Non-Empirical Physics from a Historical Perspective: New Pathways in History and Philosophy of Physics

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Abstract

In this Special Issue, we explore the rise of non-empirical physics from a historical perspective. This exercise is meant, furthermore, as an attempt to open new pathways in contemporary history and philosophy of physics. We use this introduction to provide the theoretical background necessary to flesh out this program and to appreciate the manner in which the articles in the collection substantiate it. To do this, we proceed in the following manner. First, we briefly lay out the development of contemporary philosophy of physics, and the manner in which the range of topics covered in the specialized literature expanded over the past few decades. After that, we chronicle the advent of non-empirical physics during the second half of the twentieth century, and we introduce the philosophical debates triggered by this development. These debates, as we show, did introduce new topics of discussion in philosophy of physics. However, these discussions did not arise as a deliberate attempt to add new ideas to the philosophy of physics repertoire. Instead, they emerged as a natural consequence of the historical development of physics itself. Taking this observation as our starting point, we argue that engaging with the debates around non-empirical physics, and with the historical circumstances behind their appearance, provides a more fruitful, more historically grounded approach towards updating the canon of philosophy of physics. We then single out some areas in which historical work would be particularly illuminating, and we highlight the contributions made by each of our authors. We conclude by inviting others to join the philosophical program sketched here, and to add their own insights to the ones contained in this Special Issue.

In recent years, philosophy of physics has experienced a gradual transformation. Over time, the range of topics covered in its specialized journals and conferences has progressively expanded. And thus, the profession has slowly moved away from its traditional focus on the foundations of relativity and quantum mechanics.

For the most part, this transformation has proceeded by incorporating new areas of physics into the canon of the discipline. Some of those additions were more of a return to topics that had once been the subject of intense philosophical scrutiny. This is the case of statistical mechanics, which gained prominence in the literature around the 1990s after a period of relative neglect. Some other times, preexisting debates on the interpretation of space-time theory and quantum mechanics gradually developed into new topics. Contemporary discussions on quantum gravity and on the foundations of quantum field theory, for instance, can perhaps be seen under this light. Finally, entirely new areas of physics were incorporated into the literature in philosophy of physics, including fields such as cosmology and astrophysics.

But there is another approach towards updating the repertoire of contemporary philosophy of physics. This alternative approach consists of drawing from the history of science in our search for new ideas. Classical debates such as those related to the hole argument and the measurement problem, after all, were highly specific not just in their subject matter. They were also highly specific in that they spoke to concerns that arose during a very particular time period, namely the foundational years of the 1910s through the 1930s. In making progress beyond this foundational era, then, one may follow the historical development of physics to find out what new philosophical problems arose as physicists advanced in their research.

Our Special Issue adopts this second strategy towards enriching the repertoire of contemporary philosophy of physics. The debate on non-empirical physics as a whole, in fact, can be seen in much of the same light. The philosophical issues at its core, indeed, arose as physicists faced new challenges in their attempts to build better physical theories. As the history of physics moved past not just the foundational period of the early 20th century, but also past the successes of the postwar period, the relation between theory and experiment changed. At some point after the mid-1970s, the energy regimes described by the latest theories of fundamental physics became too high to be probed experimentally. And unlike before, physicists could no longer count on being able to test these theories quickly and accurately. The environment in which physicists operate, in sum, changed towards the end of 20th century, and this gave rise to new philosophical problems.[1]

[1]This is not to say, of course, that attempts to theorize beyond what could be tested experimentally had not taken place in physics before the 1970s. As some of the contributions in the Special Issue show, efforts along these lines were certainly made before the completion of the Standard Model, and some of them in fact prefigured and antici-

More often than not, the new philosophical debates at the turn of the 21st century had to do with science itself, and with the scientific method. The debate on String Theory from which the literature on non-empirical physics emerged constitutes a clear example. As physicists started theorizing beyond what they could test, different theories of fundamental physics came to be developed. But by the 1990s, a single theory, namely String Theory, had managed to become hegemonic[2]. This posed the question of what the epistemic status of String Theory was and of what justified its predominant position. Did the theory amount to more than mere speculation, in spite of its lack of direct empirical support? In turn, this brought up the question of what the role of empirical data is in science, and of whether experimental testing constitutes one of its defining features. It brought up, that is to say, questions about the methods of fundamental physics and their ultimate justification. Not only are these questions genuinely philosophical, but they are also questions that physicists themselves came to ask as they attempted to break new ground in their study of physical reality.

Similar developments took place in the realm of cosmology. Here too, physicists came to question their own methods as they stumbled upon new, unexpected difficulties. Throughout the 20th century, relatively few developments took place in cosmology. [3].

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pated the much more pronounced rise of non-empirical physics that took place in the late 20th century. For more examples of these kinds of early attempts to theorize beyond the observable see (Blum 2019; Kragh 2011; van Dongen 2013).

[2]The process behind the rise to prominence of String Theory was of course a long and complicated one. For more details on how this historical process unfolded see (Cushing 1990; Cappelli et al. 2012; Dawid 2013; Rickles 2014). For a systematic presentation of the details behind the theory itself see (Polchinski 2004)

[3]For a more nuanced account including developments prior to the rise of inflation-

But towards the end of the century, two developments combined to open new research avenues. On the one hand, inflationary cosmology established itself as the dominant paradigm in the discipline, purporting to provide solutions to extant theoretical problems that had troubled Big Bang cosmology. And on the other hand, the development of ever better space observatories made the collection of unprecedentedly accurate data possible, giving rise to a new era of precision cosmology. Although empirical data was available in cosmology, its ability to provide genuine tests for the inflationary paradigm came to be contested. Indeed inflationary theory allowed for such diverse models, that it seemed as though any experimental result could be counted as evidence in its favour. The addition of the multiverse hypothesis in the early 21st century only aggravated this difficulty, and further complicated the relationship between theory and experiment in cosmology.

Perhaps because of the manner in which they arose, the new philosophical debates of the late 20th century were often historical in nature. Because these new debates were so concerned with the scientific method, and with whether modifications of it are admissible, history became an important battleground for competing narratives. The history of physics, after all, provided an obvious source of standards against which the legitimacy of the latest developments could be tested. And thus, both sides in the debate on the status of empirically unconfirmed theories came up with their own takes on the development of modern physics. While defenders of String Theory tended to emphasize the importance of unification and elegance in driving scientific progress, critics placed more weight on the role of experiment in preventing physics from going astray.[4]

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ary cosmology in the 1980s see (Smeenk 2005). A good presentation of the content of inflationary cosmology can be found in (Lyth and Liddle 2009)

[4]This is perhaps most explicit in general or popular presentations. Some accounts of

A first contribution of this Special Issue consists of making the historical dimensions of the debate on non-empirical physics explicit. This dependence can be discerned not just in scientists' own debates, but also in the more specialized body of philosophical literature that emerged after the publication of Richard Dawid's book *String Theory and the Scientific Method* (Dawid 2013). As a matter of fact, the history of science plays an important role in Dawid's framework of non-empirical confirmation. This is so in several different ways.

First, we have the idea that the current detachment of theory from experiment is far from constituting a recent phenomenon. Dawid, in fact, argues that it is only the result of a long process reaching back as far as the late 19th century. Since then, theory and experiment would have progressively decoupled from each other as fundamental physics made progress (Dawid 2013, p. 97–103). The same non-empirical methods that are currently used to defend String Theory, furthermore, would have developed in parallel with this long-standing trend. According to Dawid, non-empirical methods would have been operating in the background all along, making the process of empirical confirmation possible (Dawid 2018). As the disconnect between theory and experiment grew, physicists would have developed a number of non-empirical strategies designed to narrow down the possible interpretations of the outcomes of an experiment. It was only because of these mechanisms, Dawid says, that empirical confirmation could function as it did over the course of the 20th century (Dawid 2013, p. 103–118).

Secondly, Dawid makes a more specific claim about the development of high-energy physics after WWII. According to him, the development of this area of physics was driven by two main principles. The concept of gauge symmetry guided developments in

this sort include (Greene 1999; Penrose 2004; Smolin 2007; Ellis and Silk 2014).

theory, whereas experimental physics was driven by deep inelastic scattering. Until the mid-1970s, the two branches of high-energy physics developed side-by-side. But as we saw earlier, theory took the lead after that, providing ever more fundamental descriptions of reality that experimental physicists could no longer test. It was only at this point, Dawid says, that the weight of theory evaluation fell solely on non-empirical methods (Dawid 2013, p. 75–83). Having played a secondary role until then, non-empirical techniques became full-blown tools for theory evaluation in contexts in which empirical data was not forthcoming after the 1970s. And thus, the concept of non-empirical theory confirmation would have grown out of previously existing techniques in the discipline.

These two claims play an important role in sustaining Dawid's framework. Together, they help establish the use of non-empirical methods in support of empirically unconfirmed theories as legitimate. They do so by ingraining both the main obstacle to be overcome in physics, along with Dawid's proposed solution, into the history of science. The current separation of theory from experiment is thus presented not as a historical anomaly, but as the outcome of a long, gradual process. And similarly, the use of non-empirical methods as a response to this problem is presented not as a sudden break with established scientific practice, but as a continuation of it. This helps address critics' concern that string theorists' use of non-empirical arguments constitutes an *ad hoc* maneuver designed only to defend their own preferred theory. These two historical claims also make it unlikely that the current trend of detachment between theory and experiment will be reversed any time soon, which makes the need for a philosophical elucidation of non-empirical methods all the more pressing.

Finally, it is worth pointing out that one of three main arguments at the core of Dawid's methodology is explicitly historical in nature. Thus, the so-called Meta

Inductive Argument, or MIA, tells us that a theory is worth trusting if it was developed in the context of a research program that has tended to produce viable theories in the past (Dawid 2013, 2019). When applied to the paradigmatic case of String Theory, this claim turns into a statement about the history of the high-energy physics tradition from which String Theory emerged. Dawid, in fact, does make explicit statements about the manner in which high-energy physics developed during the construction of to the Standard Model (Dawid 2013, 30–38). Although those are made only in passing, the application of the MIA to String Theory still makes the history of high-energy physics into a crucial element of Dawid's defense of String Theory.

We can thus see how the debate on non-empirical physics is historical through and through. Not only did its main questions arise from the history of physics; these questions also concern the history of physics itself. They concern, as we have seen, the methods of the discipline, and the kinds of modifications that they can legitimately be subject to. And in trying to evaluate these questions, it is natural to turn to the history of science and consider the kinds of transformations that fundamental physics may have experienced in the past. All of this is true, furthermore, both of the polemics that originally arose among physicists, as well as of the philosophical debate on non-empirical physics that emerged out of it.

Once we realize this, a new program in history and philosophy of physics becomes visible. This research program would proceed by identifying the historical claims made in the debate on non-empirical physics and by subjecting them to closer scrutiny. Having made the historical dimensions of these debates explicit, that is to say, we can go on to engage with them rigorously. The outcome of these historical investigations may then inform the various philosophical positions in the original debate, and help reformulate them if necessary. The different articles in this Special Issue can be seen as contributions to this research program. They all identify and clarify the historical aspects of the debate on non-empirical physics, and they help us assess the accuracy of the various historical claims made in it.

For instance, Richard Dawid's own contribution studies the gradual acceptance of the atomic hypothesis in the early 20th century. Dawid examines the manner in which arguments in favor of the existence of atoms evolved since the late 19th century, and the reasons that ultimately made them prevail. According to him, the crucial factor that convinced scientists of the reality of atoms was not just the mounting body of experimental evidence that culminated with Perrin's experiments in 1908. Additionally, advocates of the atomic hypothesis had to convince their adversaries that no alternative way of making sense of this body data was available. And in order to accomplish this, they would have made use of all three of the meta-empirical arguments at the core of his own methodology. The triumph of atomism, furthermore, led to the embrace of new, more permissive standards in fundamental physics, which made the experimental detection of microscopic particles possible. In this manner, non-empirical methods would have long been part of the methodology of fundamental physics, merely supporting inferences from empirical data at first, but still shaping the foundations of the discipline in profound, enduring ways.

In his piece, Jeroen van Dongen examines the role that the figure of Albert Einstein has played in the debate on String Theory. According to him, theoretical high-energy physics finds itself in a period of crisis, with physicists publicly disagreeing over whether String Theory counts as a legitimate physical theory or not. Although attempts have been made to use philosophy of science to intervene in this debate, van Dongen argues, accounts based solely on the notions of confirmation and falsification have failed to bring much clarity to the controversy. As he shows, the reason is that the debate is partly about the identity of physics, and about who counts as a legitimate physicist. In order to shed light on this polemic, then, we ought to approach it not through the lens of a strictly formal epistemology but from the point of view of a historically rich philosophy of science. What this perspective reveals is that different figures have played a crucial role at various points in history, reworking the identity of physics around a new set of epistemic values. And what we find in the debate on String Theory are two opposing camps, both of which attempt to make Einstein into an exemplary character that embodies their preferred set of epistemic virtues. Einstein's defense of his Unified Field Theory program of the 1920s and 30s, for instance, has become a particularly important source of evidence regarding what our attitudes towards the non-empirical should be. These important dimensions of the debate on String Theory only become visible, however, when we approach it from the more comprehensive perspective that the notion of an epistemic value allows for.

Alexander Blum investigates John Wheeler's research on quantum gravity, which he undertook during the 1950s. According to Blum, Wheeler's attempts to find a theory of quantum gravity can illuminate important aspects of contemporary research in String Theory. The analogy with Wheeler's work, in particular, can put into focus the intrinsically conservative nature of String Theory. Blum's argument is as follows. During the 1950s, Wheeler developed a methodological approach that he called "daring conservatism." Wheeler's method consisted of voluntarily ignoring the latest empirical data to analyze the theoretical structure of the basic physical theories that any future theory of quantum gravity was bound to rely on: general relativity, quantum mechanics, and Maxwellian electromagnetism. By daringly extrapolating from what these theories had achieved, Wheeler thought, one would eventually obtain a theory of quantum gravity while avoiding being misled by the often confusing particle phenomenology of the time. Although detachment from empirical data is involuntary in the case of String Theory, it shares with Wheeler's program the same conservative outlook: it takes established theories as its starting point, and it then seeks to combine and extrapolate them. Unfortunately, Blum argues, this also means that the two research programs share some of the same vulnerabilities. Both Wheeler's program and String Theory, for example, neglect the important role that empirical data can play in opening new theoretical pathways. Although this is not by itself a fatal objection against String Theory, it does advise against presentations of it that overemphasize its supposedly revolutionary status.

Pablo Ruiz de Olano's piece also focuses on the 1950s, although this time on the then-nascent field of high-energy physics. More precisely, Ruiz de Olano studies a theory of the strong nuclear interaction that the Japanese-American physicist Jun Jon Sakurai introduced in 1960. In spite of the abundant empirical data available at the time, Sakurai had trouble directly comparing his theory against experience. As Ruiz de Olano shows, the reason for this is to be found in the poor state of development of renormalization theory during those years, which made the extraction of empirical predictions out of Sakurai's theory nearly impossible. Given this, Sakurai had to develop a different line of argumentation to defend his theory, which relied on one of Dawid's three non-empirical arguments—the so-called UEA, or the argument from unexpected explanatory success. As Ruiz de Olano argues, however, Sakurai's purpose in deploying this argument did not consist of showing that his theory was empirically accurate. On the contrary, all that Sakurai's arguments were intended to show is that his theory deserved to be taken up by the physics community and undergo further development. This calls into question what the ultimate purpose of non-empirical methods might be, and of how assessments of a theory's empirical adequacy and its pursuit-worthiness might relate to each other.

In her article, Elena Castellani investigates a class of methods for theory appraisal known as convergence strategies. Critics of String Theory, as she points out, have often complained that non-empirical methods constitute a departure from established scientific practice. In order to counter these claims, Castellani takes a closer look at this family of arguments, which has been used to support both theories with and without empirical basis. After reviewing the different kinds of convergence strategies discussed in the literature, she focuses on two historical case-studies. The first one has to do once again with Perrin's defense of the existence of atoms, which he supported with thirteen different derivations of Avogadro's number. Her second case-study concerns the acceptance of the existence of extra dimensions in Early String Theory, the early version of the theory that developed between the late 1960s and the mid-1980s. Also in this case, the availability of three independent paths leading to the surprising conclusion that $d = 26$ was key in leading to this hypothesis' acceptance. As Castellani reminds us, Perrin made use of empirical evidence in order to defend the existence of atoms, whereas physicists' derivations of the existence of extra dimensions were entirely non-empirical. In both cases, however, the hypothesis under examination received a significant boost in its epistemic status that relied not on the support of empirical data, but on the convergence of multiple lines of reasoning to a single conclusion. This suggests not only that at least some non-empirical arguments are legitimate, but also that they have a credible rooting in the history of science.

Casey McCoy's article focuses on eliminative reasoning, a method of acknowledged importance in the history of science, arguing that its epistemology stands in need of improved philosophical elucidation. Eliminative reasoning relies on first providing an initial set of explanatory hypotheses and then systematically eliminating them by rejecting those that do not fit with experience. In order for the method to yield epistemically justified final results, however, our choice for this initial space of hypotheses needs to be adequately justified in some manner. After criticizing previous authors for offering merely heuristic or pragmatic grounds for the initial positing of explanatory hypotheses, McCoy suggests that a properly epistemic foundation for eliminative reasoning can only be attained by making use of a kind of non-empirical evidence. Following Dawid, he points to observations about the research context in which we operate and other kinds of meta-empirical evidence as the grounds for potentially justifying our initial choice of hypotheses. Having offered this general analysis, McCoy goes on to apply it to the case of inflationary cosmology, where he argues that non-empirical evidence is also required to make sense of the logic behind actual scientific practice, and of the epistemic force behind its conclusions.

Finally, Sophie Ritson offers a historically informed account of the debate in String Theory, and of the manner in which it has recently unfolded. What she finds is that debate does not take the shape of a "meta-paradigmatic rift" between those who accept non-empirical methods and those who reject them. Instead, she finds that the discussion revolves around a number of constraints that regulate and guide physicists' assessments of the theory's fertility. Physicists' discussions around String Theory would thus revolve, according to Ritson, around two different types of issues. On the one hand, physicists may dispute the adequacy of constraints such as uniqueness as reliable indicators of a theory's fruitfulness. And on the other hand, physicists may disagree about the precise way in which String Theory satisfies criteria such as consistency or background independence, and about what exactly may be inferred from a theory possessing these traits. In this manner, the constraints identified by Ritson structure the debate among physicists, providing a common framework that allows for judgments that transcend mere optimism and pessimism about String Theory.

Together, these seven articles add new topics and ideas to philosophy of physics. They bring bring back to life theories as diverse (and sometimes neglected) as chemical and physical atomism, Einstein's unified field theory, Wheeler's theory of everything, Sakurai's theory of the strong force, inflationary cosmology, and both early and contemporary String Theory, and they use them to intervene in contemporary debates about fundamental physics and its methods. By approaching non-empirical physics from a historical perspective, we uncover the philosophical significance of past historical episodes, and we gain insight into the nature of current philosophical problems. It is our hope that this line of research will be continued by others in the future, realizing the full potential of our preferred approach towards enriching the vocabulary of history and philosophy of physics.

References

Blum, A. S. (2019). *Heisenberg's 1958 Weltformel and the Roots of Post-Empirical Physics*. SpringerLink.

Cappelli, A., E. Castellani, F. Colomo, and P. D. Vecchia (2012). *The Birth of String Theory*. Cambridge: Cambridge University Press.

Cushing, J. T. (1990). *Theory Construction and Selection in Modern Physics: The S Matrix*. Cambridge: Cambridge University Press.

Dawid, R. (2013). *String Theory and the Scientific Method*. Cambridge: Cambridge University Press.

Dawid, R. (2018). Delimiting the unconceived. *Foundations of Physics 48*(5), 492–506.

Dawid, R. (2019). The significance of non-empirical confirmation in fundamental physics. In K. Thébault, R. Dardashti, and R. Dawid (Eds.), *Why Trust a Theory? Epistemology of Fundamental Physics*, pp. 99–119. Cambridge University Press.

Ellis, G. and J. Silk (2014). Scientific method: Defend the integrity of physics. *Nature News 516*(7531), 321.

Greene, B. (1999). *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory*. New York: W. W. Norton & Co.

Kragh, H. (2011). *Higher Speculations: Grand Theories and Failed Revolutions in Physics and Cosmology*. Oxford University Press.

Lyth, D. H. and A. R. Liddle (2009). *The Primordial Density Perturbation: Cosmology, Inflation and the Origin of Structure*. Cambridge University Press.

Penrose, R. (2004). *The Road to Reality: A Complete Guide to the Laws of the Universe*. London: Jonathan Cape.

Polchinski, J. (2004). *String Theory*. Cambridge University Press.

Rickles, D. (2014). *A Brief History of String Theory*. Berlin: Springer.

Smeenk, C. (2005). False vacuum: Early universe cosmology and the development of inflation. In A. J. Kox and J. Eisenstaedt (Eds.), *The Universe of General Relativity. Einstein Studies, vol 11*, pp. 223–257. Birkhäuser Boston.

Smolin, L. (2007). *The Trouble With Physics: The Rise of String Theory, The Fall of a Science, and What Comes Next*. Boston: Mariner Books.

van Dongen, J. (2013). *Einstein's Unification.* Cambridge: Cambridge University Press.