"Why These Laws?"—Multiverse Discourse as a Scene of Response

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This paper traces the emergence of "why" questions in modern cosmology and the responding proliferation of multiverse discourse in the late twentieth and early twenty-first centuries. Critics who see speculative theorizing as delving into the metaphysical are not hard to find. George Ellis' concern that we are entering a new era of 'cosmological myth' resonates with the 1937 debate regarding "cosmythology" and the shifting boundary between physics and metaphysics. However, the charge that multiverse proposals are nothing but speculative metaphysics can be considered in terms other than criteria relating to empirical testability. A historicist reading of what metaphysics represents in this context is presented in order to emphasize that "metaphysical" as a pejorative term in science discourse is a fluid and historically contingent concept. It appears that proposals are being considered metaphysical precisely when there is no consensus on what constitutes empirical testability. Drawing on the work of Nicholas Jardine, Hans-Jörg Rheinberger and Christopher Hookway, I argue that in cosmology during this period, particularly in relation to multiverse proposals, there appears a well-defined "scene of response", rather than of fully-fledged inquiry. Thus, intelligible questions may be considered metaphysical, but not timelessly so.

1. Introduction

By the end of the twentieth century, many prominent cosmologists were fascinated by the questions why is the universe the way it is, and why does the universe appear to be just right for life to emerge.[1] Indeed, the shift to

1. For example, Bernard Carr's edited volume *Universe or Multiverse?* comprises an impressive list of contributions from many prominent cosmologists. While they propose different ways of how one goes about answering the question, they all seem to agree on the pressing question itself: why is the universe the way that it is (Carr 2007).

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posing questions beginning with why rather than what or how is a relatively recent development in modern cosmology. This paper begins by looking at the emergence of why questions in cosmological discourse by tracing affiliated anthropic reasoning and fine-tuning arguments in cosmology. I also consider recent suggestions that the laws of physics may themselves evolve. In response to the why questions, this paper then examines the proliferation of multiverse discourse in the late twentieth century.

Different interpretations of what the term multiverse signifies are presented. I consider why these positions are so often charged with being metaphysical. I argue that "metaphysical" as a pejorative term in cosmological discourse is a fluid label, which relies on historically contingent epistemologies (relating to the intelligibility of questions) and practices (relating to the tractability of questions). A historicist understanding of what the term metaphysical represents is presented, according to which cosmology is often charged with delving into metaphysics when it attempts to grapple with questions for which there is no agreement on the methods and techniques for getting to grips with such questions. Here, I take inspiration from Nicolas Rasmussen's reading of Nicholas Jardine's *Scenes of Inquiry*:

> Despite their differences, the traditional types of history of science have something in common, both the positivistic strain … and also the theory-driven strain… That is, both tell the history of science as a progressive series of *solutions* (inventions, discoveries) or *answers* (theories, models) to questions about the nature of the universe and how best to master it. With few exceptions, the history of the motivating questions has been told only incidentally, if at all… In *Scenes of Inquiry*, Nicholas Jardine has taken the innovative step toward resolving these difficulties by recasting them as problems concerning the history of scientific questions. (Rasmussen 1997, pp. 10–1)

Following Rasmussen (and Jardine), I approach the history of cosmology through the lens of the shifting questions, problems, solutions, practices, and presuppositions of inquirers. For Jardine, a scene of inquiry is a meta-concept that designates the set of questions, which are deemed real for a community of inquirers; the range of questions that it seems appropriate to pose. The reality of these questions depends on the ability of the community of inquirers to get to grips with them, both intellectually and practically (Jardine 2000, p. 4). The understanding of questions requires conceptual preconditions, and answering questions requires certain practices. Scientific theories, then, can only gain traction when the inquirers are able to tackle certain questions in their local reality. In this sense, we can see the emergence of certain cosmological theories as responses or solutions to certain kinds of questions or lines of inquiry. Thus, when considering the scene of cosmological inquiry, both its conceptual and practical aspects are important. In order to have a unified and fully-fledged scene of inquiry, research questions first need to be intelligible to the community. However, and perhaps more importantly, the questions and problems are made tractable by deploying tools, techniques, methods and epistemic practices that produce phenomena, observations or theoretical conclusions, and allow inquirers to get to grips with what they are investigating. If the tractable aspect is absent, there is confusion and debate in the community and potential contestation regarding questions of epistemology and methodology.

This paper covers a relatively lengthy period, from the late 1980s until the present day. During this time, cosmology has begun to encroach on territory traditionally reserved for religion or speculative metaphysics. Through the publication of more popular books, cosmology has also permeated the public's awareness with tantalising metaphysical answers to the ultimate questions. I argue that this period is characterized by a well-defined scene of response rather than one of inquiry. Jardine identifies periods in science where there are no ways of getting to grips with the intelligible questions. Christopher Hookway outlines: "These are the questions that are real in a stronger sense: they are experienced as needing an answer (rather than just possessing one)" (Hookway 2008, p. 18). The inquirers, (with the conviction that an answer will be found), begin to look for answers elsewhere or with other methods and techniques (Hookway 2008). A particular dimension has opened up, and questions such as "why these laws of physics?" and "why this universe?" have become legitimate lines of inquiry. There are meta-debates concerning the legitimacy of certain methods and techniques, and the inquirers are not sure how to get to grips with concepts such as the multiverse. Goals are driving techniques, and the scene of inquiry is in a state of flux.

The aim of this paper is not to offer a prescriptive articulation of existing failings in the methodology and/or epistemology of modern cosmology and to drive research directions. Rather, the paper treats the intellectual history of cosmology in the spirit of historical epistemology in the terms set out by Hans-Jörg Rheinberger—as an investigation into "the historical conditions *under* which, and the means *with* which, things are made into objects of knowledge" (Rheinberger 2010, p. 2). While the term historical epistemology has been used for a wide variety of different intellectual approaches that have emerged in recent years, it was pioneered by French thinkers such as Gaston Bachelard and Georges Canguilhem (Strum and Feest 2011). From this perspective, there are certainly no timeless forms of pure reason. Science (indeed the multiple sciences) becomes fragmented over time due to historical developments and contingencies. The norms of scientific practice and the content of scientific knowledge are the products of these long and convoluted histories, regardless of any claims to truth. There is no eternal, unchanging, objective, absolute form of scientific rationality. The fundamental tenet is that in order to understand what science is philosophically, we have to study its history.

The spirit of a historicization of Kantian critique could also characterize this approach; that is, reading Kant's conditions of possibilities in terms of dynamic, rather than timeless categories.[2] Namely, what are the (historical, diachronic) conditions of the possible certain types of knowledge? Rheinberger characterizes a great deal of the philosophy of science in the twentieth century, from Ernst Mach onwards, in this way. Rheinberger argues that several philosophers and historians of science have worked towards historicizing epistemology to the point where the undertaking is no longer concerned with what people simply believed. Instead, this conception sees science as a fluid, cultural practice, and attempts to uncover the conditions under which the vast, multifaceted sciences were shaped and transformed over time (Rheinberger 2010, p. 10).

Finally, I want to stress that the ideas discussed in this fascinating most recent period of modern cosmology (in this paper) are not entirely accepted by mainstream cosmologists. There is a great deal of observational and theoretical work going on in cosmology debates across the world, which focuses on the challenges posed by generally accepted observational relics and experimental simulations. Issues such as the nature of dark matter and dark energy for instance, based on observational data, are at the forefront of many cosmological endeavours. The increasing use of computer simulations in certain aspects of cosmology, such as galaxy formation and dynamics, has supplemented existing methods of extrapolation, and has made many problems which could not be solved by analytical methods tractable.[3]

However, the left-field aspects of cosmological inquiry presented here are not just on the periphery of mainstream cosmology. As Helge Kragh has noted, "the debate concerning the multiverse is more than an innocent pastime of a few cosmologists of a speculative inclination" (Kragh 2009, p. 549). The notion of a multiverse is a serious cosmological consideration

2. Here, I follow the re-readings of Kant by Hans Reichenbach and Ernst Cassirer in the early 1920s, as they worked towards relativizing Kant's notion of the a priori. See (Reichenbach [1928] 1958, [1920] 1965, Cassirer [1929] 1957, Friedman 1999).

3. This appears to be an under researched area of the history of modern astrophysics. Simulations began to be used seriously by the early 1970s, when the first computer models of galaxies started to emerge, but more research is required into how these techniques transformed the scene of modern cosmological inquiry. For some relevant literature, see (Winsberg 2010), (Sundberg 2012).

in many circles, even if some cosmologists are highly skeptical of its legitimacy. Kragh agrees that there appears to be a major epistemic shift in cosmological circles, especially as cosmology is being infiltrated with questions and practices from theories of quantum gravity. "As witnessed by such new branches as multiverse cosmology, astrobiology, string-based pre-big bang cosmology, and 'eschatological physics', scientific speculations are highly regarded by many physicists and seen in a different, more positive light than earlier" (Kragh 2009, p. 530).

2. The Emergence of "Why" Questions

2.1. Anthropic Motivations and Fine-Tuning Discussions

It seems that the emergence of these why questions can be traced to the mid-1970s with considerations of the anthropic principle in cosmological circles. Anthropic reasoning is now well and truly a part of modern cosmology, even though it has its fair share of critics. Remaining one of the more controversial tenets of modern cosmology, the anthropic principle comes in many forms: from the weak—we would not be here to notice that conditions are right for life if they were not right for life; to the strong—as we are here, the universe must be such that intelligent life forms evolve; to the participatory—only universes with observers at some point in their history will become real; to the final—intelligent life is a necessary property of universes, and cannot be destroyed once it comes into existence; to the completely ridiculous anthropic principle (CRAP), as coined by Martin Gardner (Gardner May 8, 1986). Today, several eminent scientists, including Stephen Hawking, Andrei Linde and Leonard Susskind, see the weak anthropic principle, in some form, as essential (Susskind 2006, pp. 22, 353).

The term anthropic principle was first introduced by Brandon Carter in 1973, discussing large number coincidences in physics and cosmology. Carter gave a talk at the 1973 International Astronomy Union (IAU) Symposium honouring Copernicus's 500th birthday in Krakow, and published the talk in the 1974 conference proceedings (Carter 1974). Carter's emphasis was on possible explanations, rather than predictions, for why the universe is the way that it is. He stated that he was influenced by Bondi's 1959 *Cosmology*, in which "certain widely known 'large number coincidences' are listed as evidence justifying the introduction of various exotic entities" (Carter 1974). The other inspiration came from a 1961 paper by Robert Dicke. Dicke discussed favourable conditions and the prerequisites for our existence and argued that life could not exist if the universal constants differed only slightly (Dicke 1961). A landmark book was published in 1986 by John Barrow and Frank Tipler (Barrow and Tipler 1986), and despite diverging from Carter's formation significantly, this work became the most cited reference for the anthropic principle,[4] and inspired many more philosophically-minded authors to discuss it as well (even if it was widely ridiculed by cosmologists).[5] Anthropic reasoning recognizes the fact that the universe seems so fine-tuned for life (as we know it), and uses this fact to explain numerous physical phenomena that would otherwise be difficult to explain. If some of the fundamental physical constants of the universe were altered only slightly, the universe would not have evolved to the state we see it today, and the existence of life would be impossible.

The more cosmologists began thinking about the large coincidences that seemed to produce the incredibly unstable set of conditions suitable for life in our universe, the more seriously they articulated the question. This fine-tuning problem, as it came to be known, relates to the effect that a slight modification of physical constants would have on the evolution of the universe. Had the universe expanded at a slightly greater rate, for instance, no galaxies would have formed. If the rate of expansion were slightly reduced, the universe would have collapsed in on itself a fraction of a second after the Big Bang. So it appears that our universe has the conditions that are just right for the development of galaxies, solar systems, and eventually, life. Some have said that the values are so fine-tuned that they are balancing on a knife's edge (Leslie 1989). Many parameters of the Standard Model of cosmology and the fundamental physical constants exhibit these fine-tuning aspects (Carter 1974). The other, perhaps more alarming fact appreciated by the early 1990s, was that the cosmological constant is roughly 120 orders of magnitude smaller than predicted by the Standard Model of particle physics (Carroll et al. 1992, Hawking 1983, Weinberg 1987). Moving away from these life-friendly (biophillic) formulations, practicing cosmologists began to seriously pose questions for possible inquiry, such as, why are the constants of nature what they are?

Philosopher Nick Bostrom explains that fine-tuning arguments normally take the form of either a design hypothesis (where these values in our universe are the result of purposeful design), or an ensemble hypothesis (where our universe is just a tiny fraction of the entire totality of physical existence or multiverse, which is sufficiently large and varied so fine-tuning becomes redundant) (Bostrom 2002). In the spirit of this second option, some cosmologists began explaining fine-tuning by positing an infinite set of universe domains with different physical laws and parameters. Then, somewhere, things will work out just right for life (Rees 1999, Susskind 2006).

4. In 2011, Carter's paper had 226 citations, whereas the Barrow and Tipler book had 1740. (Ellis 2011). Nevertheless, this high citation index is probably misleading—this book was largely ignored and ridiculed by cosmologists.

5. For a survey of the publications and presentation up to 1991, see (Balashov 1991).

Many popular science books emerged in the field of cosmology in the late twentieth century, attempting to get at the deep why questions (Hawking and Mlodinow 2010, Susskind 2006, Krauss 2012). In *Just Six Numbers* (published in 1999), Martin Rees argued that in order for life to exist, the following six constants must be set: the ratio of the electrical force divided by the gravitational force, the strength of nuclear binding, the normalized amount of matter in the universe, the seeds for cosmic structures, and the number of spatial dimensions. The overall structure of the physics, though, remains unchanged (Rees 1999). Indeed, so many values and parameters in cosmology would change the universe as we know it if tinkered with even minutely. Authors such as Hawking and Mlodinow, Krauss and Susskind make grand claims. In *The Grand Design*, Hawking and Mlodinow, for example, state that physics is now able to answer questions such as "Why is there something rather than nothing? Why do we exist? Why this particular set of (physical) laws and not some other?" (Hawking and Mlodinow 2010, p. 10).

Anthropic reasoning and fine-tuning arguments in cosmology shifted the focus for many inquirers away from the specifics of the physical history of the universe, and towards questions of meaning. George Ellis argues that "the more the issue of fine tuning was investigated, the more pressing it became" (Ellis 2011, p. 3216). There were just too many restrictions on physical parameters to ensure that life as we know it could emerge in the historical evolution of the universe.

It is important to distinguish that there were two closely inter-related questions that became pressing to the community at this time: (i) Why are the laws of physics (and constants) the way they are? (ii) Why are the laws of physics (and constants) just right for life? Both questions have emerged out of anthropic motivations and fine-tuning discussions. While the second led to other issues around biophillic principles, the first had an impact on the emergence of interest in the idea of the evolution of physics laws.

2.2. Evolving Laws of Physics?

In 1988, Geoffrey Burbidge (known for his non-standard work on Quasi-Steady State Theory), criticized the community for only accepting, "far-out theoretical ideas" if they were "related to the very early universe. There, anything and everything goes" (Burbidge 1988 p. 225). He argued that interesting questions remained (at least for him) regarding more radical theoretical ideas, such as the notion that the laws of physics themselves may have evolved. In 1988, he noted that "The current climate of opinion requires that these questions *not* be asked" (Burbidge 1988 p. 225).

However, by the early twenty-first century, physicists were beginning to take such notions seriously. In a paper published in 2013, physicist Lee

Smolin made some germane suggestions concerning how and why these questions have become pressing. Smolin claimed that, "As our knowledge of the elementary particles and fundamental interactions grew dramatically during the twentieth century we began to be interested in questions that are not answered by knowing the laws of physics. One of these is the question: *why are these the laws, rather than other possible laws?*" (Smolin 2013, p. 24). In discussing the shift from how to why, Smolin began thinking about why these laws of physics became the laws in our universe: "If there are many possible laws, each as logically consistent as those we observe, what selected the set that are realized in our universe? Another question not answered by knowing the laws is what selected the initial conditions, at or near the big bang" (Smolin 2013, p. 24). Here it would seem that metaphysics and cosmology come together.

Thinking about the question "why is an object the way it is?," a number of ways of answering it appear possible. One can give an answer in terms of the object's history: a historical or evolutionary story can be given for instance, on why a mountain range or the solar system, or a particular biological organism, has the particular features it does. Indeed, the features of the universe as a whole are nowadays explained in terms of its historicity. Another possibility is with a statistical explanation: due to some kind of probability distribution, or variations in populations, certain objects or classes of them can emerge (such explanations are given for thermodynamic movements of gases, for example). These types of explanations are given by some as suggestions that the universe emerged out of quantum fluctuations (Hawking and Mlodinow 2010). By the late twentieth century, objects within the universe were typically explained in terms of their history (Pearce 2017). However, the reasons for the beginnings of the universe, and questions concerning why the universe is the way that it is, also became realms for the application of historicist thinking.

Smolin probed the meta-questions associated with the shifts in the scene of inquiry in the late twentieth century.

> There are in science only two ways to explain why some state of affairs has come about. Either there are logical reasons it has to be that way, or there are historical causes, which acted over time to bring things to the present state. When logical implication is insufficient, the explanation must be found in causal processes acting over time. (2013, p. 24)

The problem with causal explanations here is that a causal process is usually understood as meaning processes that act in accordance with laws. If the laws themselves are the very things that require explanation, then we get caught in a vicious circle. Different levels of laws can be postulated to account for presumably lower-level laws, but at some point, a set of fundamental laws would be needed to explain the others.

Smolin suggested that in cosmology today, there is no logical explanation for why the universe is the way that it is. Smolin began thinking about the laws of physics in terms of their historicity, and wondering whether the current laws of physics are in fact the product of some earlier epoch of the universe prior to the Big Bang.

> In our analysis of the why these laws question we concluded that laws must have evolved dynamically to be explained. This implies that there were dynamical processes in our past by which the laws evolved. As we do not see any evidence that the fundamental laws or their parameters evolved in the observable past, these processes must have gone on in regions yet unresolved observationally. (2013, p. 31)

As the causal process explanation is insufficient in this context, there appears to be no alternative way of answering the why these laws question without invoking the idea of evolving laws. In short, the laws of physics as we know them today may in fact be dynamically changing over time.

The notion that the laws of physics may have evolved to their present state is not new in physics, but it has not been the accepted position since at least the middle of the twentieth century. In 1939, Paul Dirac famously suggested that the laws of physics might not be static. "At the beginning of time the laws of Nature were probably very different from what they are now. Thus, we should consider the laws of Nature as continually changing with the epoch, instead of as holding uniformly throughout space-time" (Dirac 1939, p. 128). As early as 1891, the founder of American pragmatism, Charles Sanders Peirce argued that it is not sufficient to simply know the laws of nature—they require an explanation: "Law is par excellence the thing that wants a reason. Now the only possible way of accounting for the laws of nature, and for uniformity in general, is to suppose them results of evolution" ([1891] 1955, p. 318).

These are answers to the question "why these laws?" which, although flagged long ago by these authors, were not even considered as possible answers throughout the twentieth century. Now, in the twenty-first century, the possibility of answering these questions in this way has been uncovered and is being re-assessed.

3. A Scene of Response?

3.1. Multiverse Proposals: a New Cosmological Discourse

Just as these why questions emerged in the scene of inquiry, based on anthropic motivations and fine-tuning arguments, it is clear that the inquirers were not quite sure how to answer these. Questions became intelligible to the community—such as "Why are the laws of physics the way they are?" and "Why are the laws of physics just right for life?"—but there were no accepted strategies of inquiry that made these questions tractable. In turn, what eventuated was that the questions themselves called for new techniques to be developed. A new cosmological discourse around the notion of a multiverse began to dominate the scene of cosmological inquiry, as it would appear, in direct response to this dimension of the scene of inquiry that opened up. Multiverse discourse became a critically important manifestation of the changing scene of cosmological inquiry in the late twentieth century.

Speculating about possible multiple worlds is nothing new (Bettini 2005, Kragh 2009, pp. 534–35). Such ideas can be traced back to the pre-Socratics (Anaximander and Anaximenes). However, these discussions were around the notion of a plurality or infinity of worlds. There are instances of multiverse-type ideas from Giordano Bruno in the late Renaissance, however Bruno conceived of the universe as infinite and his talk of an "infinity of worlds" was meant in terms of planets. There are also multiverse-type notions present in the writings of Thomas Wright and Immanuel Kant in the eighteenth century, and even physicist Ludwig Boltzmann in 1895. Boltzmann proposed the existence of subuniverses in connection with the law of entropy (Boltzmann 1895). Nevertheless, all of these notions were distinctly uncharacteristic of the multiverse discourse, which emerged in the late twentieth century.

Although there were multiverse-like proposals around before 1980, Kragh notes that they were "few and scattered" and "attracted little attention" (2009, p. 536). I focus on some of the first serious multiverse proposals from practicing cosmologists. Some of these appear in the very same proceedings from the 1973 IAU Symposium mentioned earlier. The papers at the symposium were, for the most part, dedicated to cosmological issues relating to the recently established hot Big Bang model, which had become well established in the community after the 1971 and 1972 publications of the Peebles and Weinberg textbooks (Peebles 1971; Weinberg 1972). Yet interestingly, there are two publications from the conference that touched on the idea of universes distinct from our own. These are Gary Steigman's contribution, suggesting that "an ensemble of very many possible universes" could solve the matter/antimatter conundrum (1974, p. 355); and Stephen Hawking's paper discussing "conceivable universes", while covering the observed isotropy of the universe (Hawking 1974, p. 285). However, these explorations were not multiverses in the way that they are conceptualized today.

Carter himself implied a multiverse in postulating the existence of "an ensemble of universes characterized by all possible combinations of initial conditions and fundamental constants" (Carter 1970). For Carter, this conception did not go "very much further than the Everett doctrine" (1974, p. 298; see Everett 1956, 1957). It also appears that Carter's world ensemble notion in his 1973 address made little initial impact. Carter explained that the Everett interpretation of quantum mechanics described a vector state of the Universe with "many branches of which only one can be known to any well-defined observer (although all are equally 'real')" (Carter 1974, p. 298). This proposal is dramatically at odds with the modern conception of the multiverse (in the string landscape), which is now in vogue (although highly controversial). The Everett view conceived of multiverses that all have the same laws of physics, whereas the laws and constants in the string landscape view vary (but more on this later). Carter concluded that "this doctrine would fit very naturally with the world ensemble philosophy that I have tried to describe" (1974, 298). Thus, Carter introduced the anthropic principle in its first modern form and connected it with an ensemble multiverse notion: "an ensemble of universes characterized by all conceivable combinations of initial conditions and fundamental constants" (Carter 1974).

Popular science books, such as Paul Davies' *Other Worlds* (1980) ensured that the public knew of the possible many-universe ideas that were emerging in cosmology. But as Kragh points out, "the majority of cosmologists considered them heterodox and speculative" (Kragh 2009, p. 536). There are a plethora of differing conceptions of the multiverse, but even more speculative ways of generating them. For instance, in 2004, Tegmark proposed a radial notion of the multiverse—that all possible mathematical structures are realized physically; whatever is metaphysically or logically possible cannot be ruled out (Tegmark 2004).[6] String theorist Brian Greene gave his own taxonomy, which covers nine types of parallel universes: quilted, inflationary, brane, cyclic, landscape, quantum, holographic, simulated and ultimate (Green 2011). In 2005, Stephano Bettini identified at least 29 ways of generating multiverses and noted that any taxonomy of multiverses would still miss other proposals:

> Oscillations, quantum world-splitting or other forms of foliation of Hilbert space, quantum vacuum fluctuations, symmetry breaking bubbles production, chaotic distributed scalar fields, inflaton's fields, wormholes, Smolin's black holes, random difference of chaotic gauge theories, moduli space of solutions of a supersymmetric M-theory, primordial antimatter domains at high redshifts, … not to speak of the idea of producing universes in the laboratory through 'a small region of false vacuum', of cosmic organism's theories or of the suggestion concerning fake 'simulated universes' indistinguishable

6. This seems a recapitulation of Spinoza's view that whatever is possible exists necessarily.

> from real ones in the eyes of their virtual inhabitants… Moreover universes can generally differ not only in size or free parameters typical of the Hot Big Bang model, but also in strength of elementary forces, masses of elementary particles, gauge symmetries, vacuum energy densities (i.e.: values of the cosmological constant), metric signatures, dimensionality and so on, thus frustrating almost any attempt of looking for an accurate taxonomy of the existing multiverse scenarios. (Bettini 2005, pp. 4–5)

The most accepted physical idea in cosmology that implies a multiverse is the inflationary scenario, which has more recently been closely linked to the "string landscape", and a range of other proposals emerging from what is now termed string cosmology. These proposals came from a fusion of string theory with cosmological questions. String theory emerged in the 1980s as the leading candidate for a theory to unify gravity with quantum mechanics, and in doing so, brought the general theory of relativity and the Standard Model of particles and fundamental forces under one overarching theoretical framework.[7] In its earlier versions, string theory claimed that the smallest constituents of physical reality are miniature vibrating one-dimensional strings, rather than particles, and different oscillations of the strings give rise to the forces and particles in the universe. However theoretical developments in the 1990s, most notably the discovery of d-branes and various dualities (such as the AdS/CFT duality) and the postulation of an 11-dimensional M-theory, have obscured this simple ontology underlying string theory. It no longer makes sense to say the fundamental ontology is string-like (Duff et al. 1995). The extra spatial dimensions (aside from our standard four-dimensional space-time), deemed necessary for consistent versions of string theory, are thought to be hidden through a process of "compactification", in which the extra dimensions are "curled up" on themselves.

For around 20 years after the mid-1980s, inflationary cosmologists speculated about different models of a multiverse or set of quasi-universes. In 2000, in the wake of the discovery of the positive cosmological constant, Polchinski and Bousso first calculated that the basic string theory equations have an enormous number of possible solutions (around 10^{1000}) and each solution represents a unique set of fundamental constants, with particles and forces constituting the universe (Bousso and Polchinski 2000);[8] the figure is now usually given as around 10^{500}. This so-called

7. For more detailed analysis of string theory and its history, see Rickles 2014.

8. The statistics of the string/M theory vacua are treated thoroughly by Michael Douglas. See (Douglas 2003).

"landscape" is due to inflationary mechanisms and has been interpreted by a number of prominent physicists, notably Linde, Susskind and Rees, as "essentially distinct universes" (Weinstein 2006, p. 1, Bousso and Polchinski 2000, Susskind 2003). The fundamental physical parameters are different in these universes, and some interpret this using anthropic reasoning (Weinstein 2006). String theorists, working with supersymmetric models linking to the Standard Model of cosmology, currently cite 10^{500} low-energy vacua solutions. While not all agree that these represent other real universes, the string landscape is believed by many to represent an "ultimate ensemble" type multiverse—though no exact correspondence with our universe has ever been found.

The notion of an ultimate ensemble multiverse raises an important issue within multiverse discourse. One ambiguity in most multiverse discourse is defining precisely what a multiverse means, especially in relation to the meaning of the term universe. The term universe is often used to refer to all that exists in a materialist sense of matter and energy, although it may include all of space and time. More recently, cosmologists have used the term universe to refer to the set of fundamental laws and physical constants that govern our universe. A multiverse can thus refer to the different sets of laws and constants that may operate at different times and in different regions of the universe (being all that exists). So the multiverse in this formulation represents different pockets of the same larger universe. Some metaphysics is unavoidable here in a sense, as it remains necessary to articulate the meaning of "existence". So in presenting the universe as an ensemble of pockets with different laws, it may just be that cosmologists will need to more carefully define what they mean by universe. There appears to be an interesting shift in multiverse discourse away from a universe constituting all that exists (*qua* matter and energy) and towards a universe representing one particular realm of physical laws.

Multiverse proposals were seen by many as a means for explaining the fine-tuning problem. This was a main driver of connecting anthropic reasoning with the multiverse. The fact that the parameters of the Standard Model of cosmology exhibited fine-tuning aspects, as mentioned earlier (Carter 1974; Carroll et al. 1992; Hawking 1983; Weinberg 1987), implied for many that no matter how delicate the balance of these values appears to be, the fact that we live in a universe with them is somehow important (Rees 1997). Bernard Carr explains:

> These multiverse proposals have not generally been motivated by an attempt to explain the anthropic fine-tunings; most of them have arisen independently out of developments in cosmology and particle physics. Nevertheless, it now seems clear that the two concepts are

> inherently interlinked. For if there are many universes, this begs the question of why we inhabit this particular one, and—at the very least—one would have to concede that our own existence is a relevant selection effect. Indeed, since we necessarily reside in one of the life-conducive universes, the multiverse picture reduces the strong anthropic principle to an aspect of the weak one. For this reason, many physicists would regard the multiverse proposal as providing the most natural explanation of the anthropic fine-tunings. (Carr 2007, p. 4)

While fine-tuning was the problem that the multiverse proposal solved, cosmic inflation was the physical mechanism by which the multiverse idea became more seriously considered in the community (Kragh 2009, p. 536). The link of inflation to a possible multiverse was first proposed in 1982 by Linde (Linde 1982) and followed by a more detailed discussion in 1983 (Linde 1983b). It was proposed that the speed of the expansion of the universe during inflation could have created areas of the universe, which are in effect separate bubbles of space-time (or, subuniverses). Another paper by J. Richard Gott in 1982 explored inflationary cosmology as a theory of multiple universes (Gott 1982). Linde's 1983 paper connected the universe with different properties corresponding to different vacua of supersymmetric theories (Linde 1983a). The multiverse arising from the inflationary model was then explicitly proposed by Linde in 1986 (Linde 1986). He covered the anthropic implications of eternal inflation on the multiverse. The advances in string theory and the subsequent amalgamation of the multiple string theories by M-theory brought with them more support for the multiverse notion. This was despite the fact that there remained no empirical verification of string theory, nor any conceivable observational tests on the horizon.

Vilenkin believes that eternal inflation means that the multiverse picture is essentially inevitable (Vilenkin 2007, p. 163). Others, like Ellis dispute the claim that chaotic or eternal inflation implies a multiverse:

> Some claim such a multiverse is implied by known physics, which leads to chaotic inflation, with different effective physics necessarily occurring in the different bubbles of chaotic inflation. But this is not the case. The key physics (e.g. Coleman-de Luccia tunneling or the hypothesized inflation potential, the string theory landscape) is extrapolated from known and tested physics to new contexts; the extrapolation is unverified and indeed is unverifiable; it may or may not be true. For example, the parameter values that led to eternal chaotic inflation may or may not be the real ones occurring in

> inflation, assuming that inflation happened. And in particular, the supposed mechanism whereby different string theory vacua are realized in different universe domains is speculative and untested. (Ellis 2014, p. 15)

In a conference paper in 2006, Alan Guth explained "The combination of the string landscape with eternal inflation has in turn led to a markedly increased interest in anthropic reasoning, since we now have a respectable set of theoretical ideas that provide a setting for such reasoning" (Guth 2006, p. 10).[9] Even though the theories were speculative and the reasoning anthropic, they were generally becoming respectable.

> To many physicists, the new setting for anthropic reasoning is a welcome opportunity: in the multiverse, life will evolve only in very rare regions where the local laws of physics just happen to have the properties needed for life, giving a simple explanation for why the observed universe appears to have just the right properties for the evolution of life. The incredibly small value of the cosmological constant is a telling example of a feature that seems to be needed for life, but for which an explanation from fundamental physics is painfully lacking. Anthropic reasoning can give the illusion of intelligent design, without the need for any intelligent intervention. (Guth 2006, p. 10).

Nevertheless, in 2006 Guth acknowledged that "many other physicists have an abhorrence of anthropic reasoning" (Guth 2006, p. 10). Physicist David Gross has argued that the recent trend towards embracing anthropic reasoning and multiverse hypotheses by some string theorists is "premature and defeatist" (Gross 2005, p. 105). In a recent interview, Gross has reiterated his objections to the notion of a multiverse and the deployment of anthropic reasoning—a view that is shared by a number of other physicists (Byrne 2013).

Critics of the multiverse idea would no doubt disagree with the following claim from cosmologist Max Tegmark: "The borderline between physics and philosophy has shifted quite dramatically in the last century ... I think it's quite clear that parallel universes are now absorbed by that

9. Linde makes similar remarks: "I believe we are now entering 'the age of anthropic reasoning.' Inflationary cosmology—in combination with strong theory—leads to a picture of a multiverse consisting of an infinite number of exponentially large domains ('universes') with an exponentially large number of different properties. In addition to a somewhat subjective notion of beauty and naturalness, we are adding the simple and obvious criterion that the part of the Universe where we live must be consistent with the possibility of our existence" (Linde 2007, p. 145).

moving boundary. It's included within physics rather than metaphysics" (Seife 2004, p. 465). The question of what counts as demarcation remains a hotly contested one. Similar to disputes in cosmological circles in the 1930s,[10] the protagonists seem to get caught up in a demarcation dispute; a dispute which goes right to the heart of the accepted tools of inquiry that allow inquirers to get to grips with intelligible questions.[11]

3.2. Defining Metaphysics in Terms of Historicity

Just as the questions became pressing, the tractability of the methods and epistemic practices was tested. The most powerful tool that cosmologists were able to apply in attempting to answer these questions was the very tool that had been deployed successfully since 1980—speculative theorizing. Countless theoretical proposals were put forward, each more elaborate than the last. Whereas the inflationary scenario immediately solved several problems for standard Big Bang cosmology, and made the temporal evolutionary narrative of the universe more consistent, multiverse proposals did not solve problems in the evolutionary history of our universe. Rather, if they did solve problems, they were not ones that had any direct bearing on the history of our universe as we know it. Without accepted methods or techniques to build evidence for any of the proposals, these speculative theories remain metaphysical in the eyes of many. It will become clear that the meaning of such a charge, however, is complex and somewhat fluid.

Some cosmologists have expressed concerns that multiverse proposals delve into metaphysics. Ellis, for instance, does not reject the idea of multiverse altogether, and agrees that cosmologists "must explore all alternatives: Models based in the wave function of the universe; Pre-big bang and cyclic cosmologies; Brane cosmology and string cosmology; Loop quantum cosmology" (Ellis 2014, p. 17). However, "all of them are highly speculative untested physics, and most suffer from mathematical problems such as ill definition, or divergences, or arbitrary assumption of a matter behavior that is nothing like what we have ever encountered in a laboratory" (Ellis 2014, p. 17). Ellis also calls for caution in testing these theories in the way described above, "only by matching the CMB [cosmic microwave background] anisotropies, which they all laudably strive to achieve … CMB predictions are crucial—they are necessary for a viable cosmological theory—but

10. The 1930s saw vehement debates regarding the legitimate methodology for dealing with questions concerning cosmology. (Gale 2002; Gale and Shanks 1996; Gale and Urani 1999).

11. For an analysis of how this plays out in the context of string theory, see Ritson and Camilleri 2014.

by themselves are not sufficient to establish any specific such theory" (Ellis 2014, p. 17).

Carr explains that some physicists reject the notion that the multiverse is real science. "Since our confidence in them is based on faith and aesthetic considerations (for example mathematical beauty) rather than experimental data, they regard them as having more in common with religion than science" (Carr 2007, p. 14). Although this is a somewhat unsophisticated simplification of a multifaceted debate, the sentiment of Carr's comment is indicative of a general distrust towards multiverse discourse. This view can be seen, for instance, in the work of physicists such as Ellis (2007), Smolin (2007) and Martin Gardner (2003). Paul Davies, another critic of the multiverse, regards the multiverse notion as just as metaphysical as that of a divine creator (Davies 2007). Davies underscores that many multiverse explanations are "reminiscent of theological discussions. Indeed, invoking an infinity of unseen universes to explain the unusual features of the one we do see is just as ad hoc as invoking an unseen Creator. The multiverse theory may be dressed up in scientific language, but in essence it requires the same leap of faith" (Davies 2003).

There are concerns from the standard circles about the methodological practices and metaphysical speculations in multiverse proposals. Ellis is concerned that "cosmological myth" is taking over in these endeavors, "but this time in a scientific rather than religious mode. By *myth*, I mean an explanatory story or theory that gives means of understanding what happens but remains hypothetical rather than proven" (Ellis 2008 p. 538). Writing in 2014, Ellis was also worried about cultural shifts in cosmological circles:

> Currently, there is a culture of allowing anything whatever in speculative cosmological theories—sometimes abandoning basic principles that have been fundamental to physics so far… claims emanating from this approach should be regarded with great caution: they are in many cases unsupported by evidence and are based on arbitrary assumptions that don't satisfy usual physical criteria. (Ellis 2014, p. 17)

Ellis cautions cosmologists (and other physicists) against the claims emanating from this approach: "Once the gold standard of experimental support has been dropped and basic scientific principles are disregarded, why should such theories be regarded as good science?" (2014, p. 17).

Bernard Carr notes:

> Despite the growing popularity of the multiverse proposal, it must be admitted that many physicists remain deeply uncomfortable with

> it. The reason is clear. The idea is highly speculative and, from both a cosmological and a particle physics perspective, the reality of a multiverse is currently untestable. Indeed, it may always remain so, in the sense that astronomers may never be able to observe the other universes with telescopes and particle accelerators. (2007, p. 14)

The issue of empirical testability is a crucial and complex one when considering multiverse discourse, as possible multiverse-domains are by definition, beyond the particle horizon of the visible universe. These realms remain, therefore, unobservable even in principle. Critics of multiverse cosmology seem to ubiquitously draw on criteria relating to empirical testability to reject multiverse proposals. There are caveats around this observable boundary, and the only conceivable observational tests for the multiverse proposals are in the form of remnants, relics, and signatures or imprints in observable phenomena in our visible universe.

It is worth reflecting very briefly on the observational verifiability of multiverse proposals. Recent cosmological research has produced some of the first observational tests of eternal inflation, but the results are sketchy at best. Some researchers have outlined an algorithm for simulating CMB skies with and without collisions of possible bubble universes in a previous point in some multiverse cosmic history. They look for promising signals and perform searches for causal boundaries in the CMB; possible signatures or imprints in the spectrum using real 7-year data from the Wilkinson Microwave Anisotropy Probe (WMAP). The researchers note that more precise polarization data from the new *Planck* satellite is needed, but like the BICEP-2 experiment ((BICEP2 Collaboration 2014a, b) See also (Seljak and Zaldarriaga 1997)), it is difficult to determine whether the signatures are truly bubble collisions or in fact, just noise (Feeney et al. 2011). This incredibly complex area of the observational corollaries of multiverse scenarios requires further probing.

It is evident that the multiverse-related proposals in cosmology have generated much debate. Critics who see speculative theorizing as delving into the metaphysical are not hard to find when examining string landscape discourse, for instance. However, the notion that opponents of the multiverse must all also be Popperians or strict empiricists seems overly simplistic. Drawing on notions of empirical testability, and challenging the legitimacy of the very possibility of "in principle" empirical verification, seems to have become a neat rhetorical device that some cosmologists employ to criticize views they disapprove of, but a device which is hardly applied consistently across all areas of cosmology and, indeed, physics in general. After all, many cosmologists happily accept the notion of inflation (which is yet to be empirically verified and, as Dawid has argued, is "arguably more detached from empirical testing than any other current theory" (Dawid 2013, p. 7)), but vehemently reject the multiverse. Countless other areas of cosmological inquiry have also been characterized as bordering on the limits of metaphysics in previous times, but at later times they seem to comfortably sit in the accepted realms of the scene of inquiry. Notions such as the Big Bang, the very early universe, and realms beyond the limits of our galaxy were all considered at previous times to be beyond the limits of scientific inquiry.

The point I am trying to make is that the charge that claims multiverse proposals are nothing but speculative metaphysics can be considered in terms other than criteria relating to empirical testability. Applying a historicist reading of what metaphysics means may help unpack what is going on here, even if the actors in the scene of inquiry do not present it in these terms. It appears that proposals are being considered metaphysical precisely when the methods by which testability is established are contested. In other words, there is no consensus on what constitutes empirical testability precisely when the means of inquiry are contested. From this view, the debate regarding the legitimacy of multiverse proposals stems from implicit disagreement regarding which tools of inquiry can and/or should be used to answer the pressing why questions.

From the standpoint of a scene of inquiry, the demarcation between physics and metaphysics seems to hinge on the acceptability of the methods, techniques and practices used by the community of cosmological inquirers. Actors seem to be labelling theoretical proposals as metaphysical when the questions are intelligible to the community and have become pressing, but are not yet tractable with the accepted means of inquiry. Thus, intelligible questions are being labelled metaphysical, but may not be labelled this way indefinitely; if inquirers do find a way to make the questions tractable by means of accepted methods and techniques, (and if consensus can be reached regarding the legitimacy of such tools), then the multiverse proposals could become accepted in the domain on inquiry.

The multiverse scenarios seem to be a primary exemplar of physicists disagreeing about what constitutes physics and metaphysics in a scene of inquiry—arising from a scenario where they disagree with how to get to grips with the questions. The inquirers still pursue inquiry in the hope that the questions become scientific at a later period. Thus, in cosmology during this period what we see is a well-defined scene of response, rather than of fully-fledged inquiry. This conception of an evolving scene of inquiry makes it a rational pursuit for the inquirers to pursue the questions, even if the means of inquiry are contested.

As Hookway explains,

> It can still be rational to inquire into such questions, guided by the confident *hope* that answers will emerge, and by the hope that we will evaluate those answers in light of evidence. But in that case, our strategy of inquiry will be primarily focused, not on refuting or defending particular answers, but on looking for possible answers. (2008, p. 19)

Consider, for example, the earlier exploration of the possible evolution of the laws of physics. Hookway notes that revising the answers to questions long-thought illegitimate is a standard avenue for inquiry in a scene of response, and having evolving laws is now a potential answer to why questions.

> The motivational force rests on a substantial presupposition; there is a real question here, and we can discover what it is, and when we do, it will be a question we can handle directly. And the first task of inquiry is to create a situation in which our interrogative expresses that real question. In order for that to happen, we may have to revise answers that, we had thought, had been rejected. We may have to uncover the possibility of answers that, at present, we are not aware of. We can see the initial interrogative, which expresses no real question, as setting in motion a course of activities designed to enable us to find such a question. (2008, p. 19)

As noted above by Smolin's comments regarding the landscape problem as an answer to explaining "why these laws", the quest to give an explanation to physical properties of the universe can be traced back all the way to Leibniz (who, as the history of philosophy attests, failed to realise his dream):

> … the landscape problem as it arises in string theory is symptomatic of a much older and deeper issue: that the completion of a scientific understanding of our universe requires that we not only know what the laws of nature are, but explain why these are the laws. Thus, what is at stake is whether Leibniz's old dream that we can give a sufficient reason for every physically meaningful property of the universe can be realized. (Smolin 2013, p. 42)

Leibniz's "dream" largely disappeared from physics (as natural philosophy) by the second half of the eighteenth century. Although instances of this tradition of thought can be found in Peirce and Dirac, as mentioned earlier, there was no ongoing discussion of such questions in the field of physics. Of course, alternative ways of getting to grips with the why questions were proposed, albeit primarily by theologians and metaphysicians. However, in the scene of response of the late twentieth century, a historical explanation to the "why these laws" question was clearly back on the table as a distinct possibility.

3.3. Rethinking the 1937 Attack on Cosmythology

As flagged earlier, the 1930s also saw a meta-debate about the legitimate ways of getting to grips with the cosmos as a whole. Once observational developments had been coupled with theoretical models of a non-static universe by the end of the 1920s, the 1930s saw a huge increase in interest in cosmological questions in physics and mathematics circles. There were a plethora of competing theories, based on relativistic scenarios, but a great deal of debate and disagreement in the theoretical community regarding the legitimate means of undertaking cosmological inquiry. Cosmology was a young science—new questions had begun to emerge (such as "What is the large-scale structure of the universe?"; "Is the universe expanding and, if so, what is the mechanism of the expansion?", and "Was there a beginning to the universe?"), but were not yet consolidated through a unified discipline or a long history of discourse. There was no clear understanding in the community of what kind of science cosmology should be. Rather, there were multiple competing views about how cosmological methodology should proceed.

The debate in the 1930s centred on the demarcation between what constituted legitimate, scientific cosmology and a metaphysical type of cosmythology; a notion which has surprising resonance with Ellis' concern regarding cosmological myth. One of the most important alternative cosmological theories for this period is the picture developed by Edward Milne in England (Gale 2002; Lepeltier 2006). From 1932, Milne developed a theory of kinematic relativity, based on Einstein's special, but not the general, theory of relativity. Galaxies in Milne's model receded proportionally with time. As Kragh points out, Milne's theory "set the agenda for a large part of cosmological work" in the 1930s (Kragh 1995). However, the reason for this turned out to be due not to the physical arguments presented by Milne, but rather to the epistemological viewpoint that underpinned his theoretical approach. Milne's system explicitly aimed to be deductive proceeding from axiomatic principles: with a spirit of rationalist thinking at its core. Milne's approach was the source of much controversy. Willem De Sitter, for instance, was concerned when metaphysical assumptions entered physics discourse. Speaking in the language of logical positivists, de Sitter implied a demarcation criterion: "Strictly speaking every assertion about what has not been observed is outside physics and belongs to metaphysics … there is nothing an orthodox physicist abhors more than metaphysics" (de Sitter 1932, p. 5).[12]

In 1937, thanks to the provocative proposals by Milne, Eddington and Dirac, the debate reached a climax (Kragh 1982, Gale and Shanks 1996). Herbert Dingle[13] launched a vitriolic attack on Milne and his metaphysical assumptions. With a title that can only be interpreted as deliberately vexatious, Dingle attacked cosmythology in his *Nature* piece "Modern Aristotelianism". Employing highly provocative language, Dingle stated "The phenomenon may be described in broad terms as an idolatry of which 'The Universe' is the god … This cosmolatry, as might be expected, came by metaphysics out of mathematics" (Dingle 1937, p. 786). He likened metaphysics to a disease that had contaminated certain realms of cosmological inquiry: "Nor are we dealing with a mere skin disease which time itself will heal. Such ailments are familiar enough; every age has its delusions and every cause its traitors. But the danger here is radical. Our leaders themselves are bemused; so that treachery can pass unnoticed and even think itself fidelity" (Dingle 1937, p. 786). Dingle argued that it is we who must decide what is "proper"—to "deduce particular conclusions from *a priori* general principles or derive general principles from observations? … the question presented to us now is whether the foundation of science shall be observation or invention" (Dingle 1937, p. 785).

12. However, even de Sitter at times showed how vague the boundary between physics and metaphysics could become. George Gale has identified that de Sitter accepted the cosmological constant, even though it had metaphysical origins. "It has such obvious advantages from many points of view, that it has been generally adopted, even before any phenomenon has been observed which could be explained by the equations containing *lambda*, but not without it" (de Sitter 1931, p. 3). Gale notes that de Sitter was content to tread close to metaphysical limits if the process undertaken was one guided by extrapolation (Gale 2005, pp. 162–63). This is precisely where methodological rhetoric is exposed as inadequate. The way these inquirers actually proceeded in practice was often in tension with their hyperbolized methodological positions.

13. Herbert Dingle subscribed to an operational philosophical perspective, which he found present in the general theory of relativity, as well as being a keen follower of Mach's positivist empiricism. Dingle followed Rudolf Carnap and other logical positivists in rejecting all that is over and above experience. But he went further: still "I make this more rigorous: only that which is *practically observable*—that is, only that which would be observable if we were able to use known means of observation to the known limits of their possibilities—*is significant*" (Dingle 1938, p. 25). He was an empiricist who propounded a rejection of any *a priori* methods, and even published a book defining science as organized common sense (Dingle 1933). This seems an absurd view from a practicing physicist, and formed part of a positivist manifesto to avoid metaphysical statements at all costs (at least those that could not be empirically verified). Indeed, it is difficult to imagine a way of doing physics in strict adherence to this approach.

The community found itself in a difficult situation after 1937. After the debate degenerated to scathing assessments of the views in opposing camps, there was no clear way forward. Neither methodological position had clear ways of being defended. Few involved in cosmological inquiry adopted the extreme rationalism of Milne or the extreme empiricism of Dingle. This slinging match about the very possibility of cosmological inquiry seemed to halt an already tenuous scene of inquiry, in which not a great deal of work was being done. The scene effectively collapsed or unravelled, as the inquirers did not even agree on what questions were intelligible, let alone which methods made the questions tractable.

In this sense, it may be tempting to equate the scene of response relating to multiverse discourse identified at present in cosmological circles with the methodological debates in the 1930s. However, there is a crucial difference—today, cosmologists do agree on what questions are intelligible even if they disagree on how cosmologists should go about answering them. In 1937, there is no evidence that the inquirers even agreed on what the intelligible questions were. Unlike today, there was no readily identifiable tight-knit community of inquirers who were devoted to what we would today recognize as cosmology. Even by the late 1940s, there was a lack of conceptual unity and institutional support, and what little attention was focused on cosmological questions came from a loosely formed conglomeration of people working on what Kragh terms cosmo-physics from an array of different technical backgrounds (Kragh 1996, p. 142). Thus, the scene in the 1930s could be more accurately described as an unravelling scene, rather than a scene of response.

4. Conclusions

In tracing the development of multiverse discourse, it appears that the multiverse proposals are all possible answers to a set of questions; answers which the community may deem physical answers in time. The string landscape interpretation of the multiverse has become the most popular for multiverse-subscribing cosmologists. Through the lens of a historicist definition of metaphysical, it appears that the practices of string cosmologists—especially the innovative theoretical treatment arising from string theory—are seen by many as the best way of getting to grips with intelligible questions. In a sense, this is because the string landscape multiverse proposals make the why questions the most tractable. The extent to which this becomes a widely accepted method of inquiry, and the contestation surrounding similar methods in the future, is yet to be seen.

Cosmology has now begun to encroach on territory that has traditionally been reserved for religion and metaphysics; the limits of the possibilities of the space of possible scenes of inquiry have been dramatically extended. Anthropically inspired questions such as "Where do the fine-tuning values come from?" and "Why this universe in a sea of vast possible multiverses?" are posed as legitimate issues for scientific inquiry. Charges of being too metaphysical are rife, as the ways of making questions tractable remain contested in the scene of response. Questions such as "What happened before the Big Bang?" are now deemed legitimate problems to be solved using new speculative theoretical models and practices from string cosmology, and other such fusions between cosmology and theories of quantum gravity.

Speaking at a string cosmology conference in 2003, science writer Margaret Wertheim made the following damming, albeit somewhat jocular assessment of the cosmological scene:[14]

> That string cosmology conference I attended was by far the most surreal physics event I have been to, a star-studded proceeding involving some of the most famous names in science… After two days, I couldn't decide if the atmosphere was more like a children's birthday party or the Mad Hatter's tea party—in either case, everyone was high… the attitude among the string cosmologists seemed to be that anything that wasn't logically disallowed must be out there somewhere. Even things that weren't allowed couldn't be ruled out, because you never knew when the laws of nature might be bent or overruled. This wasn't student fantasizing in some late night beer-fuelled frenzy, it was the leaders of theoretical physics speaking at one of the most prestigious university campuses in the world. (2012)

Wertheim's assessment does not seem to be based on what is actually happening in the day-to-day practice of cosmological inquiry—it is a general feeling, which arose from attending the conference. However, this assessment goes some way to highlighting a general excitement, and perhaps hubris, which has permeated the cosmological community. Nevertheless, the upshot of this facet of cosmology being a scene of response is that all possibilities are on the table—the community is looking for answers in the hope that one of them will be substantiated at a later date.

We should not forget that there has remained a great deal of accepted, uncontested cosmological inquiry being practiced since 1980: Cosmologists working on cosmological questions are still practicing observation, experimentation, and exploring computer-generated temporal simulations of the evolution of the universe. The tools of inquiry are widely accepted

14. I thank Ellis' 2014 paper for alerting me to this excerpt.

means of addressing the goals of inquiry. This generally accepted scene of inquiry is strongly grounded in historical reasoning, but does not bring untested and nascent physical pictures into the practices of cosmology, unless they are deemed valuable elements of the standard cosmological picture. Inflation is an example of a speculative idea that is generally accepted by cosmologists today, even if they agree that it is somewhat *post hoc* and will potentially be replaced in the future. Cosmologists working in this standard scene of cosmological inquiry may well believe in multiverses, but their scientific scepticism stops them from propounding models of the multiverse before more scrutiny can be turned on the proposals. It is unclear whether scepticism towards metaphysics constitutes the norm in cosmology, especially as notions such as metaphysical boundaries have become so blurred.

There are many examples in recent philosophical and historical literature on modern physics regarding debates of the legitimacy of speculative hypotheses in physics and the use of non-empirical rather than empirical criteria to establish veracity. Richard Dawid's work examining string theory, and the case where researchers pursue theoretical proposals despite the lack of empirical testability, attempts to explain "the trust physicists have in contemporary theories despite the absence of empirical confirmation" (Dawid 2013, p. 7). His work criticizes sociological accounts for physicists' commitments to such theories which assume that physicists have some ingrained tendency to stick together (such as those offered by Smolin 2006; Woit 2006). Rather, Dawid's claim is that modern physics has undergone swift and radical changes which have led to a natural methodological shift in the way that inquirers assess the veracity of theories. Non-empirical criteria are beginning to play a major role, especially when empirical data is more difficult to gather (at higher energies and probing deeper than ever before). The same could be said for cosmology, where inquirers are probing space-time realms beyond the linear historical narrative of our universe.

There are varying non-empirical argumentative strategies being deployed in physics today, which influence the way inquirers assess the status of theories that are popular, but remain empirically unverified. For example, in probing Kaluza-Klein theories, Koray Karaca has recently argued that "*comparatively greater explanatory power*, in terms of capacity to produce *testable* conclusions regarding natural phenomena, is an important *desideratum* in the physicists' pursuit of the higher dimensional unification of fundamental forces (emphasis in original)" (Karaca 2012, p. 309). Where empirical methods are contested, it appears that non-empirical ones emerge as fair game in the scientific community.

This paper did not set out to give a conceptual analysis of multiverse proposals, or to give an argument for which empirical or non-empirical criteria should be drawn upon when arguing for the veracity of such proposals. Rather, the approach was to look historiographically at the new questions that became intelligible to the cosmological community, and to trace the resulting multiverse discourse that emerged. Importantly, I wanted to highlight that the lack of consensus regarding the tools of inquiry (the methods, techniques and epistemic practices) is a strong indicator for why there is debate regarding the legitimacy of such questions. Applying Jardine's notion of a scene of inquiry to modern cosmology adds a different meta-perspective on the current debates that prevail, and emphasizes the diachronic nature of epistemological and methodological debates in scientific circles. Perhaps Dawid's suggestion of a natural methodological shift applies to these aspects of cosmology as well—cosmological inquiry has become a scene of response as a result of the rapid shifts in the available tools of inquiry available to the practitioners. Answers to previously intractable questions suddenly appear tantalisingly close.

References

Balashov, Yuri. 1991. "Resource Letter AP-1: The Anthropic Principle." *American Journal of Physics* 59: 1069.

Barrow, J. F., and F. J. Tipler. 1986. *The Anthropic Cosmological Principle*. Oxford: Clarendon Press.

Bettini, Stephano. 2005. "A Cosmic Archipelago: Multiverse Scenarios in the History of Modern Cosmology." *arXiv:physics/0510111v1 {physics.hist-ph}*.

BICEP2 Collaboration. 2014a. "BICEP2 I: DETECTION OF B-mode POLARIZATION AT DEGREE ANGULAR SCALES." *Physics Review Letters* 112 (241101).

BICEP2 Collaboration. 2014b. "Detection of B-Mode Polarization at Degree Angular Scales by BICEP2." *Physical Review Letters* 112 (231101). doi: http://dx.doi.org/10.1103/PhysRevLett.112.241101

Boltzmann, Ludwig. 1895. "On Certain Questions of the Theory of Gases." *Nature* 51.

Bostrom, Nick. 2002. *Anthropic Bias: Observation Selection Effects in Science and Philosophy*. New York: Routledge.

Bousso, Raphael, and Joseph Polchinski. 2000. "Quantization of Four-form Fluxes and Dynamical Neutralization of the Cosmological Constant." *Journal of High Energy Physics* DOI: 10.1088/1126-6708/2000/06/006.

Burbidge, G. 1988. Problems of Cosmogony and Cosmology. Pp. 223–38 in *New Ideas in Astronomy*. Edited by F. Bertola et al. Cambridge: Cambridge University Press.

Byrne, P. 2013. "Waiting for the Revolution – Interview with David Gross." *Quanta Magazine*, May 24. https://www.quantamagazine.org/20130524-waiting-for-the-revolution/ (accessed 4 February 2017)

Carr, Bernard. 2007. Introduction and Overview. Pp. 3–28 in *Universe or Multiverse?*. Edited by Bernard Carr. New York: Cambridge University Press.

Carroll, S., W. Press, and E. Turner. 1992. "The Cosmological Constant." *Annual Review of Astronomy and Astrophysics*: 499–542.

Carter, Brandon. 1970. Large numbers in astrophysics and cosmology. Unpublished preprint University of Cambridge.

Carter, Brandon. 1974. "Large number coincidences and the anthropic principle in cosmology." Confrontation of cosmological theories with observational data. IAU Symposium No. 63.

Cassirer, Ernst. [1929] 1957. *The Philosophy of Symbolic Forms: Volume Three: The Phenomenology of Knowledge*. Translated by R. Manheim. New Haven: Yale University Press.

Davies, Paul. 2003. "A Brief History of the Multiverse." *New York Times: Opinion Pages,* 12 April. http://www.nytimes.com/2003/04/12/opinion/a-brief-history-of-the-multiverse.html

Davies, Paul. 2007. Universes Galore: Where Will It All End? Pp. 487–506 in *Universe or Multiverse?*. Edited by Bernard Carr. New York: Cambridge University Press.

Dawid, Richard. 2013. *String Theory and the Scientific Method*. Cambridge: Cambridge University Press.

de Sitter, Willem. 1931. "The Expanding Universe." *Scientia* 49: 1–10.

de Sitter, Willem. 1932. *Kosmos*. Cambridge: Harvard University Press.

Dicke, R.H. 1961. "Dirac's cosmology and Mach's Principle." *Nature* 192: 440–441.

Dingle, Herbert. 1933. *Through Science to Philosophy*. London: Williams & Norgate.

Dingle, Herbert. 1937. "Modern Aristotelianism." *Nature* 139: 784–786.

Dingle, Herbert. 1938. "Science and the Unobservable." *Nature* 141: 21–28.

Dirac, P. A. M. 1939. "The Relation between Mathematics and Physics." *Proceedings of the Royal Society of Edinburgh* 59: 122–129.

Douglas, Michael R. 2003. "The Statistics of String/M Theory Vacua." *Journal of High Energy Physics* 2003 (5): 046 (hep-th/0303194).

Duff, M. J., James T. Liu, and R. Minasian. 1995. "Eleven Dimensional Origin of String/String Duality: A One Loop Test." *Nuclear Physics B* 452: 262–282.

Ellis, G. F. R. 2007. Multiverses: Description, Uniqueness and Testing. Pp. 387–410 in *Universe or Multiverse?*. Edited by Bernard Carr. New York: Cambridge University Press.

Ellis, G. F. R. 2008. "*Cosmology Down the Ages*. Book Review: Cosmology down the Ages, Conceptions of Cosmos, from Myths to the Accelerating Universe: A History of Cosmology." *Journal for the History of Astronomy* 39: 537–538.

Ellis, G. F. R. 2011. "Editorial Note to: Brandon Carter, Large Number Coincidences and the Anthropic Principle in Cosmology." *General Relativity and Gravitation* 43: 3213–3223.

Ellis, G. F. R. 2014. "On the Philosophy of Cosmology." *Studies in History and Philosophy of Modern Physics* 46: 5–23.

Everett, Hugh. 1956. "Theory of the Universal Wavefunction." Thesis, Princeton University.

Everett, Hugh. 1957. "Relative State Formulation of Quantum Mechanics." *Reviews of Modern Physics* 29: 454–462.

Feeney, Stephen M., Matthew C. Johnson, Daniel J. Mortlock, and Hiranya V. Peiris. 2011. "First Observational Tests of Eternal Inflation: Analysis Methods and WMAP 7-Year Results." *Physics Review D* 84 (043507).

Friedman, Michael. 1999. *Dynamics of Reason: The 1999 Kant Lectures at Stanford University*. Stanford, California: CSLI Publications.

Gale, George. 2002. "Cosmology: Methodological Debates in the 1930s and 1940s" in *The Stanford Encyclopedia of Philosophy (Summer 2002 Edition).* Edited by Edward N. Zalta. http://plato.stanford.edu/archives/sum2002/entries/cosmology-30s/

Gale, George. 2005. Dingle and de Sitter Against the Metaphysicians, or Two Ways to Keep Modern Cosmology Physical. Pp. 157–174 in *The Universe of General Relativity.* Edited by A.J. Kox and Jean Eisenstaedt. Boston: Birkhäuser.

Gale, George, and Niall Shanks. 1996. "Methodology and the Birth of Modern Cosmological Inquiry." *Studies in History and Philosophy of Modern Physics* 27 (3): 279–296.

Gale, George, and John Urani. 1999. Milne, Bondi and the 'Second Way' to Cosmology. Pp. 343–376 in *The Expanding Worlds of General Relativity*. Edited by Hubert Goenner, Jürgen Renn, Jim Ritter and Tilman Sauer. Boston: Birkäuser.

Gardner, Martin. 2003. *Are Universes Thicker than Blackberries?* New York: W. W. Norton & Co. Ltd.

Gardner, Martin. May 8, 1986. "WAP, SAP, PAP, and FAP." *The New York Review of Books* 23 (8): 22–25.

Gott, J. Richard. 1982. "Creation of Open Universes from De Sitter Space." *Nature* 295: 304–307.

Green, Brian. 2011. *The Hidden Reality: Parallel Universes and the Deep Laws of the Cosmos*: Alfred A. Knopf.

Gross, D. 2005. "Where Do We Stand in Fundamental (String) Theory." *Physica Scripta* T117: 102–105.

Guth, Alan H. 2006. "Eternal Inflation and Its Implications." 2nd International Conference on Qunatum Theories and Renormalization Group in Gravity and Cosmology (IRGAC), Barcelona, Spain, 11–15 July.

Hawking, S. W. 1974. "The Anisotropy of the Universe at Large Times." Confrontation of Cosmological Theories with Observational Data. IAU Symposium No. 63.

Hawking, S. W. 1983. "The Cosmological Constant." *Philosophical Transactions of the Royal Society* A310: 303–310.

Hawking, Stephen, and Leonard Mlodinow. 2010. *The Grand Design*. London: Bantam Press.

Hookway, Christopher. 2008. Questions, Epistemology and Inquiries. Pp. 1–22 in *Knowledge and Questions*. Edited by Franck Lihoreau. Amsterdam - New York: NLD Editions Rodopi.

Jardine, Nicholas. [1991] 2000. *The Scenes of Inquiry: On the Reality of Questions in the Sciences*. 2nd edn. Oxford: Clarendon Press.

Karaca, Koray. 2012. "Kitcher's Explanatory Unification, Kaluza-Klein Theories, and the Normative Aspect of Higher Dimensional Unification in Physics." *British Journal for the Philosophy of Science* 63: 287–312.

Kragh, Helge. 1982. "Cosmo-Physics in the Thirties: Towards a History of Dirac Cosmology." *Historical Studies in the Physical Sciences* 13: 69–108.

Kragh, Helge. 1995. "Cosmology Between the Wars: The Nernst-MacMillan Alternative." *Journal for the History of Astronomy* 26 (2): 93–115.

Kragh, Helge. 1996. *Cosmology and Controversy: The Historical Development of Two Theories of The Universe*. Princeton, NJ: Princeton University Press.

Kragh, Helge. 2009. "Contemporary History of Cosmology and the Controversy over the Multiverse." *Annals of Science* 66 (4): 529–551.

Krauss, L. 2012. *A Universe from Nothing: Why There Is Something Rather Than Nothing*. New York: Free Press.

Lepeltier, Thomas. 2006. "Edward Milne's Influence on Modern Cosmology." *Annals of Science* 63: 471–481.

Leslie, J. 1989. *Universes*. London: Routledge.

Linde, Andrei. 1982. "Nonsingular Regenerating Inflationary Universe." *Preprint DAMTP University of Cambridge*.

Linde, Andrei. 1983a. "Inflation can Break Symmetry in SUSY." *Physics Letters* 131B: 330–334.

Linde, Andrei. 1983b. The New Inflationary Universe Scenario. Pp. 205–249 in *The Very Early Universe*. Edited by G.W. Gibbons, S.W. Hawking and S. Siklos. Cambridge: Cambridge University Press.

Linde, Andrei. 1986. "Eternally Existing Self-Reproducing Chaotic Inflationary Universe." *Physics Letters B* 175: 385–401.

Linde, Andrei. 2007. The Inflationary Multiverse. Pp. 127–150 in *Universe or Multiverse?*. Edited by Bernard Carr. New York: Cambridge University Press.

Pearce, Jacob. 2017. "The Unfolding of the Historical Style in Modern Cosmology: Emergence, Evolution, Entrenchment." *Studies in History and Philosophy of Modern Physics*.

Peebles, P. J. E. 1971. *Physical Cosmology*. Princeton NJ: Princeton University Press.

Peirce, C. S. [1891] 1955. The Architecture of Theories. Pp. 315–323 in *Philosophical Writings of Peirce*. Edited by Buchler. New York: Dover.

Rasmussen, Nicholas. 1997. *Picture Control: The Electron Microscope and the Transformation of Biology in America, 1940–1960*. Stanford: Stanford University Press.

Rees, M. J. 1997. *Before the Beginning. Our Universe and Others*. London: Simon & Schuster.

Rees, M. J. 1999. *Just SIX Numbers: The Deep Forces That Shape the Universe*. London: Weidenfeld and Nicholson.

Reichenbach, H. [1920] 1965. *The Theory of Relativity and A Priori Knowledge*. Translated by M. Reichenbach. Berkeley and Los Angeles: University of California Press.

Reichenbach, H. [1928] 1958. *The Philosophy of Space and Time*. New York: Dover.

Rheinberger, Hans-Jürg. 2010. *On Historicizing Epistemology: An Essay*. Translated by David Fernbach: Stanford University Press.

Rickles, Dean. 2014. *A Brief History of String Theory: From Dual Models to M-Theory*. Dordrecht: Springer.

Ritson, Sophie, and Kristian Camilleri. 2014. "Contested Boundaries: The String Theory Debates and Ideologies of Science." *Perspectives on Science*. doi:10.1162/POSC_a_00168.

Seife, Charles. 2004. "Physics Enters the Twilight Zone." *Science* 305: 464–465.

Seljak, U., and Zaldarriaga M. 1997. "Signature of Gravity Waves in the Polarization of the Microwave Background." *Physics Review Letters* 78 (11): 2054–2057.

Smolin, Lee. 2006. *The Trouble with Physics*. Boston: Houghton Mifflin Company.

Smolin, Lee. 2007. Scientific Alternatives to the Anthropic Principle. Pp. 323–366 in *Universe or Multiverse?*. Edited by Bernard Carr. New York: Cambridge University Press.

Smolin, Lee. 2013. "A Perspective on the Landscape Problem." *Foundations of Physics* 43: 21–45.

Steigman, G. 1974. "Confrontation of Antimatter Cosmologies with Observational Data." Confrontation of cosmological theories with observational data. IAU Symposium No. 63.

Strum, Thomas, and Uljana Feest. 2011. "What (Good) is Historical Epistemology?" *Erkenntnis* 75: 285–302.

Sundberg, Mikaela. 2012. "Creating Convincing Simulations in Astrophysics." *Science, Technology & Human Values* 37 (1): 64–87.

Susskind, L. 2003. "The Anthropic Landscape of String Theory." *arXiv: hep-th/0302219*.

Susskind, L. 2006. *The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*. San Francisco: Back Bay Books.

Tegmark, M. 2004. Parallel Universes. Pp. 459–491 in *Science and Ultimate Reality: From Quantum to Cosmos*. Edited by J. D. Barrow. Cambridge: Cambridge University Press. https://arxiv.org/abs/astro-ph/0302131

Vilenkin, Alexander. 2007. Anthropic Predictions: The Case of the Cosmological Constant. Pp. 163–180 in *Universe or Multiverse?*. Edited by Bernard Carr. Cambridge Unviersity Press.

Weinberg, Steven. 1972. *Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity*. New York: Wiley.

Weinberg, Steven. 1987. "Anthropic Bound on the Cosmological Constant." *Physical Review Letters* 59: 2607–2610.

Weinstein, Steven. 2006. "Anthropic Reasoning in Multiverse Cosmology and String Theory." *Classical and Quantum Gravity* 23: 4231–4236.

Wertheim, M. 2012. *Physics on the Fringe: Smoke Rings, Circlons And Alternative Theories of Everything*. New York: Walker & Company.

Winsberg, Eric. 2010. *Science in the Age of Computer Simulation*. Chicago: The University of Chicago Press.

Woit, Peter. 2006. *Not Even Wrong: The Failure of String Theory and the Search for Unity in Physical Law*. New York: Basic Books.