Retroduction, Multiverse Hypotheses and Their Testability*

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Abstract

The actual existence of collections of universes – multiverses – is strongly suggested by leading approaches to quantum cosmology, and has been proposed earlier as an attractive way to explain the apparent fine-tuned character of our universe. But, how can such hypotheses be tested? After briefly discussing the key distinction between possible and really existing multiverses, and the importance of an adequate generating process, we focus on elaborating how multiverse hypotheses can be retroductively tested, even though they will probably never be directly observed. In this approach, scientific acceptance of multiverses would rely on the long-term success and fertility of quantum cosmological theories including them as essential elements or as inevitable consequences.

1 Introduction

As we struggle to understand our universe more fully, using all the resources of physics, astronomy, cosmology and even philosophy, we are finding more and more indications that it may very well be just one of a very large number of universes, or universe domains. We often refer to such a collection, or ensemble, of universes as a "multiverse." If these preliminary indications are correct, the multiverse to which our own universe belongs would have emerged from some quantum cosmological process that, from our present very limited perspective, is hidden in what we often refer to as the Big Bang. In other words, the more we delve into trying to understand how our own universe, or our own region of a much larger universe, was generated, the more we encounter the likelihood that whatever primordial process was involved generated a very large number of other universes, or universe domains.

The emergence of such multiverses was first proposed and discussed in detail by Linde (1982, 1983a). In doing so he emphasized that a multiverse as such is a collection of different universes, or one universe consisting of different large regions, representing a wide-range of different properties and different low-energy laws of physics (in particular, very different values of the gravitational, electromagnetic and nuclear coupling constants, and very different masses of the fundamental particles). Thus, as he then proposed, it provides a way of explaining the apparent fine-tuning of our universe for complexity ("the anthropic principle"). About the same time, Vilenkin (1983) described in a similar vein the creation of many universes by inflationary processes, without referring to their possible application to resolving the fine-tuning issue. Soon afterwards Linde (1983b, 1990) developed his multiverse idea much more fully in his chaotic inflationary scenario. Basically, Linde envisions a primordial cluster of tiny, causally separate regions as physical reality emerges from the Planck era, where quantum gravity dominates. Each of these regions becomes a separate universe or universe domain – some inflating, and some not, depending on the value of the fluctuating scalar fields in a given region as the transition to classical space-time is negotiated. Besides Vilenkin's and Linde's work, many others (Sciama 1993, Leslie 1996, Deutsch 1998, Tegmark 1998, 2003, Smolin 1999, Weinberg 2000, Lewis 2000, Rees 2001) have since discussed general ways in which an ensemble of universes might originate. More recently superstring theory has given more specific impetus to the multiverse idea. Versions of it provide "landscapes" populated by extremely large numbers of vacua, each of which could initiate a separate universe domain (Kachru, et al. 2003; Susskind 2003; Freivogel and Susskind 2004; Freivogel, et al. 2005; the other articles in this volume, and references therein).

The recognition that our universe appears to be fine-tuned for complexity, and for life and consciousness (Dicke 1961, Collins and Hawking 1973, Carter 1974, McMullin 1993) has actually been an independent and earlier stimulus to considering multiverses. If any one of a number of key constants, or other parameters, describing our universe and its dynamics had slightly different values, our universe would be so different that it would not support chemically complex systems. Therefore, it would be forever without the possibility of life. This has become known as the "anthropic principle." What accounts for this apparent delicate adjustment of constants and parameters? Why do they have the values they have, rather than other values? The existence of a large collection of universes, which represents a significant range of possible cosmic parameter values and to which our own universe belongs, would be a possible scientifically acceptable way of explaining such apparent fine-tuning – even though it would not provide an ultimate philosophical explanation. This solution was first suggested by Collins and Hawking (1973), and has since become the predominant and really only scientific proposal for resolving the anthropic enigma (see McMullin 1993, Carr 2006, and the other articles in this volume, and references therein). If quantum cosmological processes naturally produced a large variety of universes, including ours, then we would simply find ourselves in one in which all the many conditions for life and consciousness have been fulfilled. This would be similar to how we might explain the very special conditions we enjoy on Earth and in our Solar System – our Sun being one of several hundred billion stars in the Milky Way.

Of course, the multiverse answer to the fine-tuning puzzle is scientifically acceptable only if multiverses themselves are really legitimate objects of scientific inquiry! Are they? Some have argued that, since we shall never be able to directly detect multiverses or make observations of them, they fall outside the realm of scientific investigation (Gardner 2003). This important question leads us directly to the focus of this chapter, the testability of multiverse hypotheses as a philosophy of science issue. In other words testability is a necessary condition for scientific legitimacy. Relying on the fundamental insights of the American philosopher C. S. Peirce concerning "retroduction," and its development and historical confirmation as "the inference which makes science," by Ernan McMullin (1992), I argue that multiverse hypotheses are scientifically testable. Then, I shall briefly outline what general *scientific* requirements must be met to satisfy the philosophical standards of retroductive testabililty. Before tackling the specific issue of testability itself, I shall briefly address the connected issues of the difference between possible and existing ensembles of universes – possible and really existing multiverses – and the need for a definite generating process for any existing multiverse. [1] Many of the points I shall emphasize in this regard may seem obvious or trivial, but they are crucial in providing a secure basis for our consideration of testability, as well as of other related physical and philosophical issues.

2 Possible and Existing Multiverses, and Generating Processes

From both a physical and a philosophical point of view, it is crucial to distinguish between the ensemble of all possible universes or universe domains, and any ensemble of existing universes (Ellis, *et al.* 2003, Stoeger, *et al.* 2004). Though we may conceive all possible universes existing, philosophically, it is almost certainly the case that only a subset of these actually exists. Secondly, it is obvious that an existing ensemble of universes or universe domains requires some process or series of processes to produce them – to actualize them. This is one of the challenges of quantum cosmology – to determine the physics of the primordial process by which our universe was born, and the collection of universes or universe domains, and their specific properties, which have emerged in association with it. It is the set of all existing universes which needs to be explained by cosmology and physics, *not* the ensemble of possible universes. Finally, it is only the set of really existing universes which would provide an adequate answer to the fine-tuning problem (McMullin 1993, p. 371; Ellis, *et al.* 2003; Stoeger, *et al.* 2004).

[1] There are other important and fascinating philosophical issues raised by the possibility of multiverses, such as those of realized infinity (can we really have an infinity of really existing universes?), ontological and causal reductionism (can new qualities emerge in the course of the evolution of a given universe, or all possible emergent qualities simply latent in the physics from the beginning?), and that of the choice between the generic and the special (can we completely avoid fine-tuning and/or special "initial" conditions?). But the issue of testability, and the closely connected ones of possible and existing multiverses, and the need for a physical generating mechanism, are the most urgent for multiverse cosmology at present.

Though we cannot adequately describe the space $\mathcal{M}$ of possible universes m, we can set up a heuristic classical framework for doing so (see Ellis, *et al.*, 2003), based on different reasonable assumed sets of laws of nature – either laws of physics or meta-laws that determine the laws of physics – the general parameter classes of which all m have in common. [2] Without this we have no basis for defining $\mathcal{M}$. In general we must incorporate in $\mathcal{M}$ at least the geometry of the allowed universes and the physics of the matter they contain. Clearly, we do not have any way of reliably determining the contours of what is really possible. However, on the basis of what does not contradict philosophical or sensible physical principles, we can set up a parameter space for what we presently consider possible universes (Ellis, *et al.* 2003; Stoeger, *et al.* 2004).

In any really existing ensemble of universes or universe domains many of the universes in $\mathcal{M}$ will not be realized, and some may be realized more than once. Essentially, the physics of the primordial vacuum, or other fundamental configuration, out of which a given multiverse emerges, together with that of the generating processes operating to produce it, will effectively determine a distribution function $f(m)$ specifying how many times each m in $\mathcal{M}$ is realized (Ellis, *et al.* 2003). This expresses the contingency of any multiverse actualization – the fact that not every possible universe has to be realized – and the detailed physical dependence of the existing multiverse on the underlying physics, whatever that may be. [3]

[2] Such a classical, non-quantum-cosmological description of $\mathcal{M}$ is provisional, not fundamental. It provides us with a preliminary systematic framework, consistent with our present limited understanding of cosmology, within which to begin studying multiverses. As quantum cosmology matures, we shall have to develop a more fundamental quantum framework which takes such issues as quantum entanglement and decoherence into consideration. It may very well be that as "the wave function of the universe" decoheres, an entire ensemble of universes emerges. These would all be entangled with one another, and "the wave function of the universe" would provide the fundamental basis for the quantum ontology of the multiverse, as well as the seed from which it was generated. Then, we might very well want to consider the meta-structure of the set of all possible "waves functions of the universe." However, at present we do not have an adequate theory of quantum gravity, or of quantum cosmology, to enable us to proceed meaningfully in accomplishing these two tasks.

[3] There are other technical issues related to this, of course, including whether or not we can define a unique measure on the $\mathcal{M}$ and on its subset of realized universes.

Two almost trivial implications follow from this. The first is that there is no unique really existing multiverse – there are an infinite number of possible such multiverses (that is distribution functions $f(m)$ which could be defined on $\mathcal{M}$). Which is the one to which our observable universe belongs depends, as I have stressed, on the primordial physics that is operative. The second implication is that, though a knowledge of the primordial physics would give us an account of the beginning of our universe and of the multiverse to which it belongs, as well as of the apparently fine-tuned character of our universe, it would raise the further even deeper question of its own origins, and whether or not it and the processes it governs require fine-tuning. Here an infinite regress lurks in the wings. From a philosophical point of view, then, any such primordial quantum physics, though making our universe more intelligible from a scientific point of view, would not provide an ultimate explanation for it nor account for its ultimate origin. We would still be able ask with good reason for an explanation of the primordial vacuum and for the physics which governs it.

We have been discussing the need for a definite generating process for any existing multiverse. That requires some definite, detailed quantum-gravity physics, which in turn would have to be shown to determine the overall distribution $f(m)$, and the range of properties represented by $f(m)$. Obviously, at least one of those universes would have to have the properties of our universe. This is very a demanding requirement! As we now know from considering the apparent fine-tuned character of our universe, there are very narrow ranges of values of the fundamental constants, and of other cosmic parameters (e. g., the density of dark energy), that allow for chemical complexity and for life. Outside of these ranges, complexity, and life, would not be possible. A little reflection also assures us, besides, that it is the underlying physics of the multiverse generating process which induces certain common features of structure and content in all the universes it produces, despite their great variety. Thus, it will be the basic link connecting all the universes in the ensemble. Through that generating process they will all be governed by a common set of fundamental primordial laws, or meta-laws. Otherwise, there would be no reason to consider the universes to be members of the same multiverse, nor any way of relating them to one another. Their common origin in a specific physical process, or chain of processes, governed by a common physics in the only way of achieving that.

Finally, in this regard, it is helpful to realize that there may be, as has been often mentioned, innumerable multiverses which constitute reality. In light of what we have just been discussing, all but our own multiverse would, by definition, be causally and generationally disconnected from us. Thus, we would evidently have no possible way of discovering their existence, nor any reason to postulate their contribution to the intelligibility of our universe (Stoeger, *et al.* 2004; Stoeger 2004). The only way that would be conceivable is if the generating processes of those multiverses were associated with those of ours. But in that case they would really be part of our multiverse.

3 Retroduction

From what I have just pointed out, it is fairly clear that really existing multiverses completely disassociated from ours will not be subject to any scientific confirmation. We will never be able to rule them out, but we shall never be able to present positive direct or indirect evidence for their existence. But how about for the existence and character of our own multiverse – for universes or universe domains primordially connected in some way to ours? It seems that, if they are connected in some way to our universe, e. g. by a common generating process or an initial vacuum state, then there should be in principle ways to find out about them.

There may, in fact, even be relatively direct ways, as pointed out by Freivogel and Susskind (2004), who demonstrate that the bubble universes out beyond our horizon are not, according string theory models, completely decoupled. Our horizon will contain information, scrambled though it be, concerning the other universes which exist beyond it and to which it is generationally linked. However, according to some experts in that field (Susskind, private communication), recovering such information would probably not be feasible – it would take an enormously long time.

There is an attractive and compelling approach to scientific testability which would enable us to indirectly establish the existence of our multiverse, and its characteristics, in much more promising way – under certain well specified conditions. This brings us to a consideration of C. S. Peirce's concept of of "retroduction," or "abduction," which has been rather compellingly argued by Ernan McMullin (1992) as "the inference which makes science." Retroduction, according to McMullin, is the rational process by which scientific conclusions are most often and most fruitfully reached.

How does retroduction function? On the basis of what researchers know, they construct imaginative hypotheses, which are then used to probe and to describe the phenomena in deeper and more adequate ways than before. As they do so, they will modify or even replace the original hypotheses, in order to make them more fruitful and more precise in what they reveal and explain. The hypotheses themselves may often presume or directly imply the existence of certain hidden properties or entities (like multiverses!) which are fundamental to or consequent upon the explanatory power they possess. As these hypotheses become more and more fruitful in revealing and explaining the natural phenomena they investigate and their inter-relationships (rendering them more and more intelligible), and more central to scientific research in a given discipline, they become more and more reliable accounts of the reality they purport to model or describe. Even if some of the hidden properties or entities they postulate are never directly detected or observed, the long term success and fruitfulness of the hypotheses indirectly leads us to affirm that something like them probably exists.

Thus, from this point of view, the existence of an ensemble of universes or universe domains would be strongly, though provisionally, supported (but not logically deduced!). The fundamental retroductive requirement is that the existence of the multiverse is a key component or consequence of hypotheses which are successful and fruitful in the long term. In other words, as a basic, though observationally inaccessible component of the theory, it provides greater intelligibility and understanding of our universe. The hypotheses themselves enable us to make testable predictions which, if fulfilled, provide a more thorough and more coherent explanation of cosmic phenomena we observe than competing theories do. If such indirect support is not forthcoming, then all we can do is to treat the multiverse hypothesis as a promising speculative scenario needing further development and requiring further fruitful application. That is where we are now, I believe. But there are definite prospects for improving our confidence in it.

At this point we should briefly indicate how we are to judge "long-term success and fruitfulness" of a given set of hypotheses. In general, a theory is fruitful and qualitatively and quantitatively supported if it (McMullin 1992; also, see Allen 2001): 1.) accounts for all the relevant data (empirical adequacy); 2.) provides a *continuing* foundation for explanatory success, and stimulates further fruitful investigation (theory fertility); 3.) establishes the compatibility of previously disparate domains of observed phenomena (unifying power); 4. manifests consistency (or correlation) with other established theories (theoretical coherence). These are the broad criteria we need to apply to specific theories predicting the existence of a multiverse. We now briefly discuss what that involves.

4 Retroductive Testability of the Multiverse Hypothesis

Relying on these insights concerning retroduction, then, we could make a reasonable claim for the existence of a multiverse, if we could show that its existence was a more or less inevitable consequence of well-established physical laws and processes. This is essentially the claim that is made for chaotic inflation (Linde 1990). However, the challenge is that the proposed underlying physics has not been adequately tested, and may be untestable. We need evidence that the postulated physics – particularly that governing the quantum cosmological generating processes – is true in this universe.

Thus, there are two further basic requirements which must still be met, once we have proposed a viable ensemble or multiverse theory. The first is to provide some credible link between these vast extrapolations from presently known physics to the physics in which we have some confidence. The second is to provide some at least indirect evidence that the scalar potentials, or other overarching cosmic principles central to generating bubble universes (e. g., a superstring theory of a given type), really have been functioning in the very early universe, or before its emergence.

The issue is not just that the inflaton has not been identified and its potential is untested. It is also that, for example, we are assuming quantum field theory remains valid far beyond the domain where it has been tested, especially given the unsolved problems at the foundations of quantum theory, the divergences of quantum field theory, and failure of the theory to resolve the cosmological constant problem.

Once these basic requirements are met, then the theory involving multiverses must, as it is further developed, continue to receive indirect support from further theoretical and observational work, lead to new promising lines of inquiry which open up and enrich cosmology, and contribute substantially to the overall coherence and unity of physics and cosmology. In short, it must, over time, continue to provide a reliable foundation for increasing our understanding of our universe, its origin and its characteristics.

In conclusion, despite the rigor that it demands, the retroductive approach to scientific testability does open the way for scientific confirmation of the existence of a multiverse to which our universe belongs, and thus to a scientific resolution to the fine-tuning problem. Thus, at least potentially, the issues connected with multiverses *can* be brought in from the realms of pure metaphysics to those where scientific confirmation is possible.

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