Are Multiverses Legitimate Objects of Cosmology?

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I. The Importance of Multiverses:

– explanation of apparent fine-tuned character of our universe ("anthropic principle")

– natural generation by primordial processes responsible for our observable universe

The focus here will be on philosophical issues. However, any resolution of such issues depends to some extent on input from physics and mathematics. Philosopical analysis and reflection can pose important questions and provide a framework for answering them, but actually doing so will require various types of scientific conclusions.

II. What is a Multiverse?

– an ensemble of separate universes;

– an ensemble of universe domains, separate regions of a single very large universe.

III. Philosophical Issues:

- Distinguishing between possible and actually existing multiverses;
- The need for a generating process for each really existing multiverse, and the requirements for such a primordial process;
- Distinguishing between ensembles of universes or universe domains which are somehow related by a common generating process or series of processes and ensembles which are not;
- Ontological and causal reductionism: can new qualities emerge in the course of the evolution of a given universe, or are all qualities simply latent in the laws of nature from the beginning?
- Realized infinity: Can we really have an infinite number of universes in a realized ensemble?
- Observability and Testability: How can a really existing multiverse be scientifically established?
- The Philosophical Choice between the Generic and the Special: Can we completely avoid fine-tuning and/or special "initial conditions"?

Here I shall focus on Testability – and, in relation to that, on the importance of the distinction between possible and actually existing multiverses, as well as on generating processes.

Testability $\Longrightarrow$ Scientific Legitimacy

IV. Multiverse Scenarios

Inflationary Cosmology $\Longrightarrow$ Many large locally homogeneous regions from different vacuum states $\Longrightarrow$ Anthropic Principle

- Chaotic Inflationary Scenario (A. Linde; A. Vilenkin);
- Superstring Theory $\Longrightarrow$ "Landscapes" populated with large numbers of vacua, representing different values of the cosmological constant (vacuum energy) (S. Kachru, et al.; L. Susskind)

V. Possible and Really Existing Multiverses:

We can conceive and even define the set $\mathcal{M}$ of all possible universes, even though we cannot reliably specify all the categories of parameters by which they would be described. The multiverse $\mathcal{M}$ is different from any realized subset of $\mathcal{M}$

- a realized multiverse requires a process or series of processes to actualize it (quantum cosmology)
- the generating process will determine the distribution function $f(m)$ specifying how many of each m in $\mathcal{M}$ is in a given realized multiverse
- a realized multiverse is not unique – there can be many different realized multiverses, depending on the generating processes
- only a set of really existing universes would provide an adequate answer to the fine-tuning problem – and not just any such set!
- such sets of really existing universes may not be able to contain an infinite number of members (?)
- obviously such a really existing multiverse cannot of

itself provide an ultimate explanation, or account for its own origin

VI. Multiverse Generating Processes

Did the process which generated our universe domain produce others? Very possibly! Any such generating process would generally be expected to satisfy these very general conditions or requirements:

- it will be effected or determined by some primordial physics – quantum cosmology
- it will induce certain regularities of structure and content in all the universes it produces, despite their differences
- it must explain the overall distribution $f(m)$ of universes in the ensemble and their properties
- it will connect all these universes to one another in some way (?) – if not causally, at least generationally; they will all be governed by a primordial set of physical laws or meta-laws

This, of course raises the problem of how that primordial physics was instantiated and realized, and whether or not the processes it governs, or it itself, requires fine-tuning. Here an infinite regress lurks in the wings.

Finally, by definition, all but our own multiverse would be causally or generationally disconnencted from us. Thus, we would have no possible way of knowing about the existence of such completely disconnected multiverses, or discovering that their existence contributes any intelligibility to our universe, or multiverse.

VII. Testability

But now, obviously, if our own multiverse enjoys some primordial or generational interconnectedness – a common generating process or an initial vacuum state – then there should be, in principle, ways to find out about these other universes in our multiverse.

It may even be that our horizon will contain information, scrambled though it may be, about the universes beyond it (Freivogel and Susskind 2004).

Even if this is not the case, there is a way of understanding scientific testability which would enable us, in principle, to establish indirectly the existence of our multiverse and its characteristics – "Retroduction"

Retroduction:

Retroduction (C. S. Peirce's "abduction") is "the inference that makes science" (Ernan McMullin). It is the "moving backward in thought or investigation from observed effect to unobserved cause" – from consequents to antecedents. As McMullin develops it as a description of how science is usually done, it involves examining what we already know and observe, using our inventiveness and imagination to construct hypotheses or models , and then employing these hypotheses as tools or instruments to probe and understand the complex of phenomena we are studying more fully. In the process, we are really testing these hypotheses or models. In the actual process, of course, the hypotheses are changed or modified (refined) many times, under the pressure of further theoretical and observational work. The success or fruitfulness of the hypotheses provides their validation.

How does retroduction function?

- Knowledge $\leftrightarrow$ Imagination $\longrightarrow$ Hypotheses
- Use hypotheses to probe the phenomena $\rightarrow$ deeper knowledge and understanding through carefully designed experiment and observation
- New observations or understandings facilitated by the theory support or fail to support the underlying hypotheses
- New knowledge and understanding $\rightarrow$ modification and/or (partial) support of original hypotheses
- Many iterations of the above $\rightarrow$ ever more fruitful and reliable theories

The hypotheses themselves may often presume the existence of certain hidden properties or entities (like multiverses!) which are fundamental to the explanatory power they possess. As the hypotheses become more refined and more fruitful over time – and IF they do! – in revealing and explaining the natural phenomena they probe, they become more established and basic to scientific understanding in the field. Even if the hidden properties or entities they postulate are never directly detected or observed, their long-term success and fruitfulness leads us to affirm that something like them exists.

In other words, from this point of view, such fundamental, though observationally inaccessible, components of the models continue to provide increasing intelligibility and understanding to the universe we do observe and investigate.

The hypotheses "work" – are qualitatively and quantitatively supported – if they:

- Account for all the relevant data (empirical adequacy)
- Provide the *long term* basis for explanatory success and stimulate further fruitful investigation (theory fertility)
- Establish the compatibility of previously disparate domains of phenomena and observation (unifying power)
- Manifest consistency (or correlation) with other established theories (theoretical coherence)

If such indirect support is not forthcoming, then all we can do is treat the multiverse hypothesis as a promising scenario needing further development and requiring further successful application.

VIII. Testability of Multiverses:

A reasonable claim for the existence of a multiverse can be made by showing that it is an inevitable consequence of well- established laws or processes fundamental to the emergence and character of our observable universe. This is essentially the claim that is made for chaotic inflation and most of the other multiverse scenarios that have been proposed.

The main deficiency is that the underlying physics has not been adequately tested, directly or retroductively. We need further evidence that the postulated physics is true in our universe:

- We need a credible link between the postulated physics in the very early universe and the physics in which we have some confidence
- We need some evidence that the scalar potentials, or other overarching cosmic principles, central to generating bubble universes really were functioning in the very early universe, or before its emergence

Obviously, this what we are all trying to accomplish! – in spite of all the unsolved problems, especially those of quantum theory, quantum field theory – including the problem of the cosmological constant – , and quantum gravity.

IX. Conclusion:

The retroductive approach to scientific testability does open the way for scientific confirmation of a multiverse to which our observable universe belongs, and thus to a scientific resolution of the fine-tuning problem. This requires the long term success and fruitfulness of the detailed and continually refined hypotheses relying on it and on the physics which generated it.