences themselves. More specifically, staying within the disciplinary narrative just produces quite gross back-projections of today's situation, with its notions, disciplinary boundaries and assumptions. Especially when dealing with fields at the interface between larger areas, we cannot afford to neglect, understate or oversimplify how the involved concepts and practices have their own story and their occasionally long process of maturation, how they not rarely undergo exaptations, and so on: all features that we have highlighted in Wheeler's case. The fictitious chronological line induced by back-projections, decorated with some numerical labels and milestones, is not history: it is just the perpetuation of the blueprint of promises associated with the emergence of that new field, even when it contests them on specific points. It is not good material for philosophical or conceptual analyses, either: all the hybridizations and analogies we have hinted at – bound to happen in those intersectional areas – are simply ignored or just assumed *de facto*, in retrospect, as given. The resulting picture, no matter how many lenticular technical details it may possess, is quite poor and ends up repeating the conflation between, for instance, nanotechnologies and the history or philosophy of nanotechnologies – as if to say: that is the disciplinary boundary, let us just look at what happened inside. As Rheinberger (2016, pp. 175-6) once put it,

> "It is no accident that I have stressed the need for historians of both the natural sciences and the humanities to keep contemporary scientific practices in close sight. At least in the shape that it is usually pursued in

> the academic and public sphere, the abiding debate on the natural sciences' relationship with the social sciences and humanities too often suffers from a failure to uncover the true intricacy of the particular front lines running through research at any one time. Yet it is important to notice that, however much we might like to retreat behind those front lines, they are currently in the process of dissolving while others are taking shape. Tracking reconfigurations like this from close up [...] and reflecting on them both epistemologically and in their historical shifts could contribute to a more realistic picture of the process of scientific development over time, a process that is both highly regionalized and highly mobile in its recombinations".

It would be indeed ironic if, after discussing, content-wise, about movable boundaries and extended cognition, we were not be able to realize the need for analogous considerations, at a conceptual and historiographical level, about today's disciplinary fences and their mutability. Likewise, after seeing Wheeler's own reflection becoming "critical" and paying attention to actual practices and preconditions, we may seriously ask what is the point, historiographically and philosophically, of a misplaced imitation of naively naturalistic attitudes just to vaguely sound "scientific" and jump on the bandwagon of "progress", while leaving intact and uncontested many undue extrapolations into the future and many gross back-projections onto the past.

> "We often find influential discourses voiced by scientists and natural philosophers using language in the future tense and one may legitimately wonder the extent to which the rhetoric of promise became intrinsic to the modern notion of science" (Mülberger, Navarro 2017, p. 167).

Granted, Wheeler himself can be characterized by that: we have seen how in 1962, in Venezuela, he was making predictions that were also promises, in the name of science in general, or how he repeatedly, almost constantly, spurred collaborators and students in new directions of physics. But Wheeler had a peculiar mixture of features, so to speak, that allowed him to offer fruitful suggestions for many decades – and this, especially in absence of a cultivated broader vision, is a rarity. As today we can clearly see in some highly speculative areas of science, the rhetoric of promise can thus even turn into an inveterate "epistemology of procrastination", that keeps writing checks in the name of a (purported) future full-fledged version of what we have nowadays. However, we may also say, without willing to neglect the specificities of the various circumstances, that it would be misleading to frame this as a peculiar

situation of recent times. The rhetoric of promise and its orientation towards the future, as Mülberger and Navarro (2017, pp. 167-8) go on saying,

> "is not new. From the days of Francis Bacon, if not earlier, natural philosophers and scientists often relied on supposed future outcomes in order to promote their specific research or their views on the world. [...] A well-known and recent example on the relevance of promises to legitimise and shape new scientific disciplines and large-scale research projects can be found in the history of nanoscience. Three decades have passed since K. Eric Drexler published his book *Engines of Creation: The Coming Era of Nanotechnology*, a key element in shaping the popular views on the future possibilities and dangers of nanotechnology. As Cynthia Selin discussed, "characterizations of nanotechnology have long occupied the space of the future, as in future benefits, future uses, and future scientific discoveries that might lead to a new world order." Granted, many scientists disregarded Drexler's rhetoric as counterproductive for the new discipline and spent much time and effort in downplaying Drexler's promises so as to prevent a general disappointment with the new field or opposition based on a purported nanotech-based apocalypse. And yet, as Selin and other STS scholars have shown, Drexler's arguments and images are still very influential in public, political, and economic debates that surround nanotechnology".

We could say that the projectuality of Wheeler's modern maestro is, in this sense, a feature of "modernity", but, in this context, it would sound a bit vague or trivial. What we have learned in this chapter, rather, is that, if the modern maestro is "full of projects" like Wheeler, it is also because there is no access to a superior *theoria* of gods and demons; or better, there is no such vision at all. My emphasis on heuristics throughout the sections was not only a necessity in order to make sense of Wheeler's changing ideas: it was also aimed at providing a view of science more subtly in line with Wheeler's reflections. In his eyes, laws are not given from eternity to eternity: they are not hyperuranian structures that grant the order of the cosmos. Getting to know them does not represent any longer that form of knowing *intensive* which, according to Galileo, is the same as God's. The saving promises of science such as those mentioned in the passage just quoted; many ways of presenting and teaching *ex cathedra* "what Science says"; a rigid and static way of considering the body of scientific knowledge, often with misplaced rigor and without any substantial historical sense; a naive Platonism about "formulae" in the more mathematized disciplines – all these are still somewhat

"theological" attitudes[369] toward science, even if everybody has learned to repeat the refrain about its perfectible and provisional character. "Law without law" can dispose of these "theological" residues and present instead an image of scientific activity that acknowledges human finitude but does not for that reason abandon its own greatest ambitions;[370] that recognizes the conditioning of our scientific knowledge without for that reason falling into those arbitrary and forms of constructivism that have little to do with science;[371] and that is heuristically transparent and flexible, as documented by all the papers Wheeler left,[372] without for that reason renouncing the efficacy of already established practices and formalizations.

> "The quantum, strangest feature of this strange universe, cracks the armor that conceals the secret of existence. In contrast to the view that the universe is a machine governed by some magic equation, we explore here the view that the world is a self-synthesizing system of existences, built on observer-participancy via a network of elementary quantum phenomena" (Wheeler 1988d, p. 103).

369I borrow this use of the adjective from Giulio Preti: I thank Fabio Minazzi for telling me about its anecdotal sources.

370There is of course some irony in the fact that Wheeler had pushed his "physical" speculations into theological realms more than once; but this comment presupposes a special status of theology, which Wheeler clearly did not admit. Besides the repeated denial (e.g. Wheeler 1982a, p. 557) that laws are eternally engraved upon granite (an obvious echo of the Tablets of the Law, given to Moses), also a statement like the following (from Wheeler's appearance in the 1991 documentary film "A Brief History of Time") is telling: "The word 'time' was not handed down from heaven as a gift from on high. The idea of time is a word invented by man, and if it has puzzlements connected with it, whose fault is it? It's our fault" (Wheeler 1991b).

371Besides everything we have been saying about "preconditions", the following passage is worth quoting (also to distinguish Wheeler from some gross scientistic on the opposite side): "There is not a word we speak, a concept, we use, a thought we think which does not arise, directly or indirectly, from our membership in the larger community. On that community the mind is as dependent as is the computer. A computer with no programming is no computer. A mind with no programming is no mind. Impressive as is the greatest computer program that man has ever written and run, that program is as nothing compared to the programming by parents and community that makes a mind a mind" (Wheeler 1988d, p. 128). We are thus seeing once again how a peculiar trait of Wheeler's way of practicing and conceiving science, in this case conviviality, gets explicitly integrated into his later vision as a constitutive, epistemological component.

372Unpublished but also published: as the reader may have realized by following Wheeler's trajectory and reading some of his passages, in his late phase he is using publications as suggestions and tentative ideas, an openly displayed work in progress (with great confusion for who was or is taking them as apodictic statements).

This character of science[373] becomes partly evident also in the way that Wheeler, after dismissing the superior kind of vision of gods and demons, recovered a strong (but at the same time modest) visual dimension in scientific knowledge, so important for his thinking. He even spoke of a new "physics of recognition" (Wheeler 1983b), namely the recognition of patterns and forms of statistical regularities as they appear to our eyes on the screens of computers elaborating large numbers of events – that is "recognizing law without law".[374]

After these considerations, we are in a position to get another glimpse at the meaning of Wheeler's phrase "at home in the universe" (Wheeler 1994c), rather than dismissing it as some sugar-coated and reassuring vision of an old American scientist. A disenchanted view like Jacques Monod's, in which human beings find themselves alienated before the inanimate cosmic expanse, was temperamentally foreign to Wheeler.[375] If, in more recent decades, we

373Those who endorse one form or another of the above-mentioned "theological" attitude would typically praise the Copernican revolution and so on (while possibly being scandalized by some of Wheeler's questions), but fail to realize that the Darwinian revolution, fully embraced, at the very least invites to scale back some of their assumptions about cognition and the mind. "David Hume asks, 'What peculiar privilege has this little agitation of the brain which we call thought, that we must thus make it the model of the whole universe?'" (Wheeler 1988d, p. 125). Instead, Wheeler's meditations on Darwin's long-range implications, as idiosyncratic as they may be, seem to have grasped that to a large extent, without losing enthusiasm or falling into the rhetoric of our meaningless finitude. We may also recall here what we have mentioned in a previous footnote, namely that, starting from the early 1960s, Wheeler's former student Peter Putnam was meditating on the Darwinian working of the brain.

374That may sound very simple, even disappointingly simple perhaps, but, once we think about Wheeler's overall reflection, we can realize that, if we look at the future, it may be easy to perceive some resonance, even at a methodological level, with new perspectives opened by big data analysis; if we look at the past, we may be reminded of Francis Bacon's *tabulae*. Once again, Wheeler's ideas can be fruitfully put in relation with both temporal directions and suggest different angles. Not to forget his contemporary interlocutors or inspirations, it is worth noticing that Feynman's famous paper "Simulating Physics with Computers" (Feynman 1982) was not only recently published, but it had appeared in the very same issue of Wheeler's "The Computer and the Universe" (Wheeler 1982a) – obviously so, since they both had been speakers at Physics of Computation Conference jointly organized by MIT and IBM in 1981. On a different level, the following analogy Wheeler drew with Impressionism is also very suggestive: "We walk through the art gallery on our way to visit again a favorite picture. We pass by the painting "Impressions", first shown by Claude Monet in 1863 at the Salon des Refusés. To a glance so brief how does the canvas project a coloration so vivid? Because quanta are so numerous. So a simple calculation informs us. A single dab of paint in the single second of our passage throws into a single pupil of our eye 50,000 photons. These quanta of light, this stream of information, is so impressive that there's no mistaking it. No wonder that our predecessors could believe light to be continuous" (Wheeler 1983a, p. 28).

375See Chapter 6 and (Blum, 2022, §4) for his affinity with, but also differences from, Prigogine's attempt at building a worldview alternative to Monod's. I am referring here to "Le

have had plenty of more or less charming evocations aimed at re-enchanting the world – which not rarely, at least within physics, owe something to Wheeler's communicative style, by the way –, the challenge he tried to face at an epistemological level, that of envisioning a deeply human basis for science,[376] is far from being exhausted. The aforementioned "theological" attitudes toward science, even if they often end up revealing themselves to be all too human, still fill the future with their more or less crass promises, sometimes ostentatiously display their postured indifference to the human side, and often ignore or tragicomically misunderstand the past. We may realize by contrast how Wheeler, at a closer look, is not only the prophet of futuristic visions, but a veritable two-faced Janus who also looks and digs into the past to anchor and enrich his own speculations.[377] Even this constant balancing between historical epochs, between generations, between past and future is, after all, something deeply human, which instead is often distorted in gross and unbalanced presentations of "Science". Yes, we can detect also in Wheeler's thought some sort of strong Baconian *élan* (see Chapter 5), as has

Hasard et la Nécessité" (Monod 1970) as a sort of paradigmatic example: Wheeler did not contrast it explicitly, unlike Prigogine. A view similar to Monod's was Weinberg's – again, Wheeler did not oppose it, but he was certainly aware of it (even if the relationship between Wheeler and Weinberg still waits to be studied, they were colleagues in Texas and, some deep mutual respect notwithstanding, many conceptual tensions between them are simply obvious). "The one account envisages an infinite ensemble of universes, one differing from another in the dimensionless constants of physics, with life totally impossible in the overwhelming majority of these systems. Life, mind, and meaning have only a peripheral and accidental place in the scheme of things in this view. In the other view, they are central. Only by their agency is it even possible to construct the universe or existence, or what we call reality. Those make-believe universes totally devoid of life are (according to this view) totally devoid of physical sense not merely because they cannot be observed, but because there is no way to make them" (Wheeler 1986a, p. 310). The following words by the much more Wheelerian (so to speak) Freeman Dyson, who was in turn meditating upon the origins of life and its place in the cosmos, are also meaningful: "The universe that I have explored in a preliminary way in these lectures is very different from the universe which Steven Weinberg had in mind when he said, 'The more the universe seems comprehensible, the more it also seems pointless'. I have found a universe growing without limit in richness and complexity, a universe of life surviving forever and making itself known to its neighbors across unimaginable gulfs of space and time. Is Weinberg's universe or mine closer to the truth? One day, before long, we shall know" (Dyson 1979, p. 459). "Life, mind, communication count for nothing in the scheme of existence? Everything!" (Wheeler 1988d, p. 125)

376In Wheeler's own words: "To me science is not something written down on a piece of paper. It is a living, moving understanding that has its existence only in the mind of man. Science done, that does not enter the mind of man is not - to me - science. And growth is not purely internal matter; there is also growth in interaction with others" (Goodman 1981, p. 80).

377"I am learning that the world of tomorrow does not grow rootless from the here and now, not unassisted out of that way of digging into questions that we call science, not nakedly out of blueprints and computer printout. Tomorrow has its roots in a past of dearly held traditions, values and loyalties" (Wheeler 1986c, p. 7)

been said of nanotechnologies (e.g. Grunwald 2010, p. 98); and, at a practical level, in order to shape the world we still have to investigate and know the laws of nature, as much as their metaphysical status has been demoted. However, the observers-participators no longer torture and put nature on the rack, no longer regard the natural world as an object that stands before them and against them (*ob-jectum*) and whose eternal laws they must understand in order to master it. "At home in the universe" is not a bourgeois hearth magnified on a cosmic scale. Scientific knowledge, with its experimental and historical conditioning, becomes in a non-trivial sense a deeply human endeavor, one of the ways in which we turn out to be participant observers of the universe. Such is "the great garden of richness on which the modern matter maestro may meditate" (Wheeler 1988c, p. 119). These words by Freeman Dyson are perhaps the right ones to conclude:

> "Fortunately, the ideas of Wheeler give us a basis for believing that the world of physics may be truly inexhaustible. […] Then there will always be new worlds to explore, new effects of observer-participation reacting back upon the laws of physics, new connections for the Einsteins and John Wheelers of the future to speculate upon" (Dyson 1980, p. 380).

Appendix B. The Smile of Mnemosyne

This appendix – which, like the other, consists of the text of a still unpublished talk (hence a few introductory redundancies about Wheeler) – casts a further glance into Wheeler's workshop, so to speak. In order to do so, we are going to recall his peculiar relationship with the past as well as with pictures, as we have seen more than once, and intertwine the two of them in a deeper way. At that point, an unexpected comparison with Aby Warburg it will seem possible and stimulating. While apparently there was no direct contact with Warburg's oeuvre, it is nonetheless important to underscore the role that the Germanophone culture of the illustrious émigrés at Princeton may have more or less directly played for Wheeler.

> Something must be at once defined ("bepaalt", says the Dutchman), and for a moment one believes to possess that unknown space, until somebody else pulls out the stakes again and plant them in a narrower or larger space.
> – Goethe, *Wilhelm Meisters Wanderjahre*

1. Introduction: "barbaric" times

During the 1950s, Erwin Panofsky repeatedly praised the scholar's "ivory tower" (Panofsky 1957; Landauer 2000), from whose height, so to speak, one could spot, like a sentinel, the barbarians *ad portas*. This is quite well-known already, perhaps also because of the contrast to the very different connotations that the expression "ivory tower" has otherwise taken on. There is something that may be added, however: even if it is only a conjecture, we may have good reasons to think that, among such barbarians, Panofsky was including in his mind, at least from time to time, this man here (Fig. 8) (the one on the right – the other is simply the Mephistophelian Wolfgang Pauli, whom Panofsky actually befriended).

Fig. 8. Copyright: Cern, Pauli-archive-pho-055.

Who is that? Panofsky's Princeton neighbor. The story goes (Panofsky 2006) that the FBI once went to ask the eminent art historian if the man living next door seemed a trustworthy and reliable person of unsuspicious ideas: at that point, Panofsky stated without hesitation that he was a mass murderer. Now, our art historian was not freaking out entirely, nor are we dealing with an extreme or somewhat caricatured form of strained relations between neighbors; and this is not a Princeton version of some American serial killer story, either. That neighbor was not an ordinary barbarian: yes, he used to put science at the service of technical 'utility' (as opposed to the attitude of the ivory tower) and even military tasks, but, to borrow a phrase from Manzoni, he was a barbarian not without some genius. His name was John Archibald Wheeler (1911-2008): even non-specialists may have heard of him at least due to a few expressions that he adopted and, then, became part of common parlance, from "black holes" to "it from bit".

Here we are going to address a couple of Wheeler's peculiarities, at least when compared with his fellow physicists: one is his overlooked relationship with the past, the other his use of pictures (far beyond standard scientific diagrams). We will see how the two, actually, are partly intertwined – hence the suggestive and unexpected comparison that we will sketch in the following, referring to some Warburgian motives. In order to do that, first of all, we have to properly situate Wheeler's activities in his era and emphasize aspects that are typically neglected by historians of recent physics.

2. Reacting to the Atomic Age

Besides allowing us to introduce Wheeler from an unusual angle, the above-mentioned anecdote also shows Panofsky's reaction against the Atomic Age (understandably, up to a point). He was certainly not alone in that: some eloquent pages by Michel Serres on what Hiroshima meant for his generation and its image of science (Serres 1992) come easily to mind, but the same goes for the incipit of Erwin Chargaff's fascinating autobiography (Chargaff 1978) or some reflections by Karl Jaspers, Günther Anders, and others (Jaspers 1958; Anders 1959). In 1960 Edgar Wind, in the first of his famous lectures on *Art and Anarchy*, remarked:

> "So Hegel drew up his bill of particulars. As he saw it, the moment had arrived in the world's history when art would no longer be connected, as it had been in the past, with the central energies of man; it would move to the margin, where it would form a wide and splendidly varied horizon. The centre would be occupied by science – that is, by a relentless spirit of logical inquiry. The kind of science which Hegel foresaw bears no resemblance to the science of today: in that he was a bad prophet. But the place of science in our lives he foresaw correctly, and he was equally foresighted in the place he assigned to art" (Wind 1985, p. 10).

Needless to say, here we do not intend to face the *vexata quaestio* of the 'end of art' in Hegel's thought, but Wind's considerations – or, perhaps better, observations – sound quite shareable. Science, however, had not just taken a central role, but had also released some unprecedented power on the human scale, thus raising doubts and fears, not only among outsiders. For instance, even one of Panofsky's sons, Wolfgang, who was going to become a quite distinguished physicist and, by the way, was also a student of Wheeler's, did not remain indifferent to such ethical dilemmas and activated himself from within the community of physics (and also tried to problematize the situation when talking to his father, without much success) (Panofsky 2006).[378] Wheeler

378"The recently aggravated tendency to consider Science as an essential element in the preparation of war and the scientist as a cog in the Military Machine cannot be dissipated other than by continuous work in which the Unions must participate actively", as Paul P. Ewald said in the IUPAP assembly of 1947 (Anon. 1992). Here we may also recall that Wheeler's former Ph.D. student Katharine Way, right after the war, co-edited with Dexter Masters the book *One World or None: A Report to the Public on the Full Meaning of the Atomic Bomb* (Masters, Way 1946), in which the voice of people like Einstein, Bohr, Oppenheimer, Wigner, Compton, Szilard, and others was meant to offer a problematization of the perspectives opened by the Atomic Age to a larger public. Even if, in that case, the editors

too, even if he was convinced of the Cold War necessity of developing thermonuclear weapons to keep the Soviet threat at bay, meditated upon those issues in a variety of ways, not least inspired in the long-term by the visions for peace of his two mentors, Albert Einstein and Niels Bohr. He also took note of the impact of the new Promethean powers at the level of society at large, realizing that the old genre of celebrating science and his triumphs needed a renewal. Before getting there, however, we have to better characterize what Wheeler was up to during those years, on a plurality of levels. In his last essay, Irving Lavin, dedicating it to the *American Panofsky* (Lavin 2019), remarked on how, for the transplanted art historian, the United States represented a context in which the regional and national boundaries that characterized his discipline in Europe were completely lifted – well, John Wheeler was going to transgress many other disciplinary boundaries, with a 'barbaric' injection of new energy that deserves some consideration, not just for the sake of an individual focus (however remarkable), but also because of his impact on generations of students and researchers.[379]

3. Reacting to the 'particle zoo'

In the same years as the reactions to the Atomic Age, Wheeler gradually began intertwining a more complex and intriguing vision of science. Even if we have mentioned his awareness of the need for a renewal, in communicative terms, it would be misleading to suggest that he activated himself in merely rhetorical terms: as we shall examine, his peculiar way of practicing science is strictly connected to the features that his communication skills emphasized for relatively broader audiences, so that his heuristics was vitally linked to his rhetoric and vice versa. Given these premises, the point here is not much about the technical details *per se* of Wheeler's physical research of that period: suffices it to say that, towards the end of the 1940s, with the explosion of the so-called "particle zoo" – that is, the discovery of new kinds of unaccounted particles – his previous ambitious attempts at building a comprehensive picture of nature went into a crisis (Blum, Brill 2020). Some new ways of doing physics, which followed the latest experimental outputs and added *ad hoc* terms here and there to accommodate the newly available phenomenology, were not congenial to Wheeler, who even went as far as to

were, respectively, a physicist and a novelist, a serious scholarly comparison between this kind of documents/reactions from the sciences and the aforementioned texts from philosophers and humanists still seems missing: when are we going to see the "imperative of responsibility" by Hans Jonas and Leo Szilard's «ten commandments» discussed side-by-side?
379For the scientific "manpower" that was available to someone like Wheeler in the post-war US we redirect to (Kaiser 2002).

invoke a «desert island» to isolate himself from the flood of new experimental data and rather devote himself to meditating more deeply on already well-established principles, trying to explore their extreme consequences (Furlan 2021; 2022). This heuristic approach even received a name: "daring conservatism" (half-playful nod to Eisenhower's slogan "dynamic conservatism"). Wheeler then began to regard one of his two great mentors, Niels Bohr, as the hero and, later, even the father of daring conservatism (Furlan 2020a; Blum, Furlan 2022). Which principles, however, was it supposed to get applied to? To general relativity – that is, to what Wheeler considered the main legacy of his other great mentor, Albert Einstein. Wheeler would thus devote a couple of decades to trying to build everything from the geometry of general relativity, exploring its extreme implications.

It is interesting to note how, at this stage of crisis and evaluation of future strategies, Wheeler, around forty, somehow decided to reinvent his well-established career as a nuclear physicist, in an operation that was by no means obvious: as a matter of fact, after general relativity had been consecrated by the classic tests that are still illustrated every time today, it had ended up on the fringes of frontier research in physics. Wheeler would thus become a key figure, especially for the next two-three decades, of the so-called "Renaissance of General Relativity", a phenomenon that long remained completely flattened or taken for granted in certain triumphalist narratives, but was appropriately exhumed and studied in more recent years, on the occasion of the centenary of the theory (Blum et al. 2016; 2020). In light of our preceding considerations, this also means that Wheeler conceived of his own work from that period as the development of Einstein's results, but with a methodology he claimed to have taken from Bohr: for him, the great and still open challenge of quantum gravity, namely that of reconciling general relativity and quantum physics, was thus also a personal matter, in an attempt to reconcile the legacy of his two mentors, at the same time forging his own precursors (as we all forge our precursors, to echo Borges). This was a conscious and prolonged operation over the years: "If it is true, as Thomas Mann tells us, that each one of us models his or her life consciously or unconsciously on someone who has gone before..." (Wheeler 1980b, p. 102). One can better understand, then, why a seminal paper from that phase opens with an epigraph from Confucius, something decidedly unusual for a physics paper: "I transmit but I do not create; I am sincerely fond of the ancient" (Misner, Wheeler 1957, p. 525). All this has been reconstructed in some detail only in very recent years, not least thanks to the rich archives that Wheeler himself set up for posterity. The fact that he did it should not be taken as a self-aggrandizing pose: his notebooks are not afraid of showing the criticism he received from illustrious colleagues, nor is Wheeler reluctant to leave

visible traces of his zetetic attempts, unlike the fox who erases his footprints with his tail (as instead happens, for instance, in Gauss's *Nachlass* – or, much more prosaically, in all the cases of scientists simply unaware of a non-trivial historical dimension of their research). Actually, as we shall see, this sort of heuristic transparency would permeate even his late *published* works. Wheeler's archives, left to the American Philosophical Society in Philadelphia, are rather to be seen as one of the manifestations of the importance he attached to history and historiography, as well as of his "transgenerational" concerns (as would perhaps be phrased today).

4. On the uses of history for life

In parallel with the physical program just outlined, there was another of Wheeler's activities worth noting, as it is even more overlooked and perhaps unexpected. Between the late 1940s and the mid-1950s, that is in the turning years after the first phase of his career, Wheeler spent rather extensive periods in Europe, notably in Paris, first, and in Leiden, where he was Lorentz Professor in 1956. In Paris, among other things, he took drawing lessons to improve his graphic skills, so important – as we shall discuss – for his way of practicing and communicating physics (Wheeler 1994a; Hentschel 2014). It was during that period that Wheeler also became a reader of *The Paris Review*, a magazine founded in 1953 in which established writers – it would include names ranging from Eliot to Borges, from Pound to Nabokov – were interviewed with a special emphasis on their creative process: the series was in fact called *Writers at Work*.[380] An original thinker and skillful communicator such as Wheeler was predictably intrigued and he soon envisioned something similar in order to collect and pass on to posterity the creative experiences, heuristic strategies, and more generally the testimony of the founding figures of the new physics, who were starting to be relatively old and pass away (Wheeler 1963a). This sense of *vanitas*, along with the need for new ways of communicating physics to a wider audience in the middle of the gloomy fears of the Atomic Age, prompted Wheeler to help set in motion the organization of one of the largest projects in the history of science, *Sources for History of*

380 In terms of the Cold War scenario in the background, it is not irrelevant to add that, its apolitical appearance notwithstanding, *The Paris Review* was originally used as a cover for CIA-related activities by the magazine's founding editor Peter Matthiessen. The CIA covertly funded various magazines – for a list, see e.g. (Iber 2015) –, even with socialist inclinations, as a 'soft power' move to promote a kind of moderate buffer against the far left. Similar considerations, regarding both the role of the history of science in the post-war US and "soft power" moves, can be found with partly similar overtones in (van Dongen 2020), even if putting them next to Wheeler is a new operation.

Quantum Physics, then led by Thomas Kuhn and others. Wheeler would also write a preface to the whole endeavor (Wheeler 1971a).

The interview format (a source of much frustration for Kuhn and for the historiography he had in mind) had been suggested by Wheeler on the model of *The Paris Review* and its *Writers at Work* (te Heesen 2020). It is of course possible to debate whether such a medium of historical investigation, under those circumstances and after decades from the original events, was appropriate (depending also on historiographical aims), but what is certainly interesting to point out is not only the active engagement of a distinguished physicist (still very active, in terms of scientific research) such as Wheeler, but also the unified conception of the "works of the mind", so to speak, that he evidently nurtured.[381] Later he would make explicit his idea of a sort of heuristic repository (and, in terms of variety of inspiration, the literary reference he would resort to speaks volumes): "Do analogies form themselves out of thin air? Does our problem click by magic into parallelism with another idea from our own area, or with a thought from quite another field? Not by magic alone, but magic plus the prepared mind, Abraham Flexner reminds us. We recall the leader of industry who went to Arthur D. Little for something in writing on the proper organization of a research laboratory. He came away with John Livingston Lowe's inspiring book, *The Road to Xanadu*. And where could one see better than in that study of where Coleridge got his ideas how the storehouse of the imagination is stocked by conversation, story, book and observation?" (Wheeler 1985, p. 16).

Even conceptually, Wheeler's tentative analogical transfer of the model of *The Paris Review* was not trivial: his emphasis on the dynamic dimension of the creative process, rather than on the final product, is quite remarkable (and many historians and philosophers of physics are still blind to that, even nowadays). In this sense, the awareness that Wheeler displayed regarding the importance of archives and historical perspectives is certainly a pleasant surprise for future scholars too, but, well beyond that, he seems to have been thinking, *in nuce* at least, about some integrated history of sciences and arts. For sure, even thinkers such as Cassirer had tried to find a common ground, considering arts and sciences as symbolic forms, but their differences in the way of relating to the past had not been challenged as openly as Wheeler's seemingly innocent was implying. He himself was aware of that, as he commented on other occasions, although mainly to contrast his own pragmatic and "optimistic" attitude about science and the "pessimism" of a few humanists (Wheeler 1962b). That is, after all, our starting point about the

381It is not a coincidence that Wheeler was thanked for stimulating conversations in an original book – which historically integrated scientific and artistic dimensions – such as (Lipking 2014), as the author himself confirmed to me.

reactions to the Atomic Age. Nonetheless, even if we can easily concede that Wheeler's attempt has assumptions that are problematic and to be discussed, his effort deserves attention and, instead of considering it merely wishful, we may read it as an indication of Wheeler's own peculiar relationship with the past. Indeed, it should already be quite clear, at this point, that Wheeler's uses of history were actually quite multifaceted (Furlan 2020a): we may echo Nietzsche's famous tripartition and claim the partial co-presence of an *antiquarian* effort, aimed at the respectful and self-serving preservation of the past; a *monumental* instrumentalization, with the aim of spurring new recruits to feel involved in a great tradition and, more generally, pointing the research directions of collaborators with grand narratives; and a *critical* gaze, capable of selectively identifying, or transfiguring by analogy, certain traits that can be used in present situations. *Pace* Panofsky, his saying that a humanist is someone who rejects authority but respects tradition (Panofsky 1974, p. 3) applied quite well to his neighbor.

Of course, these references to Panofsky are not just an ironic *leitmotiv*, but also serve the purpose of impressionistically evoking the cultural *milieu* of the German é*migrés* at Princeton, so important for Wheeler. Needless to say, a study dedicated to the impact that it had on him is totally missing, but here, for the sake of discussion, we can highlight a few further elements. It is not hard to imagine the strong impression that, also from a cultural point of view, Bohr's court – to a large extent Germanophone – must have left on the young Wheeler in Copenhagen during the mid-1930s. By the end of that same decade, after moving to Princeton, he would find again a similar context, due to the presence of his other great mentor, Einstein, and other highly distinguished German *émigrés*. As Eugene Wigner – another European refugee and longtime friend of Wheeler's – once put it, "with the coming of the Einsteins, Weyls, and Manns, Princeton began to become a little capital of German culture in exile" (Wigner 1990, p. 529). The impact of all this on Wheeler has not to be related only to some of these personalities' scientific stature, which later would make Wheeler even boast a sort of continuity in a "Göttingen-Princeton tradition" (Wheeler 1986b, p. 371). His relationship with Hermann Weyl (besides the already remarked importance of Einstein as an inner model) is an excellent example, as if there were an overall process of intensification and articulation of youthful impressions, once Wheeler came face to face with those personalities. He himself made it quite explicit: "I first knew Weyl before I first knew him. Picture a youth of nineteen seated in a Vermont hillside pasture, at his family's summer place, with grazing cows around, studying Weyl's great book, *Theory of Groups and Quantum Mechanics*, sentence by sentence, in the original German edition, day after

day, week after week" (Wheeler 1986b, p. 366).[382] While celebrating Weyl's 100th anniversary in 1985, Wheeler also recalled the long walks and conversations he had had with him on a plurality of topics – in short, everything he could learn from him, ranging from the work of Herman Hesse to Jacob Burckhardt. It is thus interesting to remark for our purposes that, while Wheeler was promoting historiographical operations in the 1950s, with an eye on the post-atomic cultural situation, great questions about mankind and history were being debated within that Princetonian enclave of German culture, as particularly rich as it was spatially delimited; in particular, we may mention the *Kreis* of Erich Kahler (1885-1970) (Frank 2012; Corngold 2022). Among the distinguished names that can be included in the circle of friends around Kahler[383] and his wife Alice, we can list Albert Einstein, Thomas Mann, Ernst Kantorowicz, Erwin Panofsky, Kurt Gödel, Hermann Broch, Hermann Weyl, Wolfgang Pauli – a good number of which Wheeler knew personally.

As George Steiner portrayed him in a tribute, Kahler "was at Rilke's side In Munich when the first world war was ending; Einstein was to be a frequent guest; without Kahler's guardian presence, Hermann Broch would, most likely, not have written *The Death of Virgil*. In short, his life is not only rich in itself, but is at work in the genius of others. To read his books, to hear him teach, is to be in immediate reach of that lineage of humanistic hope which extends from Erasmus to Goethe. Underlying the manifold of Goethe's work we experience the conviction – profoundly rational yet animate beyond reason – that certain harmonic structure initiate and energize the seeming chaos of sensible and historical life" (Steiner 1969, p. 193). In 1943, in the midst of the collapse of a whole world, Kahler, already in the US, published *Man the Measure: A New Approach To History*, reprinted in 1956, while in 1957 it was the turn of *The Tower and the Abyss* – the tower being that of Babel, not the ivory one (Kahler 1957; 1967 [1943]). These two books had, among their central questions, the following: "What could be salvaged of the past? More crucially, could the concept of civilization itself be so re-thought as to make less probable future crises of self-destruction? […] The lunatic ravage of the culture in which he grew up, the pressures of loss and of exile that have marked his own life, give to Kahler's discourse its urgency and grandeur" (Steiner 1969, p. 194). As one may expect, in-between he also promptly commented on the Atomic Age, which however was framed within a sort of conceptual *longue durée* accompanied by a quite original perspective. Just to

382For some glimpse about Weyl's reactions to the Atomic Age, see (Sieroka 2020, p. 113). Cf. also (Sieroka 2010, p. 161) for some remark about those of Fritz Medicus, Weyl's philosophical companion in Zürich before the great mathematician left for the US.

383Not to be mistaken, in Wheeler's case, with the mathematician Erich Kähler!

give a flavor with its incipit: “The appearance of the atomic bomb has not created a substantially new situation, but it has nevertheless completely changed the world. The state in which mankind finds itself today is no different from what it was before Hiroshima; it is one that long ago crept upon us unobserved. The atomic bomb has simply, at a single stroke, made it acute, perceptible to the senses, visible to all eyes. What formerly could be considered the extravagant interpretation of intellectuals, or lightly dismissed as pious warnings from podium and pulpit, has now risen up before mankind as unavoidable, menacing reality – not words, but fact. This realization is the only new element introduced by the ‘Atomic Age’” (Kahler 1946, p. 167).

The fact that Kahler published the first volume during World War II and gave that evocatively gloomy title to its “sequel” may generate a partly misleading first impression: how the collapse of a world was reached is indeed a crucial issue to Kahler, but he was no Spengler in his tones or overtones – his narrative has a different light from the twilight of the West. His meditations are not merely backward-looking: as we may partly guess even from the quote above, his approach to history is rather to consider the vicissitudes of the human species in a unitary and organic way, examining the enduring marks they left on the human psyche. “History implies a continuity of something more than time; only if history can be seen as a one and consistent human evolution, only then has it a meaning. Otherwise it would be nothing but an incoherent mass of rising and falling powers, growing and dying peoples and individuals” (Kahler 1967, p. 4). *The Tower and the Abyss*, then, builds on such understanding in order to put the focus on “the transformation of the individual” – as the subtitle reads (Kahler 1957) – that mankind was undergoing. Disruption and fragmentation on a plurality of levels were indeed taking place, but, in Kahler's view, that was a phase of transition from the previous individual form of existence to a new supra-individual one, yet to be distinctly delineated. It would be quite suggestive to say that Wheeler tried to find his own form of supra-individual and transgenerational existence in his peculiar way of conceiving scientific activity, marked by conviviality, the dialogue with past, present and future “colleagues”, and the feeling of belonging to a living tradition that was flowing directly from history toward an excitingly open future. In the 1980s, besides carrying on his relentless role as animator and prompter of ideas, without any egotistical posturing, he would even try to encapsulate this view into his physics, with a special emphasis on the function of a community of observers-participators, scattered in space *and* time across the universe, not just studying it, but contributing to bringing the cosmos itself into being (Wheeler 1990).

Of course, directly juxtaposing Kahler's writings and these further

developments of Wheeler's ideas would be far-fetched, but, if we go back to the postwar and the 1950s, these hints are still useful to keep in mind, since, in that *milieu*, one could indeed breathe a kind of attitude toward history that was very different from the one dominating today the Anglophone *koiné*, especially in scientific areas. Referring to *Man the Measure* on the occasion of Kahler's sixtieth birthday, Thomas Mann called it "no more and no less than the novel of mankind, narrated by a poetic thinker and historical rhapsode, inspired by the deep feeling that in this gravest of human crises nothing is more urgent, nothing more vital than the knowledge of man, of his historical background and the direction of his evolution" (Frank 2012, p. 121): that "deep feeling" was not so remote from Wheeler's historical pathos. Thus, even if, at least at the current state of exploration of his archives, there does not seem to have been any direct contact with Kahler's texts, and unfortunately a list of his readings or personal books does not seem to be available, it is hard to believe that in the same Princeton no echo, however mediated, reached someone like Wheeler – curious, culturally sympathetic, attentive to history.

5. Zum Bild das Wort

Wheeler, in addition to drawing ideas and anecdotes from history, as well as updating or transforming them by analogy, had a very similar attitude towards the past and its "untapped potential" when it came to the use of pictures with a long tradition, which retain a powerful symbolic or rhetorical power, survive their previous contexts and get gradually charged with new meanings. This very last characterization, at this point, almost spontaneously suggests a reference that, in the beginning, would have sounded outlandish: Aby Warburg. Even in this case, it does not appear that Wheeler had any direct contact with his thought (even in the case of Panofsky, just to name one of Warburg's associates, it is uncertain whether he had any direct familiarity with his writings, although a curious comparison between the disheveled Einstein and Dürer's wood engravings (Wheeler 1966, p. 9; 1968a p. 2) may perhaps suggest so).[384] Nonetheless, there are some fascinating affinities with Warburg

384Perhaps it was actually Einstein's own self-irony: in some 1974 handwritten notes for *Reminiscences of Einstein and Bohr* (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, box 80), Wheeler was marginally annotating: "Walking talking Dürer". As a merely circumstantial piece of information that we may recall here, David R. Finkelstein, who had long been interacting with Wheeler, displayed an interest for Panofsky's celebrated work on Dürer and, much later, condensed his considerations into a curious "physical" reading of the latter's *Melencolia I* (Finkelstein 2006). Finkelstein was trying to link melancholy to the post-quantum mechanics situation (at least as he saw it) of knowing subjects and their separation from the world; we may add that the vibrant enthusiasm which transpires from Wheeler's observer-participator seems instead to overcome that brooding

and we can, at least theoretically, make leverage on the latter's ideas to highlight some peculiar features of Wheeler's thought, mainly in terms of his relation to the past and to pictures.[385]

A first – and possibly not extremely deep – level is represented by Wheeler's refunctionalization, sometimes ironic, of images from earlier centuries, such as, for example, the sibyls from Cesare Ripa's 1603 *Iconology,* used to illustrate the inspiring «aids» of his heuristics in physics (Wheeler 1994c, pp. Viii-ix),[386] or no less than a phrenological diagram adapted at the end of the textbook *Gravitation* to indicate the various skills one must have 'in one's head' to deal with the legacy of general relativity (Misner et al. 1973, p. 1219). We may also mention the tree of physics: it can be found in the draft plan of a comprehensive course Wheeler was to teach in Leiden (Fig. 9).[387]

attitude or divide.

385As discussed elsewhere (Costa, Furlan 2023), one can see this attempt as a way of putting in unexpected tension two authors with great dialogical potential; or as an experiment to apply to Wheeler's case some form of analysis or considerations inspired by the *Warburg-Forschung* (undoubtedly more developed); or perhaps even as a more general suggestion about the (mediated) relevance of some of Warburg's ideas to seemingly remote scientific fields.

386Actually, it is Wheeler who calls them «sibyls»: they were just allegories. "Sibyline" [sic!] is also used elsewhere by Wheeler to convey the ambiguity, paradoxicality, openness but also depth of his bold heuristic quests: e.g. in (Wheeler 1980a, p. 341), where it appears as "The Sibyline Strangenesses of the Landscape" of new physics. It may also be worth stressing that Gombrich, in the 1970s, played an important role in renewing attention to Ripa's *Iconologia* (Laganà 2022). However, even if Wheeler already referred to the "sibyls" in the mid-1950s (Wheeler 1956), it was only in the anthologized version of his paper, in (Wheeler 1994c), that he resorted to Ripa's illustrations.

387Relativity Notebook 4, p. 90.

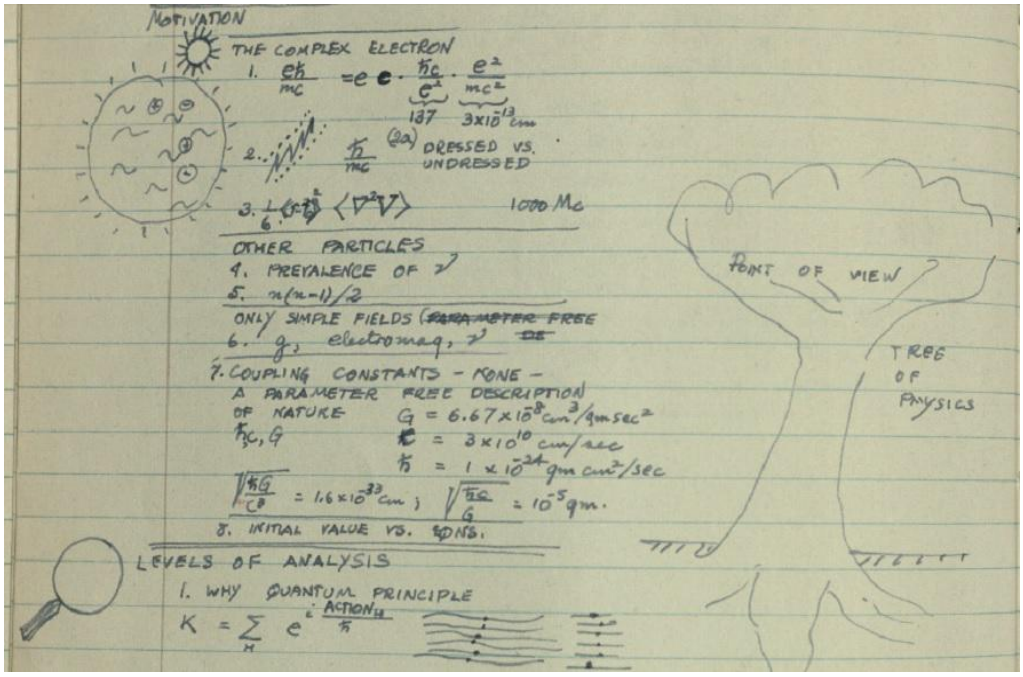

Fig. 9. From *J.A. Wheeler Papers*. Copyright: American Philosophical Society, Philadelphia.

This is clearly an echo of the *arbor scientiarum*, but it is curious how, in the particular context of those years – the confusion deriving due to the 'particle zoo', the tree retains, yes, the value of a structured and in some ways hierarchical organization of knowledge, but it also appears ambiguous, with the risk of mistaking roots for branches. Out of metaphor, this misunderstanding consisted for Wheeler in considering as fundamental (as roots) many of the new particles that were being discovered, instead of considering them only as branches.

Fifteen years of intense research in geometrodynamics followed: if we now jump to the 1970s, we can see that the ideas and bold research program begun by Wheeler in the 1950s had crystallized,[388] the new field of relativistic astrophysics was flourishing, and he, now in his sixties, was recognized as one of the top leaders also in general relativity and gravitational issues. We are all accustomed these days to cloying poses of physicists and mathematicians displaying blackboards thickly filled with symbols in the background; it is now standard iconography (te Heesen 2019a), imitated and propagated even in a fictitious or 'hieroglyphic' manner on tv and whatnot. These pictures seem singularly suited to reinforce stereotypes. Now, if we instead take a look at this blackboard (Fig. 10), it is a safe bet that there is no physicist who, in the

388By this expression I do not necessarily mean that they had become commonly accepted knowledge: a number of them retained their status as conjectures or idiosyncratic suggestions. In this sense, one has to distinguish between a "crystallization" resulting in notions which came to be considered standard tools and a 'crystallization' that just reflected Wheeler's way of repeatedly presenting and articulating his own ideas.

light of any standard expertise, would be able to fully illustrate its meaning, which includes Gödel, quantization, black holes and astrophysics, Leibniz's monads. Were it not associated with Wheeler, the blackboard would be easily dismissed as the work of a madman or a "crackpot".[389]

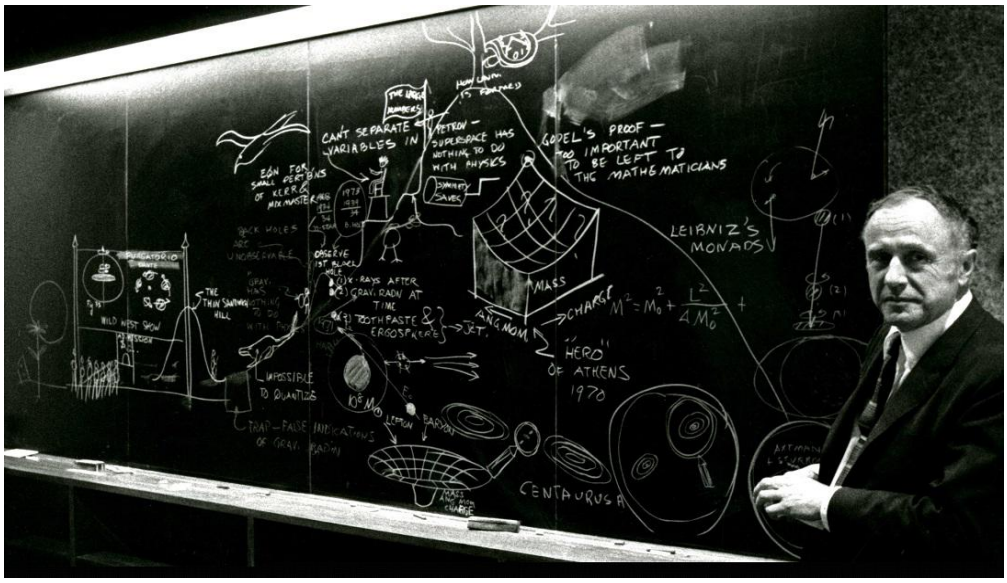

Fig. 10. At Princeton, 1970. Copyright: Johns Hopkins University Sheridan Libraries, jhu_coll-0002_14283.

The previous picture is in black and white (as presumably was the portrayed blackboard), but we should also take note of how colorful these other blackboards are (Fig. 11):

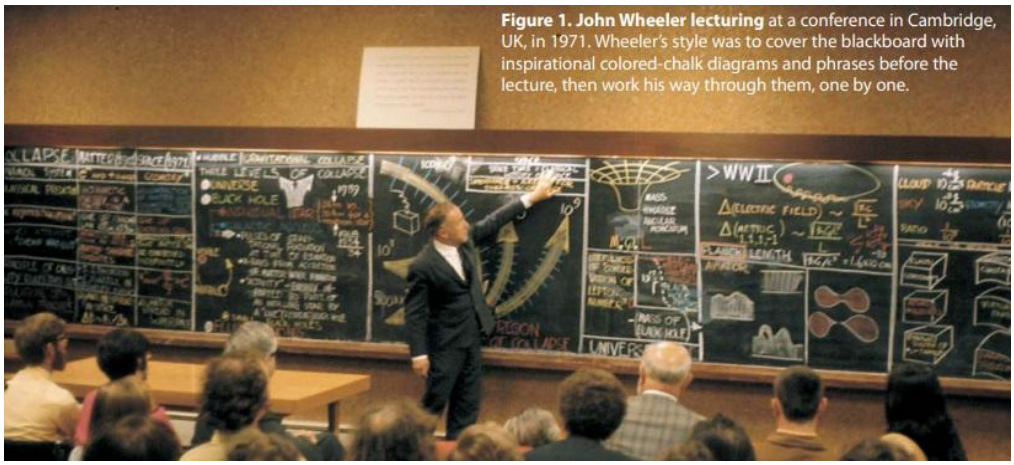

Fig. 11. Taken from (Misner et al. 2009, p. 41). Credit: Kip S. Thorne.

389Even without strictly focusing on the content, in front of a picture like that there is arguably something to learn from Rudolf Arnheim's work and his considerations on visualization and spatial disposition (Arnheim 1954). Also the medium itself – the blackboard – would deserve further attention. These two points will be addressed in some other publication.

There is no question that even these photographs are to some extent posed, or betray, if nothing else, some awareness of being seen. Indeed, we might even say that they are pictures that are 'watching us': perhaps not much or not only by having some agency *à la* Bredekamp, but by means of the fact that their content breaks away from the idiosyncratic way of talking of a single scientist (such as Wheeler) and gets cloaked in a naturalistic aura. This aura is then increased by the suggestion that such pictures guard some fundamental and yet-unsolved natural enigma. "Quantum foam", for instance, today is no longer just a pictorial-evocative expression of Wheeler's conjectures or expectations about physical realms very far from experience, but has typically become something fascinating and exotic, directly conceived as being "out there". The picture originally evoked by Wheeler is by now almost perceived as one of those Byzantine icons which were supposed to have descended directly from heaven and had not been made by the hand of man, the *acheiropoieta*; or at least we can say that, as often the case with painters of icons, the 'painter' here has faded into a kind of anonymity, after opening a supposed window onto realms hard to see. We may also be reminded of a recent notion, proposed in very different contexts, by Andrea Pinotti: *an-icons* – that is to say, pictures which seem to deny their iconic status and hide their role as icons of something else (Pinotti 2020). All this, needless to say, is not entirely under the control of the originator: the way people speak of quantum foam nowadays is usually much 'poorer' and less phantasmagorical than Wheeler's, who was not only thinking about quantum fluctuations of space at the smallest scales, but was dreaming of building everything out of nothing starting from such fluctuations in the vacuum (Wheeler 1957). That is another reason for some serious historical-critical perspective.[390]

Indeed, the story of Wheeler's dream-like imagery of foam at the smallest scales, which was of course informed by mathematical-technical aspects and constrained by them, has many strata that involve a plurality of Wheeler's activities and interests, from the bubbles he had seen in pictures of

390Even Wheeler, at some level, must have been aware of that and, in general, of some "affinity" between the historicity of pictures and the historicity of science. It is known, after all, that also Thomas Kuhn (Kuhn 1977, pp. 340-341) spoke of Ernst Gombrich's work as «a source of great encouragement». More or less in the same years, Wheeler too came in contact with Gombrich's books: see e.g. the illustration in (Wheeler 1980a, p. 358), taken from *Art and Illusion* and used to express the idea that what we call 'reality' is rather a *papier mâché* of iron posts of observation linked by theory (Wheeler's Bohrian emphasis on paradoxes may have been another stimulus to look into that book). In 1979 Gombrich and Wheeler even met at a symposium in Kronberg (Medawar, Shelley 1980). Regarding some aspects of Gombrich's legacy and scientific pictures, another far more recent reference is (Skulberg, Sparre 2023).

underwater explosions (related to his military work) to the cosmological analogies he drew from the latter (Blum, Furlan 2022), not to omit – see e.g. (Wheeler 1978, p. 14) – Shakespeare's famous lines from *The Tempest* (IV, 1) about the "stuff" of dreams.[391] There is even a sort of "eschatological" dimension to it: "As surely as we now know how tangible water forms out of invisible vapor, so surely we shall someday know how the universe comes into being. We will first understand how simple the universe is when we recognize how strange it is" (Wheeler 1978, p. 44). In any case, it should be clear that a historical-epistemological analysis, without simplistic back-projections, is particularly important, given the peculiar situation of recent decades: (some of) the frontiers of theoretical physics are extremely speculative and in lack of empirical support, a few vague and evocative expectations are widely shared, research questions are framed in a certain way rather than in another, but who and how shaped them like that has been forgotten, while the spell persists – perhaps leading to some fruitful result, perhaps just enchanting with a mirage. Wheeler's communicative style and its impact – for better or worse – on the way the extreme frontiers of physics have been popularized and sensationalized in recent decades represent a topic that certainly deserves attention.

6. Visual exhibitions

There is no doubt that Wheeler was making operations such as the above on purpose, not out of 'sloppiness'. Let us consider the following picture (Fig. 12), for instance, taken from a long paper (Wheeler 1968c) which in several respects is the *summa* of his quantum geometrodynamics program:

391 The notion of *rêverie* suffused in Bachelard's work may not be irrelevant here. More prosaically, we may also comment that it is not surprising to discover that, in the 1970s, Wheeler taught a course called *Physics for poets* at Princeton (see e.g. John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, folder Nold Chip, box 203).

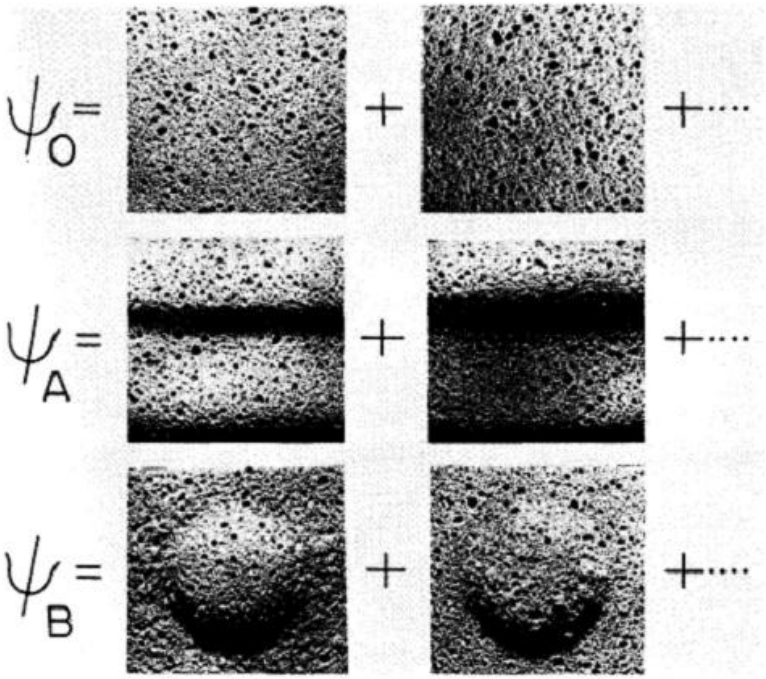

FIGURE 5. Symbolic representations of three alternative probability functions $\psi(^{(3)}\mathcal{G})$. Above, ψ_0, normal fluctuations alone; middle, ψ_A, macroscopic classical gravitational wave plus superposed fluctuations; below, ψ_B, localized excitation plus superposed fluctuations. The complex number ψ gives the probability amplitude for the occurrence of the 3-geometry $^{(3)}\mathcal{G}$. Those 3-geometries that contribute most to the totalized probability are highly multiply connected at the scale of the Planck length ("foamlike structure of space in the small").

Fig. 12. Source: (Wheeler 1968c, p. 265).

Wheeler was in the middle of illustrating his ideas about quantum foam, the quantum fluctuations of space, the formation of wormholes and the whole tower of physics he was hoping to build upon all that, and suddenly showed this photo. He surely specified that one had to look at it "symbolically", but there was still no relation between a microscopic image of matter and what is supposed to happen to space itself at a scale twenty orders of magnitude smaller than that! It could just provide a tool of visualization or of persuasion, clearly: if we examine it today, it would be simply ridiculous and patronizing to frame it as a logical fallacy. This is an obvious example of visual rhetoric, as well as one of the many analogies that, at different levels (mathematical, visual, linguistic), Wheeler used to draw (Furlan, Gaudenzi 2022); but it is also interesting to compare it with the technique of *montage*. In this case, in a sense, the *montage* is only implicit, since there is no picture other than the microscopic view of matter which gets juxtaposed to it: the other picture (quantum foam) is actually evoked by the text in the nearby pages (perhaps we

could then call it an *intermedial montage*). Looking at the structure of Wheeler's papers from the 1970s on with this key of interpretation would easily highlight the strict and indissoluble intertwining between his rhetorical strategies and his heuristic suggestions, as if he were opening his workshop in front of everyone, instead of publishing clear-cut results. Then, let us try to make that reference to *montage* more precise, or at least to underline other features – resonant with Warburg's – that could provide some insight.

In a late interview, Wheeler (1994a) played with the idea of an exhibit about images of creation from the Middle Ages and the Renaissance:[392] if we apply the same suggestion to his own work between the 1950s and the 1980s, it is not too far-fetched to claim that, in his "mental museum", he had many such pictures of creation, largely conjured up by Wheeler himself. Some of them did find their way to even broader forms of scientific popularization, but they were first scattered by his papers, which in his last decades may resemble a *Wunderkammer*[393] – but the emphatic display of variety and bizarreness always goes with the strive for a deep underlying unification. The aspiration towards a Sistine Chapel-like diagram for all of physics, or the all-pervasive and almost dream-like quantum foam, a cyclic cosmology similar to an underwater explosion, the folding of space in gravitational collapse and its reverse process,[394] the participatory universe,[395] an updated monadology, the alleged Chinese (Taoist) resonances of his *Physics and Austerity* program, "it from bit":[396] these are just some of the "pictures of creation" that Wheeler conceived and that, after they were disseminated in a sort of "explosion" of his mental museum, have quite frequently become part – in varying degree and with some metamorphosis – of suggestive evocations at the frontiers of theoretical physics.

392We may add that, in June 2004, during the artistic celebration called "The Big Nothing" in Philadelphia, some artists at Tyler School of Art (Temple University) dedicated their show to Wheeler's work, drawing upon the archival material he had donated to the American Philosophical Society Library (in Philadelphia as well). The name they chose was "Mixmaster Universe", even if the expression actually refers to part of the work of Wheeler's former student and collaborator Charles W. Misner.

393Quite exemplary in this regard are the following three papers, each one in a sense summarizing – with fireworks! – a decade of research and speculation, as well as trying to open new horizons for the future: (Wheeler 1971b; 1980a; 1990).

394This actually got "condensed" in diagrams, more precisely the "embedding diagrams" first devised by D. Beckedorff and Misner in 1962. For their crucial role in Wheeler's struggle with the physics of gravitational collapse and black holes, see (Thorne 1994; Furlan 2022).

395This too actually received an ostensible picture, the quite famous capital U with an eye on one of the two tops looking "back" at the other (Wheeler 1978, p. 23), like the observer who looks back into the past of the universe in a kind of autopoietic circle or, in Wheeler's words, "a self-excited circuit".

396The reconstruction and contextualization of all these ideas is not concluded yet, but the essential guidelines can be found in (Furlan 2020b; Blum, Furlan 2022).

Not only do these mental "pictures" mirror well-defined periods and interests of Wheeler's long life and career, thus calling for a contextualization and a diachronic perspective, but also represent options that he occasionally pursued in parallel and that are at least in tension, when not mutually exclusive. Echoing Bohr, Wheeler used to recall over and over the need for paradoxes and clashes of concepts in order to have creative progress.[397] This also applies to individual papers of his late period, if we try to visualize the *tableau* of such a *montage* of ideas, so to speak. Obviously, we are not talking here about the directly visual aspects of Wheeler's papers, as much as they can be quite richly illustrated: in that respect, they do not look like a panel of Warburg's Atlas at all (even if one may very well think of arranging a Wheelerian exhibition like that). The focus is rather on the disposition of Wheeler's ideas in the conceptual space outlined by these papers, in which his suggestions are partly juxtaposed, partly put in tension, partly concatenated – they are definitely not in a single chain of analytic deductions.[398] In an operation similar to when, in crystallography, we consider the reciprocal of a lattice (shifting the focus, as it were, from vertices to interstices), we must focus on the "intermediate spaces" left by Wheeler and realize that they are not, trivially, a series of mistakes: the gap in-between is not a mere *non sequitur* or a formal/logical lacuna. That *Zwischenraum* is the conceptual space in which those ideas (and what they entail) are free to clash, produce transformations, or provide a field of tensions that we can try to navigate during our heuristic explorations. It is important to remark that, once again in the wake of Bohr's example, Wheeler used to consider his suggestions as questioning, not as apodictic claims, as much as their popularization may also have the effect, as already mentioned, of turning them into some "oracle" of science.[399] In other words, Wheeler's "pictures" (in a proper sense or even as verbal evocations) must be kept in motion and in the process of clashing:[400] in this sense, my use of the term *Zwischenraum* actually intends to mirror the role of the space between pictures in Warburg's Atlas, always open to a new rearrangement or metamorphosis of those same pictures (Costa 2019; 2020; te

397See e.g. (Wheeler 1980a, p. 341).

398One has just to take a look again at the blackboard in (Fig. 3): it is a disposition of concepts, not a physical calculation or a series of passages in the demonstration of a theorem.

399Speaking of Bohr, there is an intriguing association, at least visually, that we can make between Warburg's panels and a couple of photographs found in Wheeler's archives (John Archibald Wheeler Papers, American Philosophical Society Library, Philadelphia, folder Bohr #2, box 165). Their subject is a display of papers, (open) books, and pictures of Bohr, under an inscription with his name and years of birth and death (the two photographs are thus related to some celebratory event after 1962); on the back, there are Wheeler's annotations of the various titles and the mark of the Los Alamos Photo Laboratory. For sure Wheeler, often going back to Bohr's work in search of inspiration or analogies, kept those papers in motion!

400This is a quite different meaning that we can thus give to the term "iconoclash", once made relatively famous by (Latour 2002).

Heesen 2019b). In short: Wheeler is often thinking *in* (not just "with the aid of") pictures, which have their own story and are subject to further metamorphoses, and his way of dealing with them is quite similar to Warburg's attempt, in his last years, at a visual epistemology: *zum Bild das Wort* (Costa, Furlan 2023).

7. Thinking in images

After what we have been saying, it would be misleading, when examining Wheeler's pictures and their links to his physics, to assume just an illustrative-pedagogical point of view, dealing with already formulated and systematized notions. We must not forget that these suggestions concerned a research still *in fieri*, with highly speculative aspects, and that, in any case, all this visual feast required preparation: Wheeler preparing the blackboards before his lectures, carefully and with many colors, and, even before that, unearthing the right image, the proper metaphor, the effective expression – operations he did first and foremost for his own understanding, often in areas little or not at all explored ("If I can't make a picture, I don't understand" (Wheeler 1994a)). At this point, it should be clear that what I am emphasizing is rather different from the "visualization" that is often talked about among recent historians of science. The images that constellate a heuristic path such as Wheeler's should not appear as inert products of widely shared practices or static material residues, *exuviae*, but be recognized as "charged" poles of reasoning, indications that push in one direction instead of another, footholds for the reconstruction, and so on. They are not mere scientific diagrams, providing quantitative information: the pragmatics implied by Wheeler's graphic condensation of ideas is different, in that they do not ask the viewer to apply some standard expertise. They are not ancillary illustrations, but, indeed, as we have just said, symbolic diagrams that impress one's memory and generate thought: *imagines agentes*.

Assuming this genuinely heuristic viewpoint, then, one can also better grasp the Warburgian nod present in the title of this contribution, namely *Mnemosyne*. The allusion is clearly to Memory, the Mother of the Muses, that is of the arts and sciences, as reflected in the Wheelerian way of relating to the past: a creative, productive memory.[401] But there is also a subtler and perhaps

401 The above-mentioned crystallization (never definitive, never abruptly abandoned) of Wheeler's ideas makes also clear how his speeches and papers showcase a series of recurring *loci*, not entirely unlike a Brunian form of mnemotechnics. The reference to Giordano Bruno is not entirely arbitrary (even if Wheeler mentions him only in other respects), nor merely exemplary: the use of pictures in order to actually think, as well as the active and productive character of Bruno's arts of memory (not just a conservative memory), *do* resonate with

more interesting aspect that Wheeler shares with Warburg, particularly the late Warburg of the Atlas *Mnemosyne*, as already suggested. Resorting to pictures represents for Wheeler an effort to *think in images,*[402] just as his collections of pictures are evocations that *produce* thought and suggestions for the unexplored, not mere illustrations.[403] In this sense, Wheeler's case is at odds with the kind of visualization studies alluded to earlier, but also with a certain scientific attitude which, of course not with all the wrongs, looks with suspicion on pictures (in a sort of iconophobia), but also on the words that accompany them by way of captions, and keeps them pedestrianly separate – and both words and pictures must then be kept all the more separate from "formulae", needless to say. Here, in Wheeler's example, instead, we can clearly notice an intermedial (or transmedial) circulation (Fig. 13), or at the least interference, between the implicit iconicity of the mathematical formula, the skillful evocation through ordinary language, and the actual picture itself. "And as imagination bodies forth / the form of things unknown, the poet's pen / turns them to shapes, and gives to airy nothing / a local habitation and a name", to recall a few Shakespearean lines from *A Midsummer Night's Dream* (V, 1), quoted at the very end of *Gravitation*, right above the phrenological diagram (Misner et al. 1973, p. 1219). It is precisely that peculiar mixture that constitutes the highly original feature of both Wheeler's heuristic process and his communicative style (without of course suggesting that these elements are, in general, equally important or decisive).

Wheeler's own visual style and his indissoluble intertwining of rhetoric, heuristics, and personal experience (and not by chance Warburg was struck by Giordano Bruno as a visual thinker (Ghelardi, Targia, 2008; Johnson 2012, pp. 194-ff.)). A further affinity could be detected in the 'ascending' character that Warburg ascribed to Bruno and in Wheeler's notion of the "seekers of the larger view" (or in other iconic moments such as the "staircase of physics" (Wheeler 1975, p. 282)), but it would lead us far away from our considerations about memory and its recurring *loci*. In any case, if these may just be taken as intriguing suggestions, we can also apply some less unconventional tool to the frequently repeated elements of Wheeler's narrations and visualizations, drawing inspiration from studies such as (Gruber 1974) or (Tweney 1991). What Gruber calls the «network of enterprise» of Darwin's notebooks (an example that Wheeler certainly had in mind, as witnessed by many references to him scattered in the papers from the 1970s on), or in those of Michael Faraday, is quite close to the consistent set of Wheelerian evocations and pictures we have been talking about. The latter represent, altogether, Wheeler's evolving network of enterprise across decades of investigation on the mysteries of the universe – or, to use again an old metaphor (also dear to Bruno), the net that he used in his hunting for knowledge, his *venatio sapientiae*. All this sheds light not only on Wheeler's "creative" adventure, but also on his compositional method; at a more mundane level, the fact that he was always involved in a variety of activities (overbusy, in a word) is undoubtedly a crucial factor that forced him into a kind of *ars combinatoria* of recurring elements (that is also what happens regularly today with the recycling of slides for talks and conferences, after all).

402See e.g. (Gombrich 1948).

403They are not simply "pretty pictures", to borrow the phrase quite often used in similar astrophysics-related debates: see e.g. (Ventura 2013).

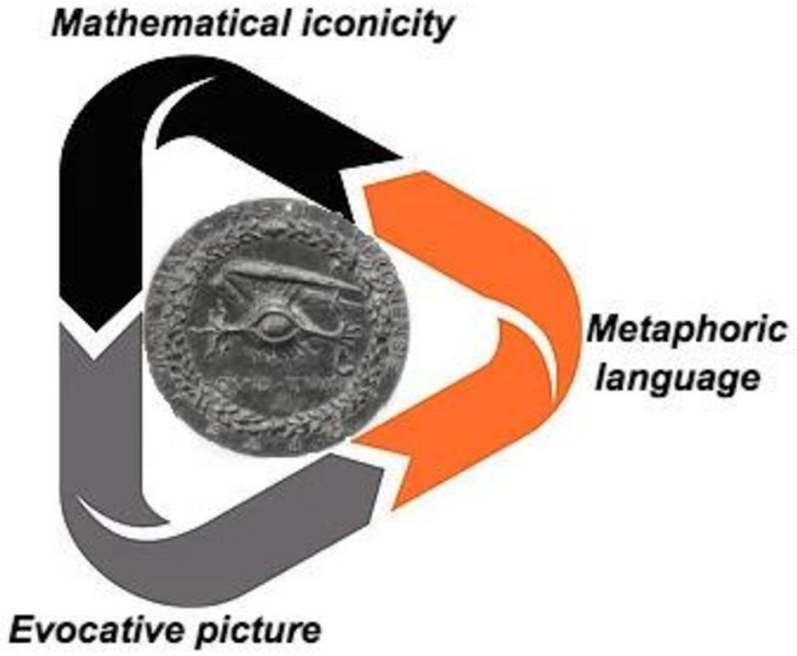

Fig. 13. Source: made by the author. The one at the center is the "winged eye" of Matteo de' Pasti's medallion of Leon Battista Alberti.

In Wheeler's case, quite unusually for a recent physicist, it is crucial to emphasize the importance of ordinary language and its metaphorical power: *rebus apta verba*. In this regard, I would just like to point out something usually overlooked: even in its simplicity, the expression "black hole" embodies an important and by no means obvious shift of attention that from the collapsing object – the star or whatever – redirects the focus towards the surrounding space and the way its curvature is altered; there is in a sense a conceptual leap, which from focusing on a sequence of states of *something* imploding leads to a kind of *hole*. Wheeler's initial resistance to the pioneering results on black holes (*ante litteram*) ended up putting him in the ideal position to grasp the importance of that conceptual obstacle and how the leap it required could be codified in a phrase of disarming concreteness and simplicity, "black hole". Recalling Horace's *Ars poetica*, we can even speak of a *callida iunctura* to emphasize how, thanks to the cunning juxtaposition of two entirely common words, "hole" and "black", a new meaning, well-on-point, is conveyed.[404] We are evidently far from considering metaphorical

404Even the story of the phrase "black hole" being born when someone suggested it by shouting from the public at a conference at the end of 1967 is, in light of Wheeler's archival material, certainly fictitious (Furlan 2022). The episode may have nonetheless happened and even marked the public adoption of the name, but it was already used, *with its specific meaning*, in earlier exchanges between Wheeler's and Dicke's groups in Princeton. Although by now it has become a dead metaphor (or an abused one), "black hole", back then, nicely encapsulated, as already mentioned, the not-so-trivial shift of attention from the collapsing

expressions as a rhetorical frill or merely as a whimsical way of expressing oneself at the level of ordinary words.

8. The meeting between Einstein and Warburg, and further explorations

If we go back to the early 1950s, we may find out that Wolfgang Pauli (whom we met at the very beginning) was working on an essay about Kepler and 'archetypal' material in his work; it was dedicated to Panofsky, whom he also thanked for discussions (Pauli 1952). As is well known, Pauli had quite strong ties with Jung, but his essay is not a naïve application of Jungian notions. He had been envisaging even a *Hintergrundsphysik* (Pauli 1948), which could recognize recurring "archetypal" structures in the ideas of physics throughout the ages – an open project that, however, has not necessarily to be charged with more or less hypostatized archetypes in a Jungian sense. Indeed, if we just focus on pictures that enter into the physical discourse, on their metamorphoses, on their power of suggestion, as well as on their occasionally remote sources, it may be almost spontaneous to think of a Warburg-like approach. No doubt any such analysis would find fertile ground in Wheeler's creativity, as documented by his papers and archives. Besides straightforward "refunctionalizations", such as the already mentioned phrenological diagram at the end of *Gravitation*, there are more sophisticated cases: the staircase of physics (Wheeler 1975, p. 282), for instance, can be compared with the *scala cognitionis* employed by Fludd,[405] which, in turn, comes from a long tradition going back at least to Jacob's ladder and its interpretations (Costa, Furlan 2023). Wheeler's "tree of physics", as we have already seen, is another example. However, a couple of decades before Pauli wrote of a *Hintergrundsphysik*, Aby Warburg himself, a little more than a year ahead of passing away, tried one move.

On September 4, 1928, Warburg met Albert Einstein for the first and only time, at the seaside resort of Scharbeutz, in the Bay of Lübeck. It was Warburg who had requested this meeting, for which he had high expectations

object to its surroundings and their geometrodynamical transformation, as discussed at length in the referenced works. This was mirrored by the change in nomenclature, from the "frozen stars" of the Soviet world or Wheeler's own "completely collapsed gravitational object" to the emphasis on the "hole" in space. The aspect of *callida iunctura* is also reiterated by the following simple observation: in European idioms, the phrase "black hole" has been every time recreated with its corresponding very ordinary terms: *trou noir, gaură neagră, schwarzes Loch, buco nero, μαύρη τρύπα, zwart gat, agujero negro, forat negre, чёрная дыра, buraco negro*, and so on. The Japanese case looks like an exception, in that nobody seemed to have ventured into recreating the expression: the English sound was just "imported", *burakkuhoru*. In Chinese, instead, the phrase was recreated by simply juxtaposing the character for "black" and the one for "hole".

405Robert Fludd was another subject of Pauli's 1952 essay, by the way.

(Bredekamp, Wedepohl 2015). "Four hours of travel, four hours of conversation" – during which he showed Einstein some of the pictures of the Atlas *Mnemosyne*, where the presence of Kepler's work immediately leaps to the eye that can recognize it. As a matter of fact, in Warburg's view Einstein was not so much the one who dethroned Newton, but a new Kepler: a transitional figure (*Übergangstype*) in whom an ancient background (in German, *Hintergrund*) persisted alongside elements of great novelty. Kepler, by abandoning the circularity of the orbits – so entrenched in the old cosmic visions – and adopting the ellipse, which (as is well known) strongly fascinated Warburg, had initiated modernity. Einstein, similarly, with his conception of spacetime, had disclosed a new vision, which led to an *Aufhebung* (Warburg actually used the related Hegelian verb) of the previous world system. Like any *Aufhebung*, or arguably any historical process, this did not simply leave the past behind: Warburg sensed an *Urboden* or *Urgrund* still resonating in the Einsteinian vision (as in the case of Kepler) and, by showing the above mentioned series of pictures (*Bilderreihe*) to Einstein ("like a schoolboy at the movies"), he was hoping to bring it to the surface.

The story of the meeting between Warburg and Einstein has been told essentially from the former's point of view. Einstein appreciated the "exhibition" of Warburg's pictures and probed his conclusions with attentive questions, but had perplexities about the extra-physical reading of Kepler's work, nor does the exchange, overall, seem to have been symmetric. Bredekamp and Wedepohl (2015) suggest that, if we consider a 1930 article on the genesis of Kepler's ideas that was printed in the *Frankfurter Zeitung* under the title of *Albert Einstein über Kepler*, and the related drawing of elliptic orbits that appears only in the draft of the article, we can find trace of some sort of delayed and partly appreciative reply to Warburg's attempt at dialogue: after all, Einstein too presented Kepler in the light of a kind of bipolarity (two *foci*, like an ellipse) between the empirical researcher and the imaginative speculator. Maybe. Nonetheless, if we imagine who could have reacted more receptively and in tune with Warburg's ideas (or better: with his approach and use of pictures), even if some years later, Wheeler's name should now come up quite easily. Not only for the "theoretical" reasons we have discussed in this paper, but also for the role that Warburg had assigned to Einstein: Wheeler – his creative continuator – represented in turn an *Übergangstype*, a living mediator between the generations of the founding figures of 20th-century physics and the age of "it from bit". With his own daring conservatism, Wheeler, like a two-faced Janus, was looking at the past for inspiration but also far into the future, evolving powerful guiding views. When he turned to geometrodynamics – *ubi materia, ibi geometria*[406] –, he

406Wheeler himself, in the first footnote of what substantially is his last synthesis (Wheeler

was also playing in a Keplerian fashion with correspondences between the microcosm and the macrocosm: his problem was no longer to link regular solids and planetary distances, but topological features and fundamental constants (or some of their ratios) (Blum, Furlan 2022), in search of the central *mysterium cosmographicum*. Even quantum foam, in Wheeler's ambitions, can be seen as one such correspondence: it was not only conceived as a feature of space at the smallest scales: once gravitational collapse, tying together the large and the small, makes the universe itself undergoing collapse, quantum foam will take over. The fluctuations out of which he was trying to build everything were also the foam in which everything would ultimately pass away. If this was Wheeler's phantasmagoria during the 1960s, from the 1970s on this omnipervasive character of quantum foam and its fluctuations mutated into "law without law" (Wheeler 1978) – a new vision of the universe in which, to put it roughly, physical laws are not metaphysically granted from everlasting to everlasting, but rather emerge out of statistical regularities. This attempt alone is highly interesting from the point of view of the *Urgrund* Warburg was hoping to make explicit in Einstein, as if physics were undergoing another *Aufhebung*, taking another step.[407] And, in any case, it may be worth noticing that Wheeler too had clearly a certain fondness for Kepler, beyond the conventional tribute to his discoveries and beyond any scientistic *pruderie* – one has just to take a look at the Keplerian quotes in the compendium of Wheeler's two decades of geometrodynamical research: *Gravitation,* once again (Misner et al. 1973, *passim*).[408] An examination of his archives reveals Kepler as a recurring presence even in the last period.[409]

Beyond what we have emphasized, there would be other curious resonances to mention between Wheeler and Warburg (such as the distinctly

1990), quotes this Keplerian motto and mentions (Pauli 1952) as well.

407It is indeed the last step in Wheeler's aforesaid staircase of physics!

408It is worth underscoring how all these "unconventional" outcrops can be found in a widespread and successful physics textbook! Of course, one must be perceptive about the rest of Wheeler's *corpus* to identify their relevance and then use his vast archives to explore what is below the tip of the iceberg. That is not to suggest the existence of an 'esoteric' Wheeler, in the sense of some full-fledged "doctrine" of which he left some traces only for "initiates": it would be the opposite of the heuristic transparency which, especially in his last decades, he was not afraid to manifest. Still, in his reflections, attempts at dialogue, readings and so on, there is certainly much more than meets the eye.

409See e.g. Wheeler's Research Notebook from June 1986 to September 1987 (John Archibald Wheeler Papers, American Philosophical Library, Philadelphia, volume 74), in which, on p. 82, there is mention of a quote related to Galileo and Kepler (a frequent association in Wheeler's mind) that he had asked to Owen Gingerich. Obviously the various references to Kepler would need each time a contextualization, but, as we have commented in other cases, there is a regularity with which they return, as if the name "Kepler" (or "Galileo + Kepler") were a signpost, a mnemonic *locus*.

transdisciplinary linguistic borrowings; the unhinging of ‘conventional’ historical narratives to reorganize knowledge and its memory[410]; the attention to different ‘forms’, sensitive to historical enrichment but also characterized by a deep dynamic unity; the care for recurring details usually considered marginal or neglected, but which in their hands could open up distinctly new perspectives; the use – in some ways certainly idiosyncratic – of their own library as a “thinking machine”) (Costa, Furlan 2023), but this goes beyond the aims of the present paper. To conclude and summarize, three levels of intertwining between arts and sciences have thus been briefly outlined. One is internal to Wheeler's own perspective and somehow invokes a unified historiography of sciences and arts, besides calling for (or at least promoting) a historical-epistemological perspective, for instance in order to see how pictures or visual strategies get charged with specific meanings in specific contexts. Another level is actually a sort of metalevel, since it concerns the scholar who examines Wheeler's activities and takes note of the relevance of a graphic-artistic component, imbued in his thought processes. And then yet another level, which in a sense is a bolder version of the second and could perhaps fulfill the desire expressed by Wheeler himself, concerns the fluid and transmedial dimension with which one can try to characterize, through a comparison with Warburg, Wheeler’s heuristics and rhetoric, with that peculiar form of visual thinking that distinguishes them. In a case such as Wheeler’s, all this goes well beyond the dimension of individual creativity, precisely because of the extent to which his suggestions, expectations, questions and evocations have gradually shaped those of larger communities. Regardless of the level of consideration we choose, dealing with Wheeler's pictures in a merely analytic, singular, static way is a misrepresentation, to say the least; thanks to a Warburgian framework, instead, we can appreciate their dynamism, in terms of both their clash and their gradual metamorphosis. That, of course, is not to deny the huge differences between the two thinkers, but, while these are obvious from the very separation of their respective fields (and typical mindsets therein, at least for now), their affinities may well be worth a “four-hour trip” or a similar effort.

410That is also a fruitful “stretching exercise” of concepts, as Wheeler's often original viewpoints can attest. “One of the most important methods I use is to imagine a historical development for our ideas different from what actually occurred. If we do this we see the problem from a completely new angle” (Wittgenstein 1980, p. 37e).

Towards a Conclusion?

"Could a historiographer drive on his history, as a muleteer drives on his mule, – straight forward; – for instance, from Rome all the way to Loretto, without ever once turning his head aside either to the right hand or to the left, – he might venture to foretell you to an hour when he should get to his journey's end; – but the thing is, morally speaking, impossible: For, if he is a man of the least spirit, he will have fifty deviations from a straight line to make with this or that party as he goes along, which he can no ways avoid. He will have views and prospects to himself perpetually soliciting his eye, which he can no more help standing still to look at than he can fly; he will moreover have various

Accounts to reconcile:
Anecdotes to pick up:
Inscriptions to make out:
Stories to weave in:
Traditions to sift:
Personages to call upon:
Panegyricks to paste up at this door:
Pasquinades at that: ——

All which both the man and his mule are quite exempt from. To sum up all; there are archives at every stage to be look'd into, and rolls, records, documents, and endless genealogies, which justice ever and anon calls him back to stay the reading of: – In short, there is no end of it" (Sterne, *Tristram Shandy* I.14).

1. Geometrodynamics regained – or not?

"There is no living scientist, to my knowledge –
and no one in our lifetime since Einstein and
Gödel – who has combined as well as you a
mastery of the technical tools of the profession
with the cultivation of broad and deep vision".
– A. Shimony (2002) to Wheeler

When I first introduced Wheeler in the Preface, I stated that his impact is not reducible to a mere list of achievements and clear-cut results: I would then

contradict myself if I were now to make an updated list in the wake of the archival explorations we have gone through in the previous chapters. However, now that we are in a better position to appreciate his overall trajectory, as well as the more "elusive" aspects of his way of practicing science, we also have the antibodies against any one-sided exploitation of Wheeler's name or ideas. If we thus take a new look at today's context of quantum gravity, there are a few general remarks that we can make, besides the more specific points that we have already touched upon here and there. Since Wheeler remained active until the 1990s and lived until 2008, we should spend a few words about his own attitude toward contemporary quantum gravity approaches, but, before that, we have to tell a seeming "side story" that began shortly after the demise of geometrodynamics, at least *qua* Wheeler's ultimate vision or endgame.

In 1975, in the *Annals of Physics*, among the "Abstracts of Papers to Appear in Future Issues", a title signed by a trio of Wheeler's collaborators and former students – Sergio Hojman, Karel Kuchar, Claudio Teitelboim – made its appearance: *Geometrodynamics Regained* (Hojman et al. 1975). The title deliberately echoed Milton's *Paradise Regained* as well as *Time Regained*, the last volume of Proust's *Recherche*:[411] as a matter of fact, the short abstract featured a few lines of physics content, a quote from Milton[412] and a quote from Proust.[413]

> "Einsteinian geometrodynamics is the only (time-reversible) canonical representation of the set of generators of deformations of a spacelike hypersurface embedded in a Riemannian spacetime, if the intrinsic metric of that hypersurface and a conjugate momentum are the sole canonical variables".

Behind this (quite ordinary) technical jargon, there was much more. The paper was published the following year (Hojman et al. 1976), but it had been actually preceded by a less flamboyant and much shorter *New Approach to*

411They seem to have thus anticipated the pun in the title of (Wüthrich 2013), *In Search of Lost Spacetime*.

412"... at our great Feast / I went into the Temple, there to hear / The Teachers of our Law, and to propose / What might improve my knowledge or their own". Perhaps that "law" is still charged with Wheeler's daring-conservative attitude of the late 1960s...

413"And, without question, all those different planes, upon which Time, since I had regained it at this reception, had exhibited my life, by reminding me that in a book which gave the history of one, it would be necessary to make use of a sort of spatial psychology as opposed to the usual flat psychology, added a new beauty to the resurrections my memory was operating during my solitary reflections in the library, since memory, by introducing the past into the present without modifications, as though it were the present, eliminates precisely that great Time-dimension in accordance with which life is realized".

General Relativity (Hojman et al. 1973). This work of nearly 50 pages claimed a powerful and fascinating result that, curiously enough, does not seem to have received a huge amount of attention, either to build on it or to challenge it. Wheeler, however, certainly did take notice of that and mentioned it enthusiastically a few times in the papers full of ideas and suggestions for the future that he wrote in the last third of his career. Let us hear it directly from him – it is a long passage, but it is worth quoting almost in its entirety:

> "Nothing in all the great achievements of science is more beautiful than Maxwell's electromagnetism, Einstein's geometric theory of gravitation, and the Yang-Mills theory of the quark-binding field. Each expressible in a single line, these three theories are the yield of decades of research by hundreds of investigators performing thousands of experiments. However, the more we learn, the more we learn how little we have learned.
>
> Are not these three great theories of our time about to suffer the reappraisal already undergone by the great theory of elasticity of an earlier century? Look at one of the good old textbooks on that subject. In the first chapter or two the laws of elasticity are deduced from elementary symmetry considerations. To say that the energy of deformation of a homogeneous isotropic material goes as the square of the deformation is to be confronted with two alternatives. One must either take the trace of the tensor of deformation and square it, or square the tensor of deformation and take its trace. More generally one makes a linear combination of these two expressions with two disposable constants of proportionality to construct the general expression for the energy of elastic strain. From this reasoning – that there are two constants of elasticity and no more – one goes on to build up all the rest of the great treatise on elasticity of one hundred years ago, complete with theorems, methods of analysis, applications and all kinds of beautiful problems for the student to solve at the end of each chapter. Likewise in our own time we have textbooks on electromagnetism, gravitation, and the Yang-Mills quark-binding field or, more generally, on "gauge" fields, or "phase" fields, as Professor Yang suggests we call them, again complete with symmetry-argument foundations, theorems, applications, and problems for the student.
>
> When we look back to elasticity, however, we recall that the most important fact about the subject – where the forces come from, molecular interactions between dozens of different atoms and molecules, multiplied by appropriate direction cosines – was not revealed one bit by these laws of elasticity. One hundred years of the study of elasticity

> would not have revealed atomic and molecular forces. Neither would one hundred years of the study of atomic and molecular forces have revealed that these forces went back for their foundations to Schroedinger's equation and the motions of individual electrons and nothing more. We had to learn that we should explain, not electronic motions in terms of elasticity, but elasticity in terms of electronic motions. The very considerations of symmetry that had allowed one to master elasticity so early, taken by themselves, would have hidden from view forever the mechanism of elasticity" (Wheeler 1980a, pp. 342-343).

Let us take a midway stop to comment on these paragraphs. We have often spoken about Wheeler the storyteller and his characters, but we have not particularly underscored[414] the presence of recurring conceptual *topoi* in his papers: the analogy with elasticity (in a historical perspective) is one of those. Already in (Wheeler 1968c, p. 271), while speaking about the geometrodynamical attempt at constructing particles, he resorted to a similar argument, but with reference to chemistry instead of elasticity: "Today no one doubts that the Schroedinger equation accounts in principle for all of chemistry. Yet no surer way could be found to stop the advance of chemistry than to require everyone to calculate the wave function of his new compound before making it". In other words: we are having trouble deriving analytically a particle from geometrodynamics, but that does not mean that its fundamental view is not correct. Shortly after that, Wheeler realized that geometrodynamics could not be the "equivalent" of the Schrödinger equation and the argument too underwent a metamorphosis – now Wheeler's aim was to support his quest for pregeometry. We would have never reached the Schrödinger equation, he says, by diligently analyzing elasticity and its properties: we needed a bold jump to grasp something more fundamental and then recover the established phenomenology. Likewise, now we need some powerful guiding idea to understand something of the deeper level of pregeometry and, thanks to that, recover established physics with new insights. (The example of elasticity was possibly suggested to him not just by Sakharov's idea of the elasticity of the vacuum, but more in general by Wheeler's whole struggle with the topology or elastic deformations of spacetime: the analogy with a deeper quantum level, both in the case of classical elasticity and geometrodynamics, is thus even clearer).

Aside from the transformations of this unusual juxtaposition, it is clear that Wheeler was using it to underscore the need for visionary attempts such

414If not in Appendix B, while talking about mnemonic *loci*, and in Chapter 4, while identifying the threads that Wheeler's Leibniz, as a conceptual character, is made of.

as his, trying to make ambitious *abductions* that could also explain somehow the "why" of our current theories – "how come the quantum?" And Hojman, Kuchar, and Teitelboim seemed to promise something remarkable in that direction:

> "The considerations of symmetry that reveal law hide the mechanism that underlies law. This lesson out of elasticity we today see afresh in electromagnetism, gravitation, and the dynamics of the Yang-Mills field, thanks to considerations of Hojman, Kuchar, and Teitelboim. They consider a spacelike hypersurface σ1, slicing through space-time. They think of the field in question as given on all points of that hypersurface, along with the initial time rate of change of that field or, equivalently, the "field momentum." They ask: How does one go about predicting what the field will have for values at the points on a later spacelike hypersurface σ2? The general marching his troops forward from one river to another may move the front ahead faster first on the right and later on the left, or alternatively order the line to advance more rapidly first on the left and then on the right, ending up, however, in the same stance on the same river. So the analyst of the field with his computer calculations can calculate ahead from instant to instant the successive configurations of the field either on the dashed or upon the dotted sequence of intermediate spacelike hypersurfaces in the diagram. He, unlike the general, ordinarily will arrive at different results for the field on σ2 by the two maneuvers, the two alternative slicings of spacetime, the two foliations: two incompatible predictions for one future. The fault, when there is one, is wrong choice of the particular Hamiltonian law assumed to govern the evolution of the field from instant to instant.
>
> When the field in question is a vector field and we restrict attention to Hamiltonians of the second order, there is only one option that is compatible with consistency. It is Maxwellian electrodynamics. When the field is a tensor field – the metric measuring the distance from point to point on the spacelike hypersurface – the requirement of consistency leads uniquely to Einstein's general relativity theory of gravitation. Any other Hamiltonian conflicts with the requirement that different ways of figuring ahead should fit into, be embeddable in, one and the same space-time manifold. Finally, when we impose this Hojman-Kuchar-Teitelboim demand of embeddability on a vector field that has an internal spin degree of freedom, we get the Yang-Mills theory of the quark-binding field.
>
> All three great theories of physics fall straight out of the utterly elementary demand for embeddability [...]. One does not have to recall

> Einstein's now abandoned dream of a geometrical unification of the forces of nature. One does not have to have followed the exciting rebirth of this dream within the framework of that new and wider concept of geometry that is forced on us by the discovery in nature – and in mathematics – of "gauge" or "phase" fields, fields possessing at each point of space an "internal spin" degree of freedom. It is enough for the theoretical physicist to demand embeddability to deduce in a few hours what it took great men years of work to establish. Again, the more we learn the more we learn how little we have learned.
>
> Fields in the end remind us more than ever of elasticity: modes of "vibration" of something; modes of a structure quite different from anything that shows on the surface; modes of a substrate, call it pregeometry or call it what one will, that is not and will not be revealed by reasoning from the top down, only from the bottom up; not from the obvious but from the strange. Where better can we turn now for a hint of the new than to the two greatest strangenesses of the present landscape, the bounds of time and the quantum?" (Wheeler 1980a, pp. 343-344).

The elegant and spectacular promise of "unification" by Hojman, Kuchar and Teitelboim must have deeply impressed Wheeler, who could find it very much in accordance with his taste: the basic requirement, that of embeddability, had not a contrived mathematical form and, on the contrary, was even easily "visualizable"; his beloved principle of least action played a role; it seemed to allow him to update "Einstein's dream" with the powerful theoretical machinery of quantum field theory, that Wheeler himself had rather been neglecting after his turn to general relativity;[415] and it provided the kind of deeper insight he was looking for in his pregeometry quest, as much as there was still some auxiliary geometry being used.[416]

With this in mind, we can actually shed some unexpected light on some otherwise cryptic remark that Wheeler made around those years, which shows very well how he used to gel all these aspects in his mind, and how determined he was in his fundamental pursuit. In the Varenna lectures of "law without

415In Chapter 1 we anticipated this connection between gauge theories and a new sort of "geometry", as is said also in (Wheeler 1979a; 1980b). Wheeler's epic of unification, or better his pathos and goals, could thus flow into the narrative developed within the context of quantum field theory.

416The search for basic, simple principles such as that of embeddability was another aspect of pregeometry, next to observer-participancy, "how come the quantum?", the various candidates for the pregeometrical level (from the "dust" of Borel sets to the calculus of propositions, from monads to bits). Since they were supposed to be just "hints", they are not always easy to put together, clearly. After all, even the search for powerful and general basic principles is at least in tension (depending on the status one assigns them) with lawlessness.

law", where, as we know, he examined various "shapes" of Merlin/the quantum, Wheeler, when dealing with Everett's views, explicitly made two criticisms. One is rather common: no need for all those "unobservable" (Wheeler 1978, p. 6) worlds, as we have already said in Chapter 6. The other, however, is rather puzzling, and people hearing it would probably not even see why it should have been a shortcoming in the first place:

> "In retrospect, however, it [Everett's thesis] looks like the wrong track. First, this formulation of quantum mechanics denigrates the quantum. It denies from the start that the quantum character of nature is any clue to the plan of physics. Take this Hamiltonian for the world, that Hamiltonian, or any other Hamiltonian, this formulation says. I am a principle too lordly to care which, or why there should be any Hamiltonian at all. You give me whatever world you please, and in return I give you back many worlds. Don't look to me for help in understanding this universe" (Wheeler 1978, p. 6).

It is clear that Wheeler was saying this because he was looking for hints about "how come the quantum?" and Everett's viewpoint was not asking such a question. Furthermore, the comment on the Hamiltonian has arguably to be read with Hojman, Kuchar and Teitelboim in the back of our mind – since they were instead promising to offer some clue about the deeper level. As we shall see in a moment, Wheeler did not emphasize that shortcoming only in Everett's case.[417]

417There is another passage that gets unexpectedly clarified in the light of Hojman, Kuchar and Teitelboim. It deals with nothing less than evolution – not the Hamiltonian one, but the Darwinian! "Chance mutation, yes; Darwinian evolution yes; yes, the general is free to move his troops by throwing dice if he chooses but he is shot if he loses the battle. Deprived of all meaning, stripped of any possibility to exist is any would-be universe where Darwinian evolution brings forth no community of evidence-sharing participators..." (Patton, Wheeler 1975, p. 567). We can easily recognize the same metaphor used above to describe the idea of Hojman, Kuchar and Teitelboim: "The general marching his troops forward from one river to another may move the front ahead faster first on the right and later on the left, or alternatively order the line to advance more rapidly first on the left and then on the right, ending up, however, in the same stance on the same river". In both cases, idiosyncratically enough, Wheeler was thinking of a process where the extremes were given and, in-between, zigzagging or random fluctuations were allowed: the blueprint was again the principle of least action and a plurality of possible paths. That, of course, was a problematic (or simply heterodox) way of thinking about Darwinian evolution, since, after all, it seemed to involve a teleology. That was what Max Delbrück, in a 1975 letter, objected to Wheeler's ideas about the cosmogonic observer-participator and the universe in *need* of an observer that is *supposed* to emerge in a Darwinian way (Delbrück to Wheeler, 14 April 1975, in Max Delbrück Papers, California Institute of Technology Archives and Special Collections, box 24, folder 10: for some further context of that exchange, see (Blum, Furlan 2022, pp. 314-315)). But for

Geometrodynamics Regained, thus, was not – or not entirely, at least – an attempt at a revival: on the contrary, Wheeler saw it as instrumental in his new quest beyond geometrodynamics itself. If anything, it confirmed him in his belief that he was actually building on the results he had reached at the end of the second phase of his career. Now, as we have already remarked more than once, Wheeler never fully abandoned his ideas, not even when he had personally decided to move on. His third phase is arguably more in continuity with the second than the second was with the first, also for a simple reason: after the first "conversion", Wheeler already had in his hands a theory to work on and to explore – general relativity –, which was quite different from his own previous attempts; in the transition to the third phase, instead, he was trying to come up with something entirely new on the basis of his previous insights. Not everybody, of course, would work on his new, quite vague, ambitious questions, but that did not mean that nothing could be expected from those working on general relativity. That is why, when Ashtekhar (1986), with his variables, opened a new "window" – if we were to echo (Wheeler 1973) – on general relativity, Wheeler's interest in the possibility of an updated quantum geometrodynamics was revived, too. That was far from surprising: Ashtekhar had been a student of one of Wheeler's students, Robert Geroch, and also the other main personalities of loop quantum gravity obviously would largely draw upon Wheeler's earlier ideas. Curiously enough, before expressing interest in this new approach, Wheeler tried to suggest some link between his "it from bit" ideas and string theory. We should spend a couple of words on that, then, and not just for the sake of doxography.

After a decade in Texas, Wheeler finally retired and went back to Princeton, which by the late 1980s had become a hub of string theory (van Leeuwen 2024). As we have seen, we should not imagine Wheeler entirely closed to the (possible) outcomes of a theoretical tradition other than his geometrizing one. There is nothing odd in the fact that he was intrigued by the new ideas and promises of strings – there was a commonality of goals, after all. Furthermore, in Texas he had had under his wing Philip Candelas, who in

Wheeler that was not necessarily a problem: with his geometrodynamics he believed to have shown that the time-ordering is not a fundamental notion and he was thus pursuing the idea of a "wiring together" of the whole universe "before" (or beyond) time. Such a deep interconnection was in a sense fixing the extremes of the process (the beginning of the universe and the emergence of the observer, or – Wheeler's ambiguity of the mid-'70s – *our* appearance), while the process itself, in-between, could be somehow stochastic. Once again, we have to remark that Wheeler's cosmos, especially in the post-geometrodynamics phase, is very different from that of Laplace's demon: locally there seems to be enough "freedom" for lawlessness, even if globally that is not absolute. After all, Wheeler's view combined "law without law" with the the harmony of the "Leibniz-Einstein tradition": to him, as we have seen, Darwin's ideas were an inspiration on how to get order from disorder, not a meaningless and universal empire of chance.

1985 contributed an important paper on superstring compactification (Candelas et al. 1985).[418] We can almost certainly find an echo of that in one of Wheeler's papers of those years:

> "If in gravitation and the other great field theories we can derive so much from so little, why can't we go the rest of the way and obtain everything from nothing? What holds us back from a physics of total austerity? Two obstacles, above all: dimensionality and time.
>
> About dimensionality there was no doubt in the days from Newton to Einstein. There was doubt only about which one or another of a dozen arguments supplied the authentic magic derivation for the magic number three. A very different idea has received much instructive investigation in our own day: Yes, there is a magic dimensionality, but no, it is not three. The extra dimensions are envisaged as curled up into closure in a space so small as not to be susceptible to investigation by any everyday means. Particle masses appear as organ-pipe resonances in this microspace. The new question, What is the right dimensionality, has replaced the old question, What is the right derivation for three.
>
> A third assessment imposes itself on us here: Nature, examined penetratingly, has no dimensionality at all. Dimensionality implies exactly what mathematical logic denies, the continuum. The appearance of a continuum, however, is undeniable, and with it the appearance of a dimensionality. It is difficult to appraise this apparent continuity and this apparent dimensionality as other than cover-up, plastered over a more subtle structure that has neither continuity nor dimensionality" (Wheeler 1988d, pp. 120-121).

Of course, a few extra dimensions were not a big deal to someone that, in the mid-1950s, was thinking about an omnidimensional geometry, as we have seen in Chapter 4, where a generalized form of Feynman's sum over histories could perhaps make the three-dimensionality of space *emerge*. But Wheeler was proposing something of his own as well. A couple of years later, he would take notice that the string approach was, at least in some sense, the "opposite" of his "it from bit":

> "Build physics, with its false face of continuity, on bits of information! What this enterprise is we perhaps see more clearly when we examine for a moment a thoughtful, careful, wide-reaching exposition of the

418Unfortunately, despite repeated attempts, it has not been possible up to have a conversation with Candelas up to now. The materials related to him in Wheeler's archives are not helpful on this specific point, either.

> directly opposite thesis, that physics at bottom is continuous; that the bit of information is not the basic entity. Rate as false the claim that the bit of information is the basic entity. Instead, attempt to build everything on the foundation of some "grand unified field theory" such as string theory – or in default of that, on Einstein's 1915 and still standard geometrodynamics. Hope to derive that theory by way of one or another plausible line of reasoning. But don't try to derive quantum theory. Treat it as supplied free of charge from on high. Treat quantum theory as a magic sausage grinder which takes in as raw meat this theory, that theory or the other theory and turns out a "wave equation," one solution of which is "the" wave function for the universe. From start to finish accept continuity as right and natural: Continuity in the manifold, continuity in the wave equation, continuity in its solution, continuity in the features that it predicts" (Wheeler 1990, pp. 316-317).

We have already noticed how not asking "how come the quantum?" was, in Wheeler's eyes, a shortcoming; but it is also curious to see how, from the point of view of his radical and pregeometrical "it from bit", string theory and geometrodynamics – which today would seem to be in very different quantum gravity camps – were on the same boat. What was to be done, then? In the final section ("Agenda") of that paper, Wheeler's suggestion sounds as enthusiastic as imperative: "Translate the quantum versions of string theory and of Einstein's geometrodynamics from the language of continuum to the language of bits" (Wheeler 1990, p. 321). Among the names listed in the acknowledgments, we can notice in particular David Gross. The two references given for string theory are instead two recently published books: (Green et al. 1987) and (Brink, Henneaux 1988).

Wheeler's vague suggestion did not seem to have much follow-up for the time being. If we take just another step, we can see that another paper (Wheeler 1994d), very close in contents to (Wheeler 1990), has no reference to strings at all, but has a section about the recently emerging loop quantum gravity: "Fortunately, Ashtekar, Smolin, Jacobson and Rovelli and colleagues in a group of papers, more than 190 of them so far, have given us a totally different way of dealing with the quantum theory which is closer to the 'it from bit' point of view" (Wheeler 1994d, p. 291). Did Wheeler just switch sides, so to speak, or did he just happen to find someone more inclined to listen to him? There is little doubt that in those geometrizing and general relativity-based ideas he saw a continuity with seeds he had once planted, and rightly so. As for strings, from the early 1990s on he would maintain an ambiguity that, occasionally but not fully in the light of the day, would even turn into criticism. In his autobiography, he would just use for string theory a sibylline

"intriguing" (Wheeler 2000, p. 320). In a 2002 interview made by Paul Halpern,[419] he was much more explicit and his criticism was mainly of the kind we have already guessed: "We should be looking at broader questions. How come existence? How come quantum? I remember one colleague went to a lecture about string theory. He described it to me as like a Presbyterian minister preaching the Gospel".[420] Later, in another published contribution on Einstein, he again nodded ambiguously:

> "I was convinced then, and remain convinced to this day, that if there is to be a unified theory of physics it must involve more than gravitation and electromagnetism. It must also include quantum entities such as fermions. (Who knows? Maybe the string theorists are on the right track)" (Wheeler 2006).

There does not seem to have been much resonance between Wheeler and the string community, then. Nonetheless, there is no sign, to my knowledge, that the latter perceived him as hostile: he is certainly a "canonical author" for string theorists as well, at the very least for the idea of quantum foam, early speculations about topological transitions, Planck length physics, black holes, anticipations about the role of information (and its paradox), and the quest for unification. Wheeler, in turn, reviewed the 1992 Summer School in Erice on "String Quantum Gravity and Physics at the Planck Energy Scale", simply emphasizing the common quest about "Physics at the Planck Length" (Wheeler 1993). Still, it is not difficult to imagine that the highly mathematized work of string theorists *per se* probably never appealed to him, even just speaking in terms of styles. However, that is precisely why it is meaningful to take notice of what one of the leaders of the string community such as Edward Witten, whose relationship with mathematics is certainly different from Wheeler's, had to say (and recognize) in a quite recent interview:

> "The other night I was reading an old essay by the 20th-century

419Many thanks to him for a copy of the interview, made in Wheeler's Princeton office on November 5, 2002.

420It is quite remarkable that, as we have already seen above, Wheeler – the Wheeler of pregeometry and "it from bit" – perceived string theory as not being radical enough. The fact that he put it next to geometrodynamics and thus his own old daring-conservative approach resonates with a few considerations in (Blum 2021) about a conservative element in string theory. As for the "sociological" critique, that more recently has been repeated *ad nauseam*, we may just notice that it is one thing to hear it from someone who is part of other "rival" communities (at least in their self-perception), it is another thing from someone who went through various fields and communities, without fear of profound renewal each time.

> Princeton physicist John Wheeler. He was a visionary, certainly. If you take what he says literally, it's hopelessly vague. And therefore, if I had read this essay when it came out 30 years ago, which I may have done, I would have rejected it as being so vague that you couldn't work on it, even if he was on the right track. [...] When I was a beginning grad student, they had a series of lectures by faculty members to the new students about theoretical research, and one of the people who gave such a lecture was Wheeler. He drew a picture on the blackboard of the universe visualized as an eye looking at itself. I had no idea what he was talking about. It's obvious to me in hindsight that he was explaining what it meant to talk about quantum mechanics when the observer is part of the quantum system. I imagine there is something we don't understand about that. [...] I tend to assume that space-time and everything in it are in some sense emergent. By the way, you'll certainly find that that's what Wheeler expected in his essay" (Wolchover 2017).

And to the question "Do you consider Wheeler a hero?", Witten answered:

> "I wouldn't call him a hero, necessarily, no. Really I just became curious what he meant by "it from bit," and what he was saying. He definitely had visionary ideas, but they were too far ahead of their time. I think I was more patient in reading a vague but inspirational essay than I might have been 20 years ago. He's also got roughly 100 interesting-sounding references in that essay. If you decided to read them all, you'd have to spend weeks doing it. I might decide to look at a few of them".

And later on: "In my career I've only been able to take small jumps. Relatively small jumps. What Wheeler was talking about was an enormous jump. And he does say at the beginning of the essay that he has no idea if this will take 10, 100 or 1,000 years" (Wolchover 2017). Not everyone has to play the same role, but here there definitely seems to be enough room for dialogue, or to let Wheeler's "maieutic" suggestions do their work.

> "In 1995 (in my eighty-fourth year), like all of my colleagues in physics at Princeton, I prepared a set of questions for distribution to students in the department. The idea was to acquaint students with what faculty members were puzzling over, to plant ideas for possible research topics in the minds of the students, and to help them decide with which faculty member they might like to work. Three of the six questions I wrote down were "conventional" – questions that could be addressed in the context of well-understood current theory and fit a standard mold of

"suitability" for an academic department. One such question addressed an unsolved puzzle from the 1930s on the scattering of gamma rays by lead nuclei. Another was the question of black holes being created not by imploding stars or imploding galactic cores, but by intense concentrations of gravity waves. A third concerned the behavior of space geometry in certain cosmological models.

Then I diverged from the academically suitable to the battlefield and to outer space. How, I asked, could the energy from a small buried nuclear explosion be transformed into electricity to charge the batteries of electric-powered army vehicles? How could messages for all the world to read be displayed on the Moon free of the censorship of dictators?

Finally, I dared to put before the students two of my favorite questions: How come existence? and its subsidiary, How come the quantum? I hardly expected any student to say, "Aha! Those are the questions that I want to work on." As to my colleagues' reactions: Well, the questions are not for them. My goal was only to plant an idea deep in the minds of the students, an idea that might find some way to flower five or ten or fifty years later" (Wheeler 2000, p. 356).[421]

2. John Wheeler as uniquely ecumenical[422]

"Que sera-ce en fin? L'un va en orient, l'autre en occident; ils perdent le principal, et l'escartent dans la presse des incidens. Au bout d'une heure de tempeste, ils ne sçavent ce qu'ils cerchent; l'un est bas, l'autre haut, l'autre costié. Qui se prend à un mot et une similitude; qui ne sent plus ce qu'on luy oppose, tant il est engagé en sa course; et pense à se suyvre, non pas à vous. Qui, se trouvant foible de reins, craint tout, refuse tout, mesle des l'entrée et confond le propos; ou, sur l'effort du debat, se mutine à se faire tout plat: par une ignorance despite, affectant un orgueilleux mespris, ou une sottement modeste fuite de contention. Pourveu que cettuy cy frappe, il ne luy chaut combien il se descouvre. L'autre compte ses mots, et les poise pour raisons. Celuy-là n'y emploie que l'advantage de sa voix et de ses poulmons".

Were it not for some older French orthography, this passage from Montaigne's

421That list, by the way, is presumably the same that contained "the mystery of Ida Noddack", as we have seen in Appendix A.

422This is actually a reference to Wheeler's tribute to Yukawa shortly after his death: *Hideki Yukawa as Uniquely Ecumenical* (Wheeler 1982b).

Essais (III, 8), thrown in this context, might have been taken as a description of the conflict, or lack of dialogue, between various quantum gravity tribes. It is no mystery that, as mentioned in the first pages of this dissertation, today's situation was among the factors that pushed me toward "excavation" operations around a key figure at the dawn of quantum gravity, in order to better explore its genesis. While the focus on a single personality, however important and impactful, cannot lead to systematic and exhaustive answers, over the course of the various chapters we did gain insights into various little-known or usually decontextualized aspects. At this point, we could perhaps temporarily wrap them up with some fashionable notion, calling the field of quantum gravity an arena of "power struggles", or its history a "bush-like evolution" in many directions, whose shoots we have documented, but that is not what I intend to do here. If we were to throttle history with such slogans, I fear that we would betray not only Wheeler's conception, but also the interpretive moves that we have made to adequately understand the latter. Perhaps with a certain amount of naive but active optimism, let us try instead to identify some "untapped potential" in Wheeler's overall story, leaving aside his ideas and questions that live on more or less on their own.

If we take a look at a recent collection of interviews with leading quantum gravity theorists of different approaches (Armas 2021), we can easily notice that Wheeler's name – as expected – is frequently mentioned. What is also clear, however, is that everyone seemed to have little or no clue about what Wheeler was actually up to, or what was due to him. We are thus back to the situation I have sketched in the Preface: we have a well-known and respected name, associated with a few topics and many commonplaces, but confusion and embarrassment are ready to take over if one simply asks: "What did Wheeler actually do?" Physicists are not historians, of course, but this exceeds what happens in almost every other case of this caliber – possibly with the exception of Bohr, not by chance. After Wheeler passed away in April 2008, there were, predictably, a number of commemorations and tributes, such as issue 41 (2009) of the journal *General Relativity and Gravitation.* Among the papers that were included, we can see a couple of technical treatments of the superspace or the prospects of quantum geometrodynamics, such as (Giulini 2009; Kiefer 2009). While it would be out of place to contest these technical aspects, which after all *do* build on ideas introduced by Wheeler, it can also be misleading to present them as an on-going continuation of Wheeler's work, *sic et simpliciter*. We just need to recall the parable of the two lawyers and its interpretation (Chapter 3; Blum, Furlan 2022, pp. 297-298). That is not to deny that even those attempts can be seen as part of Wheeler's legacy, nor to suggest that he did not show any real interest in the work of people pursuing those ideas; but we should keep in mind his

intellectual trajectory as well, and not freeze his picture at some point decades earlier. String theorists too can (and probably do) ignore Wheeler's marginal criticisms, and claim part of his legacy in a variety of topics that this "visionary" anticipated or started to investigate. But the same goes even for the loop quantum gravity theorists that had Wheeler's endorsement at the beginning of the 1990s: that does not mean that they would still have it today, for what it is worth, since Wheeler, as we have seen, was not afraid of radically changing his own ideas and research direction if he perceived a lack of satisfying progress. With all the suggestions he disseminated over decades, there is perhaps no quantum gravity approach that could not establish quite easily some link to him, or that would not display some interest and respect if someone were to say: "Actually, this can be traced back to John Wheeler". These partisan claims, even when they have some basis, however, all have a flaw: they offer a static image of Wheeler, deeply misleading – if not false – in the case of his ever-changing thinking. What is needed – and what I tried to offer, both within the single chapters and in the *immer wieder* of the second part – is a portrait *en mouvement,* to recall a famous title by Starobinski (1982) about Montaigne and his self-reflective form of writing.

Wheeler himself left us his own rich notebooks with an usually self-reflective dimension: even if they need some work of mediation and interpretation, they can exceptionally contribute to turning Wheeler and his journey into a special opportunity for dialogue and debate. His ecumenism, as we have emphasized more than once, should not be understood as a generic irenicism that puts every position on an equal footing, but as a form of openness to confrontation that could possibly lead deeper than *any* present position. A shared heuristic *élan* is what makes one go beyond parochialism and various entrenchments. As we have discussed in Chapter 2, and reiterated in Chapter 6 in the light of the notion of the "seeker", Wheeler found himself in the position of shaping an "epistemology of procrastination", and certainly his narratives and the peculiar rhetoric – both verbal and visual – that accompanied it offered a powerful model to later communicative strategies. After all, as suggested elsewhere (Furlan 2021), even his papers of the last decades seem like a miniaturized, highly concentrated version of the popular books on the "frontiers" of physics that have appeared in the past thirty years. But Wheeler has also been able to go against his own ideas and renew himself in the face of stagnation. Evidently, we cannot make a trial of intentions to the theorists of more recent times, nor on the other hand would such an attempt be very fruitful, but it would not hurt if they asked themselves a few questions in the wake of Wheeler's example. That does not mean that he has to represent *the* role model or that we have to promote him to hero – no, not necessarily, as

Witten said in the interview above.[423] However, we must also take note that the different quantum gravity communities do not just have contrasting opinions on the conceptual and mathematical aspects to reach some kind of unification of general relativity and quantum physics, but have also quite conflicting ideas on what it means to be a good physicist, as emphasized in (van Dongen 2021) with reference to Polchinski's and Smolin's antithetic evaluations of Steven Weinberg, for instance. Wheeler's intellectual trajectory and plurality of styles (or, at the very least, his two souls described by Dyson), on the other hand, seem to potentially have something appealing both to those who are eager for new ideas, but only if accompanied by solid physics, and to those who get excited by "visionary" or "philosophical" long-shots.[424] Once people realize this, and become aware that their epistemic values are not entirely exclusive, perhaps a step has already been taken in the direction of recovering Wheeler's ability, underscored in Chapter 5, to hold together the most audacious speculation and a certain sense of "practicality", insofar as the adjective can be applied to these areas.[425]

> "I hate to think of what I do as speculation. But maybe all I'm doing is giving an elaborate definition of what speculation is, looking at all the conceivable ways to understand a situation, sizing them up, comparing one with another and looking for a concrete way to knock down this, that or the other, so one's left with a battle-tested scenario at the end of what's going on" (Wheeler 1996c).

"Comparing" is here a key word, but in this brief quote its meaning is actually limited and conventional. As we have seen, Wheeler's overall story and *modus investigandi* can show well, instead, how a comparative approach need not be

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423 Although I have not hidden my sympathy for Wheeler's originality, *this* work has been by no means a hagiography. If anything, I responded with playfulness to a certain playfulness of Wheeler, following the rules of his game. It is true that some more "delicate" aspects of his activities, especially military ones, have been touched upon rather marginally, or only with reference to their connection with scientific issues. However, these are not selective omissions to whitewash his portrait: questions that were not too relevant from the theoretical point of view developed here have not been put at the center of attention, quite simply. In any case, I believe I have provided enough guidelines to also address those aspects with their nuances and in their complexity, in order to avoid crude or tendentious categorizations. I could just redirect to Susskind's reaction reported in Appendix A.

424 I was once asked, not without provocation, what the difference is between Wheeler's boldest speculations and those of a crackpot. A pragmatic answer could be the following: serious physicists gradually grow to appreciate the former, while they easily dismiss once and for all the latter. As for why it is so, the previous chapters should have offered at least a handful of insights.

425 And it may good to keep in mind also his way of leading collective research efforts.

a hyper-technical comparison on a common ground that is not always easy to find. Whether it was when he was considering the various "windows" into general relativity or the various forms of Merlin/the quantum, or when he was trying to establish transdisciplinary dialogues in search of new ideas, there was never the naive and somewhat lazy illusion of finding nice and ready solutions. It was rather a process of broadening his horizons, even just with a kind of "distant reading" of different approaches. This is an exercise perhaps best exemplified, *mutatis mutandis*, by Wittgenstein (2007, p. 82e): "I wanted to put this picture before your eyes, and your *acceptance* of this picture consists in your being inclined to regard a given case differently; that is, to compare it with *this* series of pictures. I have changed *your way of seeing*". Shaping a mental archive of possibilities,[426] in a sense, and framing a situation within that. This comparative heuristics, Wheeler would perhaps say, must come before getting engrossed – with horse blinkers – in new attempts at formalization. And, in any case, it recognizes the usefulness of comparative conceptual analyses of different positions and strategies (e.g. Huggett, Wüthrich 2024).

In short, the fact that Wheeler said "this" or "that" may be simply the pretext to bring people from a variety of approaches closer to (t)his reflective dimension: if they think that drawing on the past means tapping directly into the right formula, it only means that, evidently, they have not received a historical education. On the other hand, we should not fall into the opposite fallacy and claim, with historicist punctiliousness, the correctness down to the smallest details of "what really happened". To get someone to pick up an "old" Wheeler article, as Witten did, and recognize the power of the ideas behind it, possibly still in need of a more precise and circumstantial formulation, is evidently a goal that is not utopian; and it would be good if those who would engage in such attempts could be informed of the existence of "reading aids" as well. Once the historian or the philosopher has offered this opportunity, then a "critical" use of history (in Nietzsche's sense, or even according to the usual meaning of the adjective), or at least a "monumental" inspiration, can manifest themselves on their own, even in unpredictable ways. As Wheeler (1984, p. 121) once exclaimed, while envisioning a new age of physics and, at the same time, echoing Bohr (in turn quoting Goethe's *Faust II*): *Kein Weg; ins Unbetretene!* He did not leave his archives to future generations just for an "antiquarian" preservation, that is for sure.

426We thus go back to the heuristic repertoire discussed in Chapter 1 with reference to Wheeler's hopes for the *Sources of History of Quantum Physics.*

3. Mediating between ages and generations

> Can any vision of science that confines itself
> to science ever reveal the scope of science?
> – Wheeler (1983a, p. 23)

From Wheeler's promotion of historiographical activities and his attempts at establishing transdisciplinary dialogues, nonetheless, we can easily surmise that what he left behind was not just aimed at physicists. Today it is not uncommon to hear questions – even rhetorical ones – about the role (if any) of history for science; and, somewhat less frequently but not so rarely, we also hear more or less clumsy and pedantic attempts to explain – typically from the outside – "why it matters". The very fact that, in the activities of a key figure in twentieth-century physics, there were all the various uses of the past that we have documented, without these being perceived as such (and, actually, being instead over-emphasized as futuristic and visionary ideas), shows that perhaps, for both sides, it should be first a matter of learning to *see*, rather than debating in the abstract with obvious underlying preconceptions.

Even philosophers of science that like to pick a given theory and explore its underpinnings, to possibly make them explicit and systematic, could learn something from daring conservatism: not just because of some resonance of method (assuming some principles and exploring their implications),[427] but also thanks to Wheeler's heuristic transparency – since a heuristic sense (or some familiarity with actual scientific practices) seems today quite often lacking in that kind of operations. Theory and concepts are not clear-cut packages that pass through history unscathed, although it is occasionally understandable to aspire to approximate that. Even the simple *awareness* of this evolving and metamorphic character of man-made science can drastically change our perspective: as we have seen this in Chapter 7, for instance, framing Wheeler's ideas on quantum foundations within an ossified "interpretation debate", instead of considering his explorations as an attempt to go deeper, is certainly different from the angle we have given. In a sense, that is also what we have suggested in the previous section here, against one-sided claims of Wheeler's quantum gravity legacy.

At this point, however, I would also like to recall a footnote of Chapter 5, where I have suggested *en passant* that Wheeler's attention, in his last phase, for the preconditions of knowledge and experimental preparation can actually offer new insights to historians and philosophers as well. I was referring to a few passages from the Varenna lectures of "law without law"

427It remains to be seen whether there is also a component worth being called "daring", and whether Wheeler's "no free novelty" is respected...

(Wheeler 1978), where Wheeler was discussing the nature of the observer in quantum mechanics, reviewing various positions. What is remarkable is that, while dealing with Bohr (p. 20), he also wondered if the development of computers could have changed his ideas; likewise, while speaking of Everett (p. 162), Wheeler was making reference to Cold War technology – not just Everett's own "servomechanisms", but, in an attempt to make his former student's ideas more explicit, aircraft guns coupled with computers, radars, and so on. Of course, I am not suggesting that Wheeler had in mind that quantum theory could depend on technology and its history, and thus be altered accordingly, but, in his restless pursuit of Merlin the shapeshifter, he seemed to have thought, at least *in nuce*, that those technological and historical novelties could have repercussions on our way of conceptualizing experimental setups (or even notions such as consciousness and observer), and thus offer new filters and new angles to look at the big question "how come the quantum?". Clearly, Wheeler was interested in answering the latter as a physicist, but, implicit in what we have just said, there is a powerful suggestion to historians and philosophers as well: why not to think (and document) more carefully the interplay between experimental technology (or technology of a certain age, more broadly) and fundamental conceptualization, seeing how it has evolved over time? In a sense, this would be a multi-layered and dynamic version of what Galison (2003) did with "Einstein's clocks, Poincaré's maps" for special relativity.

Wheeler's intertwining of physics and history, even before his manifold uses of the past, can perhaps be symbolized by the following picture (Fig. 14):

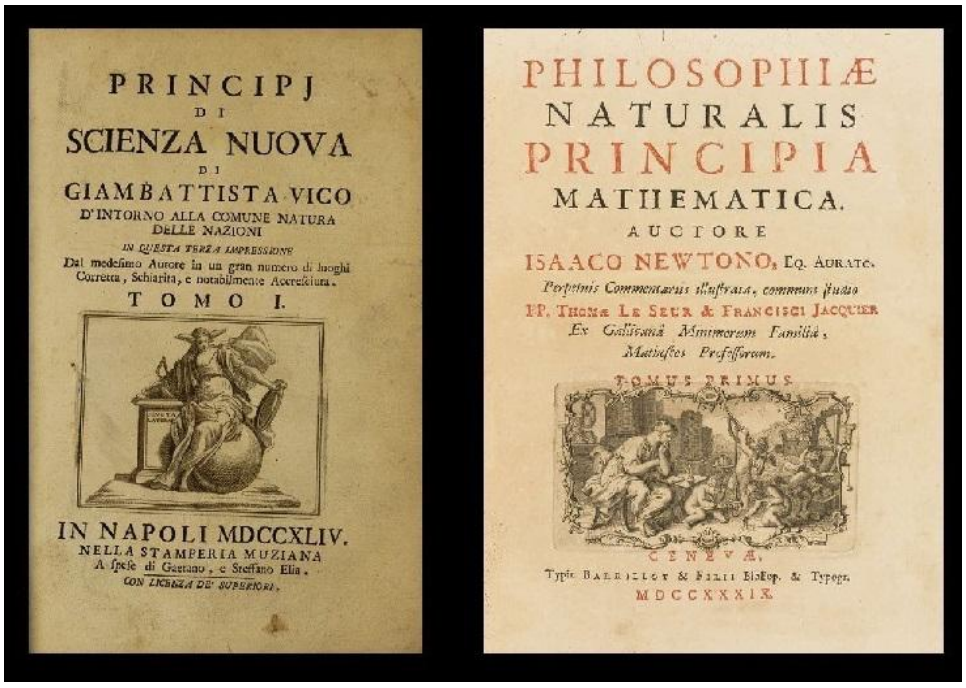
PRINCIPJ
DI
SCIENZA NUOVA
DI
GIAMBATTISTA VICO
D'INTORNO ALLA COMUNE NATURA
DELLE NAZIONI
IN QUESTA TERZA IMPRESSIONE
Dal medesimo Autore in un gran numero di luoghi
Corretta, Schiarita, e notabilmente Accresciuta.
TOMO I.
IN NAPOLI MDCCXLIV.
NELLA STAMPERIA MUZIANA
A spese di Gaetano, e Steffano Elia.
CON LICENZA DE' SUPERIORI.
PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.
AUCTORE
ISAACO NEWTONO, Eq. Aurat.
Perpetuis Commentariis illustrata, communi studio
PP. Thomæ Le Seur & Francisci Jacquier
Ex Gallicanâ Minimorum Familiâ,
Matheseos Professorum.
TOMUS PRIMUS
GENEVÆ,
Typis Barrillot & Filii Bibliop. & Typogr.
MDCCXXXIX.

Fig. 14. The frontispieces of the 1744 posthumous edition of Vico's *Scienza Nuova* and the 1739 Geneva edition of Newton's *Principia*.

The sense of this unusual juxtaposition (and I am not just playing with the "principles" in both titles) is the following. In 1962 – a rather "hot" year for the fate of geometrodynamics, or better for the struggle with the issue of gravitational collapse – Wheeler spent a semester in Kyoto, where he contributed to spark the study of general relativity. While traveling on a train, for some reason he brought a copy of Newton's *Principia* with him. It seems that Wheeler's trips to the Far East, with the kind of decentering – geographical as well as cultural – that they entailed, prompted him to dig deeper into his own presuppositions and restate them more assertively.[428] This *confrontation* with Newton, although it certainly did not lead to a commentary like the one that Chandrasekhar (1995) would make, was aimed not just at getting further material for his grand narrative from universal gravitation to geometrodynamics, but also at comparing and contrasting the starting points: lines vs geodetics, the notion of mass, etc.[429] These are just a few notes, but what is quite intriguing is, once again, the heuristic use of the past, even if here, at least from a historical point of view, it was just that of a creative *dilettante*.

Wheeler's repeated visits to Naples and Campania, instead, contributed to making him acquainted with "local" thinkers that had long meditated on history: in Chapter 1 we have already mentioned Benedetto Croce ("Only historical judgment liberates the spirit from the pressure of the past; it maintains its neutrality and seeks only to furnish light"), but he also got interested in Giambattista Vico. In an interview to a Neapolitan newspaper (Gembillo 1984), Wheeler did not hesitate to state[430] that "the historical approach" – investigating what we human beings have made ourselves, even to inquire about nature – is always the best one. Our material cultures of experiment, our practices and our concepts, after all, are not born "out of thin air", as Wheeler (1985, p. 16) put it. *Verum ipsum factum.* This may look like, once again, an imaginative use of Vico – and an extension to the natural sciences well beyond Vico's intents – but, especially from a physicist such as Wheeler, it is noteworthy nonetheless.

> "Physics at the end becomes as much history as history ever was. No longer can we accept the famous thesis of Giambattista Vico (1668-

428Cf. (Blum, Brill 2020) for his first trip to Japan.

429Relativity Notebook 8, p. 260. Once we know about that, we can find a trace also in (Wheeler 1964, p. 333).

430Although, whether due to the translation or to a partial reworking by the interviewer, Wheeler's voice seems a bit filtered, the general message cannot be equivocated.

> 1744), “In history we are the actors; in the natural sciences, mere spectators”. No longer does his distinction hold water [...]. How does it differ from any other act in history ... when the observer-participator turns his analyzer to whatever orientation he chooses and lets come in what will?” (Wheeler 1979i, p. 823).[431]

Vico, after publishing his *Principi di Scienza Nuova*, sent a copy to London for the author of some other great *Principia*, Isaac Newton. Nothing came out of that. Wheeler may very well have been the only 20th-century physicist, or possibly scientist, to try to hold in one hand Vico's *Principi* and, in the other, Newton's *Principia*. (I, for my part, regret that Wheeler, with his creative imagery, did not live in an age where he would have created frontispieces). To claim that he reached a solution would be absurd, but the problem certainly persists, with all its urgency: how to integrate the two perspectives, without falling for some naive naturalism on the one side or some arbitrary constructivism on the other? What kind of rationality – beyond crass scientistic attitudes – would that entail?

That is a question for the ages: in the meanwhile, it is valuable to have an intracranial colleague who raises it with such determination and originality. Perhaps this is another lesson that we can learn from Wheeler's attitude toward the past: history is not simply a cemetery or an inert deposit, but a hunting ground where one can gain precious intracranial companions of adventure – such as Wheeler himself. At this point, it should be evident what I meant in the Introduction by saying that it was the subject matter itself of these investigations, Wheeler himself, to call for a historical-epistemological method. Here we have definitely accepted his invitation, accompanied by a treasure hunt in his archives, which is certainly far from over. It is clear that, through the documents he has left us, Wheeler has not exhausted either what he has to say, or his work as a mediator between generations. In all these pages I have attempted to lend him voice.

431Notice that this is from the same paper that, in Chapter 7, we quoted to illustrate Wheeler's attention to the preconditions of knowledge and the preparation of experiments.

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