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ORIGINAL ARTICLE

A speculative turn in science and philosophy of science

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Abstract
This paper describes the main features and goals of the speculative work in modern sciences that has greatly accelerated since World War II due to the exponential increase in computing power and newly available theoretical and conceptual tools. It points to the long historical strand of speculative philosophical work in symbiosis with the sciences, suggests the reasons for its unexpected neglect in contemporary professional philosophy of science, why it should be a major approach, and why such pursuit is not inevitable. Finally, the paper outlines potential topics, fields, and tools for such collaborative work and argues it is likelier to be more fruitful today than at any point in the past hundred years.

KEYWORDS
computer simulations, experimental philosophy, general philosophy of science, method in philosophy of science, scientific method, thought experiments

1 | SPECULATIVE METHOD IN THE SCIENCES

1.1 | Introduction: Generative and exploratory speculations

Exponentially rising computing power and the development of advanced mathematical and numerical methods have enabled the modeling of complex phenomena across scientific domains, including very abstract free-parameter computational analyses. Imaginative and projective theorizing of this sort and, accordingly, trailblazing in new relevant phenomena recognition and testing were rudimentary without these essential tools. Entire theoretical domains, along with domains of their actual and potential applications, opened up in the twentieth and twenty-first centuries using this approach. This sort of speculative scientific endeavor often starts from limited available evidence as goal-directed speculation. It has been used to understand and anticipate phenomena based on a limited evidential base or to anticipate plausible domains of potential evidence. One aspect of this approach is the exploratory development of new theoretical frameworks prompted by big data, while another is the generation of elaborate alternatives to existing theoretical work and insights. In both cases, new kinds of phenomena and potential evidential bases are anticipated. These frequently emerge from current knowledge, often in imaginative ways, and can sometimes be applicable in concrete, practical endeavors.

In this section we provide a detailed characterization of this scientific approach using an illustrative example and then briefly discuss some notable examples in contemporary science. After that we discuss history of the approach in science and philosophy (section 2) and assess its current state in philosophy of science (section 3)—explaining why it should be a major strand in it and why such convergence with scientific methodology is not inevitable, and offering a few broad suggestions for how it could be pursued in various directions more vigorously.

1.2 | An illustrative example: Early modern cosmology

A typical example of a speculative stream within a scientific field was the early twentieth-century development of modern physical cosmology, involving Albert Einstein, Willem de Sitter, and Alexander Friedmann. It was an exploration based on Einstein's newly developed and observationally tested General Theory of Relativity (GTR), which was now applied to the physical world as a whole by these physicists, thus producing a string of ever-bolder theoretical developments that may have lacked "sufficiently reliable experimental studies of the Universe" (Friedmann 1923, trans. Tropp, Frenkel, and Chernin 1993, 144) but nonetheless implied relevant evidential options that could be sought out.[1]

The first cautious step was made by Einstein, who in 1917 applied his theory to the physical world as a whole, attempting to square the equations of gravitation implied by GTR with then widely accepted assumptions of a homogenous, isotropic, spatially closed, and static universe. He concluded that the gravitational equations needed a "slight modification" to be reconciled with the general assumptions about the physical universe as a whole. This was, in fact, the first stage of the speculative string, albeit a reluctant one. It is not surprising that Einstein did not go in the direction of De Sitter and then Friedmann, who challenged the assumptions rather than modifying the gravitational equations. Einstein drew his Special Theory of Relativity from a wealth of experimentally firm insights (Norton 2014) that he then generalized as GTR. He thus felt the need to introduce a baseline check to his endeavor of applying this new and daring theory at the cosmological scale with the observational fact of "the small velocities of the stars," as this did not warrant a bolder theoretical move.

In the second stage, De Sitter (1916 and 1917) developed the application in a very different direction, showing that the three-dimensional world could be curved even without matter uniformly distributed across it. This was a major theoretical insight, as it showed that space itself has a property of curvature.

In the third stage, in a yet bolder development, Friedmann (1922, 1923, 1965, and 2014) explored the curvature of the universe. He explicitly defined the goal of his work in the following way in his 1923 paper: "[To indicate] the possibility of obtaining a particular world, the space curvature in which, being constant in respect to three coordinates taken to be space ones, changes with time, i.e. depends on the fourth taken as a time coordinate" (Friedmann 1923, trans. Tropp, Frenkel, and Chernin 1993, 153).[2] He pointed out that Einstein's "modification" was basically just one possibility—where the radius of the

[1]For a detailed historical account see Tropp, Frenkel, and Chernin 1993.

[2]Throughout the paper we cite Friedmann's 1923 work as translated in Tropp, Frenkel, and Chernin 1993.

universe is time independent—and went on to study how the radius of the universe and density of the matter in it develop with time. He discovered that two possibilities followed from this: the increasing curvature of the universe and the curvature as a periodic function in time. Einstein's chagrin concerning these results and his initial incorrect conclusion (later retracted) that Friedmann made an error in his calculations are understandable—unlike Einstein, Friedmann was a physicist fully bent on the bold speculative development of GTR at the cosmological scale.

First, Friedmann aimed at comprehensively exploring a whole set of physical possibilities via general implications of GTR in the cosmological context, since "[t]he variable type of Universe represents a great variety of cases" (Friedmann 1923, trans. Tropp, Frenkel, and Chernin 1993, 157). This was a departure from the regular drawing of theoretical implications from within a given set of essentially unexamined cosmological assumptions. It also provided a numerical parameter for the behavior of the universe in time. His exploration went as far as the examination of "creation from nothing"—even though Friedmann was fully aware that this was not supported in contemporaneous astronomy. And all along he understood the tentative nature of the methodological approach he was practicing, warning his readers to be wary.

Second, the exploration of these possibilities resulted in understanding the limits of applying GTR at different scales. Friedmann's use of Lobachevski's geometry enabled the examination of the highly speculative negative curvature of the universe with zero or negative density of matter, leading to the key conclusion that considerations of metrics at a local surface in GTR must be accompanied by examinations of curvature at the cosmological scale (Tropp, Frenkel, and Chernin 1993). This speculative exploration occurred at a cosmological scale as defined by an additional parameter, thus taking a step beyond the two previous stages.

Third, this work aimed at shaping the kind of evidence the exploration implied and connecting it to the existing observational capacities in astronomy. These explorations generated a new theoretical domain at the limit and also anticipated the future development of observational cosmology. Friedmann summarized his results as follows: "Thus, the world's metric alone does not enable us to solve the problem of finiteness of the Universe. To solve it, we need additional theoretical and experimental investigations" (Friedmann 1923, trans. Tropp, Frenkel, and Chernin 1993, 166). De Sitter's work referred both to estimates of the horizon of the visible universe and to the density of the matter in it. This led to Friedmann's conjectural estimates of the longevity of the universe that combined its dynamics and the density of matter.

All along, Friedmann reflected on the methodology he was employing, acutely aware he was taking the trajectory initiated by Einstein's first rather cautious step to its full conclusion, while often summarizing his endeavor by referring to Dante: "The sea I sail was never crossed before" (Friedmann 1923, trans. Tropp, Frenkel, and Chernin 1993, 175).

Friedmann challenged widely accepted assumptions without closely relying on specific empirical evidence, instead opening up new theoretical domains and exploring new possibilities and parameters to be taken farther observationally. And discovery of the limits of the fundamental theory (GTR) was not an end in itself but a springboard for probing its proper applications on a cosmological scale. We would be hard pressed to point out a clear dividing line between speculative and nonspeculative work in this streak in early modern cosmology, but these advances by Friedmann stand in sharp contrast to Einstein's initial working out of theoretical consequences checked by the existing data and within the confines of the existing assumptions. Moreover, although GTR was the starting point of the entire speculative stream of thought, it resulted from the generalization of an existing well-founded theory, not from the kind of sequence of the endeavor that followed.

1.3 | Contemporary science

In general, the scientific work on the nonspeculative side draws limited theoretical conclusions within well-known domains and never veers far from the existing evidence.[3] It is bent on refining existing key parameters rather than probing them in unexplored domains, let alone coming up with new ones. These two modes, however, are complementary in scientific practice, even though quite at odds in terms of goals and methodology—the projective speculative push has always been part of scientific and philosophical endeavor, not an antagonist to traditional methodological goals. This complementarity is quite obvious in the episode we discussed. It has blossomed in recent decades in science because of the exponential rise in computing power and the number of theoreticians pursuing it. Not surprisingly, similar historical episodes abound, and we return to some of them in section 3. Let us just mention another obvious episode tying into the one we discussed. Development of non-Euclidean geometry by Riemann, Gauss, and Lobachevski is perhaps the most abstract speculative work that immediately and smoothly seeped into physics, with Lobachevski organizing observations to determine whether physical space was indeed non-Euclidean (curved).

Thus, the speculative work in science is devised in order to:

1. explore and generate new general theoretical domains, horizons, and concepts;
2. conduct goal-direct research from limited evidence to potential target phenomena;
3. improve understanding by connecting (often limited) existing evidence by devising arrays of more comprehensive coherent accounts;
4. apply these newly developed theoretical domains and potential target phenomena to concrete problem solving.

Naturally, these goals are often interrelated.[4] We are also aware that we cannot offer distinctions that provide necessary and/or sufficient conditions for a demarcation line at this point (if such a task could and should be attempted at all); we can offer only a rather broad (operational) characterization.

Cosmology, the biological study of the origin of life, archaeology, paleontology, and other sciences researching the deep past continuously generate various speculative theories, models, explanations, and interpretations based on limited evidence. To give one example of this contemporary endeavor, scores of theories of the origin of life have aimed at pulling together our knowledge of physical, molecular, chemical, and geological features to establish realistic conditions of abiogenesis. They often differ vastly in their emphasis on key parameters, and eventually new and more elaborate convergent theories emerge. Debates on adequate biosignatures that humans should seek on other planets are directly tied to these theories, as a prime example of goal-directing speculative work (e.g., Irwin and Schulze-Makuch 2020). Similarly, various cosmological simulations open up new theoretical and potentially observational domains, including the N-body simulations of galaxy formation, free parameters in the power spectrum of density fluctuations in the cosmic microwave background (López-Corredoira 2013), the correlation and autocorrelation functions of various collapsed structures, and theories of the QSO (quasi-stellar objects, that is, quasars) absorption line systems. Some of these developments shine new light on traditional philosophical issues, such as the arrow of time and the existence and ontology of "other universes" (e.g., Carr 2007). Others reveal subtle problems with accepted principles,

[3]Couching this distinction in terms of deductive and inductive reasoning in science will not be helpful, as the distinction is more specific, as much as it could be treated within this larger one that philosophers of science have thoroughly debated.

[4]See Rickles (2008, 2) for a looser characterization of such a method in relation to quantum gravity in physics.

and still others apparently enjoy posing speculative paradoxes or bizarre counterfactuals (Dyson, Kleban, and Susskind 2002 and Tegmark 2008).

As mentioned above, speculative work often anticipates and infers entire theoretical domains of potential interest, rather than carefully inducing very specific theoretical points from available evidence. The exponential increase of computing power since World War II has brought speculative scientific works of this sort into mainstream science. In contemporary physics, new theories have been generated, prompted by deficient understandings of basic phenomena. Explanations of dark matter and dark energy had to be devised in order to deal with the empirical phenomena of the discrepancy of dynamic and radiation data on masses of galaxies and the acceleration of universe data. This, in turn, led to theories such as modified gravity. Similarly, alternatives to the Standard Model of particle physics such as Super-Symmetry (SUSY) have been devised to provide a unifying, albeit still speculative, model of the microphysical world.

In a completely different area, issues in philosophy of mathematics concerning decidability, completeness, metamathematics, computer-assisted proofs, and so on may belong in this category as well. Various developments in computer science admittedly helped us reach some specific goals, but that philosophy and metamathematics should formulate the goals of such research is acknowledged by some of the leading authors in the field, notably Gregory Chaitin (2005), who promotes "digital philosophy," finding a speculative predecessor in Leibniz but also invoking Frege and Carnap and Cristian Calude.

The rise of multiverse theories in both fundamental physics and cosmology, such as M-theory multiple vacua and the widespread acceptance of Hugh Everett's many worlds theory in the quantum computing community and cosmology (such as the hypothesis of bubble-universes created by chaotic inflation), to name just a few, flies in the face of conventional methodological goals of testing and verification and has already fostered a new wave of *very* speculative theoretical work, the goals of which are forward-looking *projective* development of theoretical domains based on current knowledge with an eye on applications (for example, in quantum computing), on early discernment of novel testing possibilities, or on development of novel abstract theoretical concepts.

In an applied physics attempt, Max Tegmark (Udresku and Tegmark 2020) leads a group of physicists who are attempting to understand the "black box" of machine and deep learning by means of known physical theories and the tools of physics. His groups, as well as other groups, have also tried to train computers to perform the role of physicists. David Deutsch (1985a and 1985b) is an acknowledged pioneer of quantum computing—especially in his prescient two 1985 papers. Arguably—and Deutsch does not shy away from such a description himself, including in his popular books, notably *The Fabric of Reality*—a large part of his work is philosophy of physics. This is clear from the title of his paper "Quantum Theory as a Universal Physical Theory." And he does intend philosophy to play an explanatory role in quantum information theory and quantum computation.

The work in this vein in the social sciences has been done within the fields themselves or sometimes with collaborators from other fields (other than philosophy). In a very recent example, collaboration between David Graeber, an anthropologist, and David Wengrow, an archaeologist (Graeber and Wengrow 2022), led to exploration of possible general conclusions on the nature of human settlements and social structures from paleolithic to current times based on the evidence that has accumulated over a few decades. They pulled together various strings of specialized archaeological studies to draw a vast picture suggesting that, as a rule, human societies do not stick to a fixed social hierarchy but rather interchangeably harbor very different ones. Meanwhile, philosophers of archaeology have focused almost exclusively on the standard methodological and epistemological analysis of archaeology, a pursuit only occasionally gesturing toward an endeavor of the kind undertaken by Graeber and Wengrow (see, e.g., Salmon [2014]).

2 | A HISTORICAL SYMBIOSIS OF PHILOSOPHICAL AND SCIENTIFIC SPECULATIONS

Viewing the speculative approach as prima facie methodologically suspicious and as a likely derailment of philosophy or even of scientific method is ill informed historically. In fact, it was present in philosophy, perhaps as much as it was present in the sciences, up to the twentieth century, because science lacked the computing power that is crucial for boosting it. And it is often impossible to detach the two, as the following examples show.

Ancient Greek atomists are an early template of how speculative philosophy should be done. They used the available and rather prosaic evidence to come up with the most general imaginable account at the time of basic elements of the world and the ensuing epistemology (distinction between primary and secondary qualities). Needless to say, their account has not only survived the test of time in its own terms, as a speculative understanding of the world, it has flourished as an operational model in modern science. In other words, building an extremely elaborate speculative model or a theory with projective goals in mind may pay dividends over relatively long periods of time.

Much later, Descartes's physics and the Cosmotheoros of Christiaan Huygens went in this speculative direction as well. Kant's speculative model of the origin of the solar system and his characterization of potential life and alien intelligence on other solar planets were directly related to Huygens's work.

Giambattista Vico drew new general conclusions by summarizing the existing knowledge of history in order to reflect on the methodology of history by including global social history as part of historical analysis. His rather crude speculations on the development of social structures throughout history pointed the way to understanding the development of societies. In addition, a number of utopian, elaborate thought experiments, starting with those of Tommaso Campanella, Thomas More, and Francis Bacon, probed the role of science in future societies. This was a standard approach to philosophical considerations of politics in a changing society that grappled with scientific advances.

In his exploratory philosophical work, Giordano Bruno speculated on the limits of the universe using Copernican and Galilean theoretical insights, as well as regular astronomical observational insights, as the foundation for speculation. His speculations on stars as other worlds like the Copernican solar system (rather mind-boggling even for Galileo) pointed to future research goals and suggested what sort of potentially testable hypotheses one should devise based on the existing foundation.

Alexander von Humboldt's (1859) book entitled *Cosmos* and in fact his entire empirical and theoretical work were an elaborate attempt to establish the notion of nature as a unifying interrelated system. His essentially philosophically motivated guiding idea was subsequently thoroughly tested across the globe.

We mentioned development of non-Euclidian geometry and its applications in cosmology, but in a more recent example the famous cosmological model of Kurt Gödel (1949) presents another prototype for productive interaction between speculative philosophy and "hard sciences." Gödel's acknowledged motivation was the use of general relativity to formalize his explicit and quite strong (see Wang 1990) philosophical intuition that time is an illusion (or at least that the flow of time and chronology are products of the human mind and not something out there in the world). Of course, we evaluate the outcome quite differently today: Gödel's universe tells us something deep and rather disturbing about the role of time in our best physical theories without making any pretense to describe the cosmological reality of "our" universe.

Ludwig Boltzmann's work on thermodynamics is perhaps the most developed work of the theoretical-speculative strand in physics. This also includes the contributions of his critics, Mach, Zermelo, Culverwell, and Burbury. Arguably, the origin of the Second Law of Thermodynamics belongs to this sort of scientific research that developed and blossomed with the increase in computational power in the twentieth and twenty-first centuries. The twentieth- century debates on the origin of the Second Law of Thermodynamics by Reichenbach, Hoyle, Davies, Hawking, and others, including inflationary theory in cosmology, are an extension of this work.

Other perhaps less obvious examples are Karl Popper's (1967) idea on testing the Copenhagen "interpretation" of quantum mechanics, Wilfrid Sellars's (1979) work and that of others on causality in the language of theory, Roger Penrose's work on the role of cosmological initial conditions, and Stephen Hawking's work on the chronology protection conjecture. Nick Bostrom's very recent project on existential risks and AI risks and similar ongoing projects belong to this projective speculative work and as such are clearly distinguishable from standard ethical analysis.

Finally, any current, elaborate system-level thinking will inevitably be speculative, as it will be based on big data, and, in various contexts, we can only hope to have a complete overview of the system parameters. The complexity of realistic systems is impossible or at least exceedingly difficult to accommodate in any consistent scientific treatment, formal or informal. And even in the classical thermodynamics of Boltzmann and Gibbs multiple paradoxes, thought experiments, and emergent—often unexpected and surprising—topics (Maxwell's demon, Zermelo's paradox, Loschmidt's objection, Ehrenfest's work on phase transitions, and so on) have historically shown that the limits and boundaries of the relevant systems are poorly mapped. Thus, whenever we perceive the rise of "systems thinking" science, explicitly or tacitly (to avoid various bureaucratic, jurisdictional, and funding obstacles), we may infer the rise in speculative thinking by various means. Obviously, this is a topic in and of itself for philosophy of science. Surprisingly, however, there has been little philosophical interest in this theme, although the rise in systems thinking has been prominent in many fields of the physical sciences, the life sciences, economics, futures studies, and engineering over the past half century.

3 | CONTEMPORARY PHILOSOPHY OF SCIENCE AND THE SPECULATIVE APPROACH

3.1 | Contemporary neglect of speculative philosophy of science

Before we move on to discuss the speculative strand in contemporary philosophy of science, we should ask whether and why should we expect current developments in philosophy of science to converge with those in science itself. While acknowledging that this is a large and involved topic in its own right, one could make normative arguments in favor of such convergence parallel to the classical arguments of Michael Friedman (1974) and Philip Kitcher (1981) for the explanatory unification in science. Suppose we wish to treat those explanations specific to philosophy of science on the Friedman-Kitcher model: if they are to be successful, these explanations would have to imply unified treatment of ever-widening sectors of philosophy of science. Even if some of them were entirely independent of the actual developments in science, successful explanatory projects would be predominantly likely to include those sectors closely following such developments. Moreover, Kitcher in particular emphasized that the unificationist program is likely to "provide insight into major episodes in the history of science" (Kitcher 1981, 507). One could go even further and ask why one would invoke the "Galilean strategy" (Kitcher 2001)—if not for the historical fact that philosophy of (physical) science has converged with the development of Copernican-Galilean science.[5] Only such convergence enabled us to properly assess philosophical aspects of new physical science emerging from the Copernican revolution. Similarly, we should not avoid assimilating the speculative strategy as the major approach in philosophy

[5]See as well Friedman's (2001) analysis of different conceptual layers of philosophical analysis also reflected within the history of scientific inquiry.

of science. Yet, given the historical contingencies shaping history of both science and philosophy, there is no reason to expect that more recent revolutions in science, including the ongoing ones, have or will have an impact in the domain of philosophy of science similar to that of the "Galilean strategy." Such convergence is not inevitable and requires a concerted broad effort we advocate.

The academic discipline of philosophy of science as we know it today began to be shaped institutionally in the second half of the nineteenth century. Its origins and goals can be traced to epistemological and methodological reflections on well-established scientific theories and facts and also to attempts to fix and polish central concepts in such theories, sometimes with the help of traditional and analytic metaphysics. These attempts include various conceptual criticisms leveled at established theories and their central assumptions and posits. The original goals of philosophy of science have solidified over a century and a half, and, generally speaking, faculty and doctoral students in all four flagship departments of history and philosophy of science in the United States (Pittsburgh, Minnesota, Boston, Irvine), in a few institutions in Europe, and in countless other institutions have worked within, very broadly speaking, the logical-positivist paradigm in philosophy of science and those of its derivatives that espouse similar goals or critiques. Even when the projects pursued by philosophers of science veer from this paradigm in the direction of philosophically motivated analysis of the actual practice or history of science, their philosophical analysis is supposed to be an after-the-fact analysis of actual and historical scientific developments.[6]

Thus, professional and institutional philosophy of science has concentrated on the slow-moving inductive and theoretical process that produced fundamental theories across the sciences, assessing scientific approaches and their respective results. The process is often described as the owl of Minerva flying only at dusk (that is, wisdom comes only with hindsight) or as the work of an under-laborer—to use two well-worn phrases. If measured on its own terms, however, we could say this approach has been immensely productive and has contributed to the sciences.[7]

The trend of experimental philosophy (X-phil) stands somewhat apart, as it took a different turn about two decades ago, by applying experimental methods of psychology to philosophical issues and concerns related to the nature of cognition and ethics.[8] Experimental philosophers aim to produce relevant experimental data to address long-standing philosophical concerns by following standard experimental methodology in the relevant social sciences. In this stream, philosophers essentially collaborate with social scientists, adding novel research questions and reflections on them via standard experimental methodology. It is curious—and related to the focus of philosophy of science we just outlined and to the central point of our paper—that this approach has not been extended to those special sciences that have traditionally produced and often provoked some of the central philosophical reflections, such as physics and evolutionary biology.

Oddly enough, the speculative approach inquiry in philosophy of science appears only haphazardly and in a very rudimentary form, even though it is essential to the development of many scientific fields. An analysis of titles and abstracts of research papers in two staple journals

[6]Naturally, assessments of the development of modern philosophy of science differ and often contradict each other. We are aware of this, but we ask the reader to set it aside, as it is not essential to get a *detailed* picture of the development of modern philosophy of science as a discipline in order to convey the main point we are making. The detailed picture is a side issue here, and it is essential to focus on the forest, not the trees.

[7]For a citation analysis of the influence of philosophy of science on scientific fields, see: https://dailynous.com/2021/05/05/which-scientific-disciplines-cite-philosophy-of-science-guest-post/

[8]See: https://plato.stanford.edu/entries/experimental-philosophy/

in the field over the past decade indicates very little work pursuing the speculative methodological lines and goals we discussed, and even comparatively few papers dealing with that sort of scientific work. Somewhat paradoxically, the conservative mainstream of philosophy of science continues in the present period (roughly from the turn of the century) whereby many scientists firmly rooted in special sciences strive to extend some of the standard methodological strictures of previous eras to achieve a variety of new goals. With a few exceptions (e.g., Draper, Draper, and Pust 2007 and Tavakol and Gironi 2017) somewhat outside the philosophical mainstream, these developments have not provoked what we might have expected in earlier epochs. By and large, such work is either ignored by philosophy of physics (the majority) or downplayed and severely criticized (the minority) on the basis of *old* precepts and views of how *real science* needs to, has to, or used to be done. One exception is recent work in philosophy of quantum gravity (Wütrich, Le Bihan, and Huggett 2021). Yet, as Rickles (2008, 2) acknowledges, this area is "rather curious from the point of view of philosophy of physics," precisely because of all the properties that characterize the speculative approach. The situation has not changed much in the past decade or so. In the emerging field of philosophy of cosmology, such approach remains at the programmatic level (Ellis 2014 and 2006). Richard Dawid (2013) has taken up a methodological challenge in the area of string theory but still justifies the work within the framework of traditional methodological goals. In other fields, counterfactual analysis of history of science has remained a fledgling attempt for the past two decades (Soler, Trizio, and Pickering 2016), while discussion of human enhancement has migrated into other fields. In philosophy of biology an astrobiological project of Peter Vickers shies away from speculating on the notion of life and biosignatures and stays on the sidelines as a social-epistemological afterthought of astrobiological research.[9]

When this general pause on speculative work in philosophy of science is coupled with a preexisting penchant for some extravagant philosophical positions, such as various forms of antirealism and increasingly bizarre ontologies (criticized in Ladyman and Ross 2007), the mixture becomes a cause for alarm. While such tendencies in philosophy of science will not derail the progress of special disciplines (such as physics, cosmology, biology, archaeology, and so forth), they may deepen the rift between philosophy and special sciences. That rift has already been widening for quite some time, although for largely different reasons, but there is no need to condone such tendencies, especially when an alternative, speculative kind of philosophy of science arguably has much to contribute to our understanding and may help to resolve many trans-scientific (Weinberg 1972) issues in today's world that manifestly require both philosophical and scientific *stricto sensu* input.

3.2 | The causes of the neglect and new opportunities

There is certainly some work in contemporary philosophy of science that shares the goals of the kind of scientific speculative work we have described. There are also borderline cases some of which we have just mentioned. But trying to pinpoint exactly whether certain work belongs to this category would not be very useful. Instead, we will give two more examples where the goals of research gesture toward speculative goals *but do not press in that direction*. Our aim is simply to identify a neglected but legitimate and potentially fruitful philosophical practice. It complements

[9]See: https://www.durham.ac.uk/research/institutes-and-centres/humanities-engaging-science-society/research/eurica-project-leverhulme/. Similarly, recent philosophical work on modified gravity by Martens and Lemkuhl (2020) is a bit bolder; they try to explicate the epistemological assumptions of modified gravity as a lesson for traditional philosophical notions of space and time and space-time, rather than working along the development of new concepts within the theoretical framework of modified gravity per se.

and improves the understanding of how science is practiced and ought to be practiced, what the physical world is like and the way it could be, in the same way it does in science—by bold exploratory challenging of widespread assumptions, by probing the limits of existing theories through extending theoretical domains, and by exploring possibilities and new parameters. We can only offer hints—the task of imaginatively and fruitfully developing the field in that direction can be done only by the community itself.

The first example is the use of simulations in social epistemology of sciences (Zollman 2010 and Frey and Šešelja 2020) that aims at understanding how various parameters defining scientific communities influence scientific pursuit and desired outcomes. The general goals of such studies are not always fully explicated, but they are fairly clearly targeted at understanding various existing and historical scientific communities. Only secondarily and only very occasionally are parameters manipulated in an exploratory fashion. The chosen methodologies often explicitly avoid the underlying complexity or subsume it beneath imposed top-down properties or boundary conditions; agent-based modeling exercises are an excellent example of this trend. The central goal of such studies is never a full-scale exploration of possible, even utopian, and very differently organized scientific communities. There is a clear domain for elaborate explorations of that sort.

The second example belongs to philosophy of biology. Several authors have developed philosophical accounts of intricate causal relations and the organization of complex biological systems (Varela, Maturana, and Uribe [1991], Thompson [2010], and Nicholson and Dupré [2018]), by developing elaborate alternatives to metaphysical and epistemic notions with a strong reductionist slant often favored by analytic metaphysics and philosophy of science. They and others have also explored the kinds of explanations appropriate for such systems. We cannot enter into these complicated debates, but we do suggest this exploratory work on the nature of life that is explicitly or reticently focused on the limited evidence provided by current biology could be extended, for example, into the domain of astrobiological concerns and concerns of artificial life. Such very general philosophical insights into the nature of life would constitute a bold continuation of current work, opening new theoretical domains and ideally helped by bold experimental-philosophical methods.

These fairly rudimentary steps and possibilities aside, why philosophers of science, in particular philosophers of physics and biology, have shied away from such an approach is an important and difficult question in its own right. Part of the reason may be that at first sight it seems at odds, methodologically speaking, with the abovementioned dominant approaches. This, however, is not necessarily so. As we have pointed out, the speculative work has always converged with testing-focused scientific work and also with the elaboration of theoretical details of well-tested theories, but it has been sidelined simply because the required computational and theoretical (including mathematical and numerical) tools have not been available for it to flourish.

Other factors may contribute to this shying away from speculative endeavors. One factor may be the dominant deflationary views of such traditional tools as thought experiments, which are typically contrasted with experiments, but not used in a projective sense. They are also almost exclusively invoked to illustrate certain assumptions and probe conclusions that follow, rather than examine these assumptions, or are used projectively as elaborate plausibility tests. A prime example is the famous brain in a vat experiment that simply assumes such a possibility, rather than examining the real, plausible, and possible relationship between mind, brain, and body (such discussions emerged only fairly recently). Sometimes thought experiments are used in a projective way, as "intuition pumps," for example, by the so-called zombie experiments in philosophy of mind. Although debates around them result in refined conceptual analysis, they rarely truly connect to relevant scientific work that can provide grounds for elaborate and plausible versions of such speculations.[10] An example of the same sort is a much discussed "Boltzmann brains" thought experiment. Yet thought experiments could be elaborated in various directions if developed as (scientifically informed) plausibility tests and projections boosted by the use of suitable computer simulations and be fruitful in the same sense in which speculative scientific endeavors we discussed are fruitful. We return to this issue shortly.

On the one hand, the rise of antirealism, regarded by some (e.g., Christopher Norris, Richard Rorty, Bruno Latour in his later work) as a way of reconciling mainstream philosophy of science with continental/postmodernist philosophy, seems to imply the arbitrariness of speculative philosophical endeavor, given that, according to this view (despite all the differences between its various versions), scientific theories do not really grasp reality anyway. On the other hand, obsession with reductionism and/or determinism in many circles is an impediment as well. To give an example, this obsession leads to the otherwise inexplicable level of popularity of Bohmian mechanics in philosophical circles, completely at odds with the situation in quantum physics itself. And a kind of "antihistoricism" leads many authors to believe it is possible to discuss every scientific field and theory as path independent, for example, cosmological or evolutionary-biological theoretical arguments, without understanding the historical trajectory of relevant theories. This attitude reinforces the assumption that speculative projections are not critical or even very useful, as adequate theories are bound to emerge from evidence one way or another. It is not clear that this claim is universally correct in the historical context to start with, but certainly with dramatic changes in the projective powers of current science, based on the existing evidential base, elaborate speculative work often plays a pivotal role in providing various options, choices, and anticipations for research. The anticipatory speculative work has become a very powerful tool that traces domains and directions in which observations and experiments are eventually employed.

Another issue is the delay of philosophy of science in addressing the integrative and multidisciplinary movements noticeable in contemporary scientific practice. There are many instances of such movements. Perhaps the most obvious one is the rise of astrobiology as a substantially multidisciplinary field that has transformed, in a comparatively short period of about twenty years, even the patterns of generally conservative scientific publishing (Brazelton and Sullivan 2009 and Taşkın and Aydinoglu 2015). Similar tendencies have been observed in the life sciences, especially ecology, geosciences—today often entitled "Earth-system science"—or branches of physics, such as quantum information theory, quantum computing, and nanotechnology. While philosophers of science often experience external administrative and other pressures to *entrench* themselves within a narrowly understood discipline, science seems to be moving in the opposite, more synthetic direction.

Downplaying the importance of scientific intuition and imagination in teaching science (especially the life sciences and social sciences) is an educational factor that kicks in early on.

Finally, political and financial considerations are relevant. Obtaining funding and grants for philosophical research has faced steep obstacles for quite some time. In such an atmosphere, many aspects of siege mentality come into play, with people adhering to old-fashioned, time-tested approaches and tending to avoid controversies, charges of recklessness, and so on. Risk aversion plays an important role in both education and funding decisions—and the societal and cultural trend toward risk aversion (and the corresponding rise of "safetyism") has become increasingly pronounced since the end of the Cold War.

In overcoming these impediments, along with the two examples we discussed, obvious candidates for the speculative work that philosophers of science could undertake are scientific fields and topics on which they have focused their attention only very recently, albeit

[10]Popper's thought experiment on the deterministic universe may be closer to that goal than the zombie thought experiments.

in the traditional methodological manner we have described. These include various scientific research projects on the origin of life and its definition, cosmological models, origin of languages, including artificial and alien languages, and, related to all these, the study of possible AI worlds. The society-science interface via the development of elaborate political utopian and dystopian scenarios is also largely unexplored. It has been exploited by science fiction and other writers, however, and their work has increasingly been used as inspiration by scientists in the past half century (e.g., Johnson 2011, Miller 2012, Swirski 2013, and Ćirković 2021). The elaborate imaginative speculative work of this sort in philosophy could perform all the tasks that the usual conceptual analysis achieves only to an extent; it could explore seemingly implausible possibilities of social and political organization and relations, generate new societal features, and hence probe the limits of current social-political theories. This has been done haphazardly throughout the literature and has never developed into major disciplinary effort.

The tool that philosophers of sciences bring to the speculative science toolkit is the versatility of thought experiments. These, in symbiosis with computer simulations, have been used only fairly recently to address philosophical problems (they have been discussed and analyzed conceptually since the early 2000s) and can be extremely useful. The technical proficiency of philosophers of physics, biology, and other special sciences who dedicate their time to traditional topics and approaches is already sufficient for speculative work and collaborations. To give one example, in the study of the origin and definition of life, the pertinent questions extend far into the past but also into the future—how life could have originated, what forms it could have taken, and what sort of life can be produced by humans or be discovered on other planets. A crucial aspect of this quest is the imaginative exploration that ought to probe the limits and generate answers that are wide enough in terms of both formal and concrete (biochemical and molecular) models. Philosophers could devise elaborate thought experiments, helped by adequate simulation, to do this crucial speculative generative work. A similar endeavor can be undertaken in philosophy of cosmology following the ideas of Ellis (2014 and 2006) and similar work.

Finally, a host of old historical ideas can be recycled and refurbished to serve the goals of speculative work. All this, along with the collaboration of scientists who actually do speculative work, could provide a critical edge and add new, imaginative aspects to the endeavor. The latter will, in turn, enormously broaden the intellectual appeal of philosophy of science throughout the entire space of human culture and heighten its visibility in the eyes of many, including prospective students and fundraisers.

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