The multiverse proposal and the anthropic principle

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September 22, 2006

Claremont Cosmology Conference, October 2006: *Cosmology and Process Philosophy in Dialogue: Fundamental Philosophical Issues in Recent Cosmology and their Religious Significance.* The goal of the conference is to clearly delineate the variety of relations that obtain between physical cosmology and philosophical cosmology and to make progress in formulating the research program(s) that lie at this interface. We thus assume that its false that no relations exist between these two fields.

1 Introduction

The overall question is the nature of existence. The main issue on the physical side is

- Is there one universe or many?

- What kind of proof can one have that this is so?

(Other issues such as, *Did the universe have a start or not*?, are of considerable interest, but they do not per se have fundamental theological implications). On the philosophical side the main issues are

- The metaphysics of existence and fundamental causation: What determines what exists?

- Does matter or intention underlie the cosmos?

The two meet in the issue of fine tuning

- Why does the universe have the properties necessary for life to exist? (the anthropic issue)

It is suggested [25] that the multiverse provides an answer without the need for Intelligent Design. But this does not in fact tackle fundamental issues: it just shifts it back one stage to, *Why any multiverse at all*? *Why this one rather than that one?* One ends up with a proposition (the multiverse) that cannot be proved correct by scientific methods - belief in its existence is a matter of faith. So one needs to return to the issue of the nature of proof, and philosophical justification of beliefs:

- What is an acceptable scientific proof?

- What is a reasonable philosophical justification for a belief to be held as true?

That is in the end a key philosophic issue in the link between the two, which does help illuminate the difference between science and religion as far as belief structures are concerned. I discuss these issues by means of excerpts from a forthcoming encyclopedia article on the philosophy of cosmology (http://www.mth.uct.ac.za/ ellis/enc2.pdf). For full references, see that article.

2 Issue G: The anthropic question: Fine tuning for life

One of the most profound fundamental issues in cosmology is the Anthropic question: *why does the Universe have the very special nature required in order that life can exist?*. The point is that a great deal of "fine tuning" is required in order that life be possible. There are many relationships embedded in physical laws that are not explained by physics, but are required for life to be possible; in particular various fundamental constants are highly constrained in their values if life as we know it is to exist:

"A universe hospitable to life — what we might call a biophilic universe — has to be special in many ways ... Many recipes would lead to stillborn universes with no atoms, no chemistry, and no planets; or to universes too short lived or too empty to evolve beyond sterile uniformity" [21].

How has it come about that the Universe permits the evolution and existence of intelligent beings at any time or place? "What features of the universe were essential for creatures such as ourselves, and is it through coincidence or for some deeper reason that our universe has these features?" [12]. Whether one regards this as an appropriate issue for cosmology to discuss depends on the scope one envisages for cosmology. The viewpoint taken here will be that this is one of the major issues one might wish to explain, and indeed a substantial literature considers this. Here we explore the nature of this fine tuning, and then consider possible answers as to how it arises. There are three aspects that we consider in turn (cf. [25]).

2.1 Laws of physics and the existence of complexity

The laws of physics and chemistry are such as to allow the functioning of living cells, individuals, and ecosystems of incredible complexity and variety, and it is this that has made evolution possible. What requires explanation, *is why the laws of physics are such as to allow this complex functionality to work*, without which no evolution whatever would occur. We can conceive of universes where the laws of physics (and so of chemistry) were different than in ours. Almost any change in these laws will prevent life as know it from functioning.

The first requirement is *the existence of laws of physics that guarantee the kind of regularities that can underlie the existence of life*. These laws as we know them are based on variational and symmetry principles; we do not know if other kinds of laws could produce complexity. If the laws are in broad terms what we presently take them to be, the following *inter alia* need to be right, for life of the general kind we know to exist:

- Quantization that stabilizes matter and allows chemistry to exist through the Pauli exclusion principle.
- The neutron-proton mass differential must be highly constrained. If the neutron mass were just a little less than it is, proton decay could have taken place so that by now no atoms would be left at all.
- Electron-proton charge equality is required to prevent massive electrostatic forces overwhelming the weaker electromagnetic forces that govern chemistry.
- The strong nuclear force must be strong enough that stable nuclei exist; indeed complex matter exists only if the properties of the nuclear strong force lies in a tightly constrained domain relative to the electromagnetic force.
- The chemistry on which the human body depends involves intricate folding and bonding patterns that would be destroyed if the fine structure constant (which controls the nature of chemical bonding) were a little bit different.
- The number D of large spatial dimensions must be just 3 for complexity to exist.

Hogan has examined the freedom in the parameters of the standard model of particle physics and concluded that 5 of the 17 free parameters of the standard model must lie in a highly constrained domain if complex structures are to exist [15]. This is of course taking the basic nature of the standard model of particle physics for granted. If this were not so, it is difficult to determine what the constraints would be. However his study is sufficient to show that whatever the nature of fundamental physics, and in particular of particle physics, may be, only a small subset of all possible laws of physics will be compatible with the existence of complexity.

2.2 Laws of physics and the existence of congenial environments

The creation through astrophysical processes of suitable habitats for life to exist (the existence of planets circling stable stars, for example) depends to some degree on the nature of the fundamental physical laws. If the laws are in broad terms what we presently take them to be, the requirements for such habitats to exist include:

- The gravitational force must create large stable structures (planets and stars) that can be the habitat for life and their energy source respectively. This requires the gravitational force to be very weak relative to electrical forces. The ratio $\mathcal{N}$ of the strength of the electromagnetic force to the gravitational force must be close to the observed value: $\mathcal{N} \simeq 10^{36}$ ([20], Chapter 3).
- The weak force must allow helium production that leaves sufficient hydrogen over; it is related to gravity through a numerical factor of 10^{-11}, which cannot be much different. And for this to work, the neutron-proton mass difference must be close to the mass of the electron.
- A stellar balance should allow a long lifetime for stars like the sun, so allowing the transmutation of the light elements into heavy elements. This requires that the nuclear fusion efficiency $\mathcal{E}$ be close to the observed value: $\mathcal{E} \simeq 0.007$ ([20], Chapter 4).

- One needs to overcome the beryllium “bottleneck” in the making of heavy elements through nuclear reactions in stars [12, 25]. The production of carbon and oxygen in stars requires the careful setting of two different nuclear energy levels to provide a resonance; if these levels were just a little different, the elements we need for life would not exist. Indeed it was on this basis that Hoyle famously predicted a carbon-12 energy level that has since been experimentally confirmed.
- One needs something like the existence of neutrinos and the weak interaction with its specific coupling constant in order to underly supernovae explosions that spread heavy elements through space, as seeds for planetary formation [12].
- The nuclear force must be weak enough that di-protons do not exist, otherwise no protons will be left over to enable heavier elements to exist [3].
- The neutrino mass must not be too high, or the universe will not last long enough [3].

2.3 Cosmological boundary/initial conditions and congenial environments

Finally, given laws of physics that are suitable in terms of satisfying the requirements of both the previous sections, the universe itself must also be suitable, in terms of its initial or boundary conditions, for life to exist. If the laws of physics are basically the same as we now believe them to be, these cosmological requirements include

- The size of the universe and its age must be large enough. There could be universes that expanded and then recollapsed with a total lifetime of only 100,000 years; we need a sufficiently old universe for second generation stars to come into existence and then for planets to have a stable life for long enough that evolution could lead to the emergence of intelligent life. Thus the universe must be at about 15 billion years old for life to exist [12], hence we must have $\Omega_{matter} \simeq 0.3$ ([20], Chapter 6).
- The size of the cosmological constant must not be too large, or galaxies will not form; we need $|\Omega_\Lambda| < 1$ for galaxies to exist ([20], Chapter 7; [25]).
- The seeds in the early universe for fluctuations that will later grow into galaxies must be of the right size that structures form without collapsing into black holes: the number Q characterizing the size of primordial ripples on the LSS (and hence the geometry of the perturbed cosmological model) must therefore be of the order $Q \simeq 10^{-5}$ ([20], Chapter 8).

The complex of interacting systems in a human body could not possibly work if a series of delicate conditions were not maintained. For example, the background radiation might never drop below 3000 K, so that matter was always ionized (electrons and nuclei always remaining separate from each other); the molecules of life could then never form. Black holes might be so common that they rapidly attracted all the matter in the universe, and there never was a stable environment in which life could develop. Cosmic rays could always be so abundant that any tentative organic structures were destroyed before they could replicate. Overall,

- There must be non-interference with local systems. The concept of locality is fundamental, allowing local systems to function effectively independently of the detailed structure of the rest of the Universe. We need the universe and the galaxies in it to be largely empty, and gravitational waves and tidal forces to be weak enough, so that local systems can function in a largely isolated way.
- The fact that the night sky is dark (‘Olbers’ paradox’) is a consequence of the expansion of the universe together with the photon to baryon ratio. This feature is a necessary condition for the existence of life: the biosphere on Earth functions by disposing of waste energy to the heat sink of the dark night sky. Thus one way of explaining why the sky is observed to be dark at night is that if this were not so, we would not be here to observe it.
- The existence of the arrow of time, and hence of laws like the second law of thermodynamics, are probably necessary for evolution and for consciousness. This depends on boundary conditions at the beginning and end of the Universe.
- Presumably the emergence of a classical era out of a quantum state is required. The very early universe would be a domain where quantum physics would dominate, leading to complete uncertainty and an inability to predict the consequence of any initial situation; we need this to evolve to a state where classical physics leads to the properties of regularity and predictability that allow order to emerge.
- Physical conditions on planets must be in a quasi-equilibrium state for long enough to allow the delicate balances that enable our existence, through the very slow process of evolution, to be fulfilled.

Thus the existence of suitable local systems to be a habitat for life depends critically on the large-scale properties of very distant matter. These provides a stable local environment within which life can develop.

2.4 Fine tuning overall

Thus there are many ways that conditions in a universe could prevent life occurring. Life will occur only if: there exist heavy elements; there is sufficient time for evolution of advanced life forms to take place; there are regions in the universe that are neither too hot nor too cold; there are precisely restricted values of the fundamental constants that control chemistry and local physics; and so on. These conditions will not be true in a generic universe. In summary,

Thesis G1: Life is possible because both the laws of physics and the boundary conditions for the universe have a very special nature. *Only particular laws of physics, and particular initial conditions in the Universe, allow the existence of intelligent life of the kind we know. No evolutionary process whatever is possible for any kind of life if these laws and conditions do not have this restricted form.*

Why is this so? One should note that we can only meaningfully refer here to 'life as we know it'. One of the recurring issues is whether there could be some other quite different basis for life. You can if you wish speculate that life might exist in some immaterial form, or based only on light elements, or existent deep in empty space without the need for stars or planets to provide a viable habitat. The anthropic literature is based on assuming this is not viable, but we cannot *prove* anything in this regard. We have no idea of any basis by which life might come into existence other than the broad principles we see in the life around us. The basic principles of life as we understand it require a great degree of complex organization enabling it to fulfil a complex variety of functions that can only, as far as we know, be based in material existence with information storage, energy usage, sensing of the external world, etc., which requires at a minimum heavy elements (carbon, nitrogen, oxygen, phosphorus for example), a long-term energy source (such as the flow of energy from the sun), and a stable environment (such as the surface of a planet). When we abandon this basis for understanding — saying 'yes but some other form of life might exist' without providing any proposal for its possible structure — one enters the unprofitable realm of speculation. It does not seem to provide any useful way forward.

The Anthropic Principle. The *Weak Anthropic Principle* (WAP) is based on the comment: it is not surprising the observed Universe admits the existence of life, for the Universe cannot be observed unless there are observers in it [2, 1]. This seemingly empty statement gains content when we turn it round and ask, at what times and places in the Universe can life exist, and what are the inter-connections that are critical for its existence? It could not for example exist too early in the present expansion phase, for the night sky would then have been too hot. Furthermore one can deduce various necessary relations between fundamental quantities in order that the observers should exist (e.g. those mentioned above), so that if for example the fundamental constants vary with time or place in the Universe, life will only be possible in restricted regions where they take appropriate Anthropic values.

Hence this view basically interprets the Anthropic principle as a selection principle: the necessary conditions for observers to exist restricts the times and places from which the Universe can be observed. Because it is quite possible that conditions would not be right for life to exist anywhere in an arbitrarily selected universe, it is also usually conjoined with the idea of the existence of a multiverse, as discussed below, see Sec.3. This is an interesting and often illuminating viewpoint. For example, neither the Chaotic Inflationary Universe idea nor any other multiverse proposal works unless we add such an Anthropic component into their interpretation to explain why we observe the Universe from a viewpoint where life exists. It is now used by some physicists to explain the low value of the cosmological constant (which quantum field theory predicts should have a very much larger value than observed), and occurs in the context of the possibility landscape of string theory [25].

2.5 The relation to fundamental physical theories

Many physicists reject any Anthropic form of reasoning. They regard it as a cop-out resorted to when physical theories fail to give the needed answers, and seek to obtain a full answer from physics alone [22, 25]. One possibility is that there is a fundamental theory of everything that determines the nature of physics completely, with no arbitrary parameters left, and this still to be discovered theory just happens to be of such a nature as to admit life.

However in this case the Anthropic issue returns with a vengeance: *How could it be that such a theory, based for example on variational principles and the specific invariance groups of particle physics, could just happen to lead to biophilic parameter values*? There is no clear way to answer such a question. Uniqueness of fundamental physics resolves the parameter freedom only at the expense of creating an even deeper mystery, with no way of resolution apparent. In effect, the nature of the unified fundamental force would be pre-ordained to allow, or even encourage, the existence of life; but there would be no apparent reason why this should be so.

A second possibility is that physics allows many effective theories with varying parameters — some form of multiverse, as for example may be implied by string theory [25]. If these varying options are all equally real, life can occur because in some cases the parameters will lie in the restricted biophilic regime. Thus from this viewpoint the Anthropic idea is intimately linked with the existence of multiverses, which provide a legitimate domain for their application. We will turn to an examination of multiverses in the next section, but before doing so we will consider the range of metaphysical options for resolving the anthropic question.

2.6 The metaphysical options

To make progress on the Anthropic issue, we have to seriously consider the nature of ultimate causation: What is the fundamental cause for the phenomena we see? If we pursue the chain of physical cause and effect to its conclusion, we are still left with the question: *Why did this occur, and not something else*? Whatever the reason is, it is the ultimate cause we are seeking. Note that we are here leaving the terrain of science itself, and starting to probe the domain of metaphysics — the foundations of science and indeed of existence. As noted above, one can simply decide not to pursue such issues. If we do continue to question, there appear to be basically six approaches to the issue of ultimate causation: namely Random Chance, Necessity, High Probability, Universality, Cosmological Natural Selection, and Design. We briefly consider these in turn.

Option 1: *Random Chance, signifying nothing.* The initial conditions in the Universe just happened, and led to things being the way they are now, by pure chance. Probability does not apply. There is no further level of explanation that applies; searching for 'ultimate causes' has no meaning.

This is certainly logically possible, but not satisfying as an explanation, as we obtain no unification of ideas or predictive power from this approach. Nevertheless some implicitly or explicitly hold this view.

Option 2: *Necessity.* Things have to be the way they are; there is no other option. The features we see and the laws underlying them are demanded by the unity of the Universe: coherence and consistency require that things must be the way they are; the apparent alternatives are illusory. Only one kind of physics is self-consistent: all logically possible universes must obey the same physics.

To really prove this would be a very powerful argument, potentially leading to a self-consistent and complete scientific view. But we can imagine alternative universes! — why are they excluded? Furthermore we run here into the problem that we have not succeeded in devising a fully self-consistent view of physics: neither the foundations of quantum physics nor of mathematics are on a really solid consistent basis. Until these issues are resolved, this line cannot be pursued to a successful conclusion.

Option 3: *High probability.* Although the structure of the Universe appears very improbable, for physical reasons it is in fact highly probable.

These arguments are only partially successful, even in their own terms. They run into problems if we consider the full set of possibilities: discussions proposing this kind of view actually implicitly or explicitly restrict the considered possibilities *a priori*, for otherwise it is not very likely the Universe will be as we see it. Besides, we do not have a proper measure to apply to the set of initial conditions, enabling us to assess these probabilities. Furthermore, application of probability arguments to the Universe itself is dubious, because the Universe is unique. Despite these problems, this approach has considerable support in the scientific community, for example it underlies the chaotic inflationary proposal. It attains its greatest power in the context of the assumption of universality:

Option 4: *Universality.* This is the stand that "All that is possible, happens": an ensemble of universes or of disjoint expanding universe domains is realized in reality, in which all possibilities occur [20, 21, 26]. In its full version, the anthropic principle is realized in both its strong form (if all that is possible happens, then life must happen) and its weak form (life will only occur in some of the possibilities that are realized; these are picked out from the others by the WAP, viewed as a selection principle). There are four ways this has been pursued.

1: *Spatial variation.* The variety of expanding universe domains is realised in space through random initial conditions, as in chaotic inflation. While this provides a legitimate framework for application of probability, from the viewpoint of ultimate explanation it does not really succeed, for there is still then one unique Universe whose (random) initial conditions need explanation. Initial conditions might be globally statistically homogeneous, but also there could be global gradients in some physical quantities so that the Universe is not statistically homogeneous; and these conditions might be restricted to some domain that does not allow life. It is a partial implementation of the ensemble idea; insofar as it works, it is really a variant of the "high probability" idea mentioned above. If it was the more or less unique outcome of proven physics, then that would provide a good justification; but the physics underlying such proposals is not even uniquely defined, much less tested. Simply claiming a particular scalar field with some specific stated potential exists does not prove that it exists!

2: *Time variation.* The variety of expanding universe domains could be realised across time, in a universe that has many expansion phases (a Phoenix universe), whether this occurs globally or locally. Much the same comments apply as in the previous case.

3: *Quantum Mechanical.* It could occur through the existence of the Everett-Wheeler "many worlds" of quantum cosmology, where all possibilities occur through quantum branching. This is one of the few genuine alternatives proposed to the Copenhagen interpretation of quantum mechanics, which leads to the necessity of an observer. The many-worlds proposal is controversial: it occurs in a variety of competing formulations, none of which has attained universal acceptance. The proposal does not provide a causal explanation for the particular events that actually occur: if we hold to it, we then have to still explain the properties of the particular history we observe (for example, why does our macroscopic universe have high symmetries when almost all the branchings will not?). And above all it is apparently untestable: there is no way to experimentally prove the existence of all those other branching universes, precisely because the theory gives the same observable predictions as the standard theory.

4: *Completely disconnected.* They could occur as completely disconnected universes: there really is an ensemble of universes in which all possibilities occur, without any connection with each other [18, 21, 26]. A problem that arises then is, What determines what is possible? For example, what about the laws of logic themselves? Are they inviolable in considering all possibilities? We cannot answer, for we have no access to this multitude of postulated worlds. We explore this further below (Sec.3).

In all these cases, major problems arise in relating this view to testability and so we have to query the meaningfulness of the proposals as scientific explanations. They all contradict Ockham's razor: we "solve" one issue at the expense of envisaging an enormously more complex existential reality. Furthermore, they do not solve the ultimate question: *Why does this ensemble of universes exist*? One might suggest that ultimate explanation of such a reality is even more problematic than in the case of single universe. Nevertheless this approach has an internal logic of its own which some find compelling. We consider this approach further below, see Sec.3.

Option 5: *Cosmological Natural Selection.* If a process of re-expansion after collapse to a black hole were properly established, it opens the way to the concept not merely of evolution of the Universe in the sense that its structure and contents develop in time, but in the sense that the Darwinian selection of expanding universe regions could take place, as proposed by Smolin [23]. The idea is that there could be collapse to black holes followed by re-expansion, but with an alteration of the constants of physics through each transition, so that each time there is an expansion phase, the action of physics is a bit different. The crucial point then is that some values of the constants will lead to production of more black holes, while some will result in less. This allows for evolutionary selection favouring the expanding universe regions that produce more black holes (because of the favourable values of physical constants operative in those regions), for they will have more "daughter" expanding universe regions. Thus one can envisage natural selection favouring those physical constants that produce the maximum number of black holes.

The problem here is twofold. First, the supposed 'bounce' mechanism has never been fully explicated. Second, it is not clear — assuming this proposed process can be explicated in detail - that the physics which maximizes black hole production is necessarily also the physics that favours the existence of life. If this argument could be made water-tight, this would become probably the most powerful of the multiverse proposals.

Option 6: *Purpose or Design.* The symmetries and delicate balances we observe require an extraordinary coherence of conditions and cooperation of causes and effects, suggesting that in some sense they have been purposefully designed. That is, they give evidence of intention, both in the setting of the laws of physics and in the choice of boundary conditions for the Universe. This is the sort of view that underlies Judaeo-Christian theology. Unlike all the others, it introduces an element of meaning, of signifying something. In all the other options, life exists by accident; as a chance by-product of processes blindly at work.

The prime disadvantage of this view, from the scientific viewpoint, is its lack of testable scientific consequences ("Because God exists, I predict that the density of matter in the Universe should be x and the fine structure constant should be y"). This is one of the reasons scientists generally try to avoid this approach. There will be some who will reject this possibility out of hand, as meaningless or as unworthy of consideration. However it is certainly logically possible. The modern version, consistent with all the scientific discussion preceding, would see some kind of purpose underlying the existence and specific nature of the laws of physics and the boundary conditions for the Universe, in such a way that life (and eventually humanity) would then come into existence through the operation of those laws, then leading to the development of specific classes of animals through the process of evolution as evidenced in the historical record. Given an acceptance of evolutionary development, it is precisely in the choice and implementation of particular physical laws and initial conditions, allowing such development, that the profound creative activity takes place; and this is where one might conceive of design taking place.[1]

However from the viewpoint of the physical sciences *per se*, there is no reason to accept this argument. Indeed from this viewpoint there is really no difference between design and chance, for they have not been shown to lead to different physical predictions.

2.7 Metaphysical Uncertainty

In considering ultimate causation underlying the anthropic question, in the end we are faced with a choice between one of the options above. As pointed out already by Kant and Hume, although we may be able to argue strongly

[1] This is not the same as the view proposed by the 'Intelligent Design' movement. It does not propose that God tweaks the outcome of evolutionary processes.

for one or other of them, we cannot *prove* any of the options are correct.

Thesis G2: Metaphysical uncertainty remains about ultimate causation in cosmology. *We cannot attain certainty on the underlying metaphysical cosmological issues through either science or philosophy.*

If we look at the anthropic question from a purely scientific basis, we end up without any resolution, basically because science attains reasonable certainty by limiting its considerations to restricted aspects of reality; even if it occasionally strays into the area of ultimate causation, it is not designed to deal with it. By itself, it cannot make a choice between these options; there is no relevant experiment or set of observations that can conclusively solve the issue. Thus a broader viewpoint is required to make progress, taking into account both the scientific and broader considerations. The issue is of a philosophical rather than scientific nature. One important issue that then arises is what kind of data is relevant to these philosophical choices, in addition to that which can be characterized as purely scientific data (Sec.4.3).

3 Issue H: The possible existence of multiverses

If there is a large enough ensemble of numerous universes with varying properties, it may be claimed that it becomes virtually certain that some of them will just happen to get things right, so that life can exist; and this can help explain the fine-tuned nature of many parameters whose values are otherwise unconstrained by physics [20, 21]. As discussed in the previous section, there are a number of ways in which, theoretically, multiverses could be realized [18, 26]. They provide a way of applying probability to the universe (because they deny the uniqueness of the universe). However, there are number of problems with this concept. Besides, this proposal is observationally and experimentally untestable; thus its scientific status is debatable.

3.1 Definition

In justifying multiverses, it is often stated that 'all that can occur, occurs' (or similarly). However that statement does not adequately specify a multiverse. To define a multiverse properly requires two steps [10]. First, one needs to specify what is conceived of in the multiverse, by defining a *possibility space*: a space $\mathcal{M}$ of all possible universes, each of which can be described in terms of a set of states s in a state space $\mathcal{S}$. Each universe m in $\mathcal{M}$ will be characterized by a set of distinguishing parameters p, which are coordinates on $\mathcal{S}$. Choices are needed here. In geometrical terms, will it include only Robertson–Walker models, or more general ones (e.g. Bianchi models, or models without symmetries)? In gravitational terms, will it include only General Relativity, or also brane theories, models with varying G, loop quantum gravity models, string theory models with their associated possibility 'landscapes', and models based on the wave function of the universe concept? Will it allow only standard physics but with varying constants, or a much wider spectrum of physical possibilities, e.g. universes without quantum theory, some with five fundamental forces instead of four, and others with Newtonian gravity? Defining the possibility space means making some kind of assumptions about physics and geometry that will then apply across the whole family of models considered possible in the multiverse, and excluding all other possibilities.

Second, one needs to specify which of the possible universes are physically realized in the multiverse, and how many times each one occurs. *A multiverse must be a physically realized multiverse and not a hypothetical or conceptual one if it is to have genuine explanatory power.* Thus one needs a distribution function $f(m)$ specifying how many times each type of possible universe m in $\mathcal{M}$ is realised. The function $f(m)$ expresses the contingency in any actualization. Things could have been different! Thus, $f(m)$ describes a specific *ensemble of universes* or *multiverse* envisaged as being realised out of the set of possibilities. For example, $f(m)$ might be non-zero for all possible values of all the parameters p ('all that can happen, happens'); but it could be that f describes a multiverse where there are 10^{100} identical copies of one particular universe (the realization process finds a particularly successful recipe, and then endlessly replicates it).

Additionally we need a measure $d\pi$ that enables this function to determine numbers and probabilities of various properties in the multiverse: the number of universes corresponding to a set of parameter increments will be dN given by

$$\mathrm{d}N = f(m)d\pi \tag{1}$$

for continuous parameters; for discrete parameters, we add in the contribution from all allowed parameter values. The total number of universes N in the ensemble will be given by

$$N = \int_{\mathcal{M}} f(m)d\pi \tag{2}$$

(which will often diverge), where the integral ranges over all allowed values of the member parameters and we take it to include all relevant discrete summations. The expectation value P of a quantity $p(m)$ defined on the set of universes will be given by

$$P = \int_{\mathcal{M}} p(m) f(m) d\pi. \tag{3}$$

These three elements (the possibility space, the measure, and the distribution function) must all be clearly defined in order to give a proper specification of a multiverse [10]. This is almost never done.

3.2 Non-uniqueness: Possibilities

There is non-uniqueness at both steps. Stating "all that is possible, happens" does not resolve what is possible. The concept of multiverses is not well defined until the space of possible universes has been fully characterized; it is quite unclear how to do this uniquely. The issue of what is to be regarded as an ensemble of 'all possible' universes can be manipulated to produce any result you want, by redefining what is meant by this phrase — standard physics and logic have no necessary sway over them: what I envisage as 'possible' in such an ensemble may be denied by you. What super-ordinate principles are in operation to control the possibilities in the multiverse, and why? A key point here is that *our understandings of the possibilities are always of necessity arrived at by extrapolation from what we know,* and my imagination may be more fertile than yours, and neither need correspond to what really exists out there — if indeed there is anything there at all. Do we include only

- *Weak variation*: e.g. only the values of the constants of physics are allowed to vary? This is an interesting exercise but is certainly not an implementation of the idea 'all that can happen, happens'. It is an extremely constrained set of variations.
- *Moderate variation*: different symmetry groups, or numbers of dimensions, etc. We might for example consider the possibility landscapes of string theory as realistic indications of what may rule multiverses [25]. But that is very far indeed from 'all that is possible', for that should certainly include spacetimes not ruled by string theory.
- *Strong variation*: different numbers and kinds of forces, universes without quantum theory or in which relativity is untrue (e.g. there is an aether), some in which string theory is a good theory for quantum gravity and others where it is not, some with quite different bases for the laws of physics (e.g. no variational principles).
- *Extreme variation*: universes where physics is not well described by mathematics; with different logic; universes ruled by local deities; allowing magic as in the Harry Potter series of books; with no laws of physics at all? Without even mathematics or logic?

Which is claimed to be the properties of the multiverse, and why? We can express our dilemma here through the paradoxical question: *Are the laws of logic necessary in all possible universes?*

3.3 Non-uniqueness: existence and causation

A specific multiverse is defined by specifying the distribution function $f(m)$ of actually realized universes. It is unclear what mechanism can underlie such a distribution, and any proposal for such a mechanism is completely untestable. We need some indication as to *what determines existence within the possibilities defined by the supposed possibility space*: What decides how many times each one happens? Unless we understood the supposed underlying mechanisms we can give no serious answer; and there is no prospect whatever of testing any proposed mechanism. The mechanisms supposed to underlie whatever regularities there are in the multiverse must pre-exist the existence of not merely this universe but also every other one. If one assumes a universe that is connected in the large but is locally separated into causally disconnected domains with different physical properties(as in chaotic inflation), one attains a plausible picture of a creation mechanism that can underlie an effective multiverse — but at the expense of supposing the validity of untested and perhaps untestable physics. Because of this one does not obtain a specification of a unique multiverse: the physics could be different than what we assumed.

3.4 Explanatory power

What explanatory power do we get in return for these problems? It has been suggested they explain the parameters of physics and of cosmology and in particular the very problematic observed value of the cosmological constant [27, 25]. The argument goes as follows: assume a multiverse exists; observers can only exist in one of the highly improbable biophilic outliers where the value of the cosmological constant is very small [13]. A similar argument has been proposed for neutrino masses. If the multiverse has many varied locations with differing properties, that may indeed help us understand the Anthropic issue: some regions will allow life to exist, others will not [2]. This does provide a useful modicum of explanatory power. However it is far from conclusive. Firstly, it is unclear why the multiverse should have the restricted kinds of variations of the cosmological constant assumed in the various analyses mentioned. If we assume 'all that can happen, happens' the variations will not be of that restricted kind; those analyses will not apply.

Secondly, ultimate issues remain: Why does this unique larger whole have the properties it does? *Why this multiverse rather than any other one*? Why is it a multiverse that allows life to exist? Many multiverses will not allow any life at all. To solve this, we can propose an *ensemble of ensembles of universes*, with even greater explanatory power and even less prospect of observational verification; and so on. The prospect of an infinite regress looms. Indeed if we declare (as suggested at the start of this article) that 'the Universe' is the total of all that physically exists, then when an ensemble of expanding universe domains exists, whether causally connected or not, that ensemble itself should be called 'the Universe', for it is then the totality of physically existing entities. All the foundational problems for a single existing universe domain recur for the multiverse — because when properly considered, it is indeed the Universe!

3.5 Testability

If an ensemble exists with members not connected in any physical way to the observable universe, then we cannot interact with them in any way nor observe them, so we can say anything we like about them without fear of disproof. Thus any statements we make about them can have no solid scientific or explanatory status; they are totally vulnerable to anyone else who claims an ensemble with different properties (for example claiming different kinds of underlying logics are possible in their ensemble, or claiming many physically effective gods and devils in many universes in their ensemble).

Thesis H1: Multiverse proposals are unprovable by observation or experiment, but some self-consistency tests are possible. *Direct observations cannot prove or disprove that a multiverse exists, for the necessary causal relations allowing observation or testing of their existence are absent. Their existence cannot be predicted from known physics, because the supposed causal or pre-causal processes are either unproven or indeed untestable. However some self-consistency conditions for specific multiverse models can be tested.*

Various probability-based arguments have been given for the multiverse by Weinberg, Rees, and others. However

Thesis H2: Probability-based arguments cannot demonstrate the existence of multiverses. *Probability arguments cannot be used to* prove *the existence of a multiverse, for they are only applicable if a multiverse exists. Furthermore probability arguments can never prove anything for certain, as it is not possible to violate any probability predictions, and this is* a fortiori *so when there is only one case to consider, so that no statistical observations are possible.*

All one can say on the basis of probability arguments is that some specific state is very improbable. But this does not prove it is impossible, indeed if it is stated to have a low probability, that is precisely a statement that it is possible. Thus such arguments can at best only give plausibility indications even when they are applicable. The assumption that probability arguments can be conclusive is equivalent to the claim that the universe is generic rather than special; but whether this is so or not is precisely the issue under debate (see Thesis **D3**). The argument is useful as a plausibility argument for a multiverse, but is not *proof* of its existence.

Finally, it has been proposed that the existence of multiverses is an inevitable consequence of the universe having infinite space sections [26, 16], because that leads to infinite spatial repetition of conditions. But this supposed spatial infinity is an untested philosophical assumption, which certainly cannot be observationally proven to be correct. Apart from the existence of horizons preventing confirmation of this supposition, even if the entire universe were observable, proving it correct would still not be possible because by definition counting an infinite number of objects takes an infinite amount of time. This is an untestable philosophical argument, not an empirically testable one; furthermore, it can be argued to be implausible (Sec.4.1). Indeed current data suggest it is not the case; this is the one good consistency test one can use for some multiverse proposals (Sec.3.7).

3.6 Explanation vs Testability

The argument that this infinite ensemble actually exists can be claimed to have a certain explanatory economy, although others would claim that Occam's razor has been completely abandoned in favour of a profligate excess of existential multiplicity, extravagantly hypothesized in order to explain the one universe that we do know exists. Certainly the price is a lack of testability through either observations or experiment — which is usually taken to be an essential element of any serious scientific theory.[2] It is not uniquely definable nor determinable, and there is

[2] In [24], the framework and conditions under which the multiverse hypothesis would be testable within a retroductive framework, given the rigorous conditions formulated in that paper, are indicated; these conditions are not fulfilled.

a complete loss of verifiability. There is no way to determine the properties of any other universe in the multiverse if they do indeed exist, for they are forever outside observational reach. The point is that there is not just an issue of showing a multiverse exists. If this is a scientific proposition one needs to be able to show which specific multiverse exists; but there is no observational way to do this. Indeed if you can't show *which particular* one exists, it is doubtful you have shown *any* one exists.

What does a claim for such existence mean in this context? Gardner puts it this way: "There is not the slightest shred of reliable evidence that there is any universe other than the one we are in. No multiverse theory has so far provided a prediction that can be tested. As far as we can tell, universes are not even as plentiful as even *two* blackberries" [11].[3]

Thesis H3: Multiverses are a philosophical rather than scientific proposal. *The idea of a multiverse provides a possible route for the explanation of fine tuning. But it is not uniquely defined, is not scientifically testable apart from some possible consistency tests, and in the end simply postpones the ultimate metaphysical questions.*

The definitive consistency tests on some multiverse proposals (Sec.3.7) are *necessary* conditions for those specific multiverse proposals, but are hardly by themselves indications that the multiverse proposal is true. The drive to believe this is the case comes from theoretical and philosophical considerations (see e.g. [25]) rather than from data. The claim an ensemble physically exists[4] is problematic as a proposal for scientific explanation, if science is taken to involve testability. Indeed, adopting these explanations is a triumph of theory over testability [11], but the theories being assumed are not testable. It is therefore a metaphysical choice made for philosophical reasons. That does not mean it is unreasonable (it can be supported by quite persuasive plausibility arguments); but its lack of scientific status should be made clear.

3.7 Observations and disproof

Despite the gloomy prognosis given above, there are some specific cases where the existence of a chaotic inflation (multi-domain) type scenario can be *dis*proved. These are firstly when we live in a 'small universe' where we have already seen right round the universe, for then the universe closes up on itself in a single FL-like domain, so that no further such domains can exist that are causally connected to us in a single connected spacetime. This 'small universe' situation is observationally testable; its confirmation would disprove the usual chaotic inflationary scenario, but not a truly 'disconnected' multiverse proposal, for that cannot be shown to be false by any observation. Neither can it be shown to be true. Secondly, many versions of chaotic inflation demand $k = -1 \Leftrightarrow \Omega_0 < 1$ [25]. The best current data is consistent with $k = -1$.

3.8 Physical or biological paradigms — Adaptive Evolution?

Given that the multiverse idea must in the end be justified philosophically rather than by scientific testing, is there a philosophically preferable version of the idea? One can suggest there is: greater explanatory power is potentially available by introducing the major constructive principle of biology into cosmology, namely adaptive evolution, which is the most powerful process known that can produce ordered structure where none pre-existed. This is realized in principle in Lee Smolin's idea (Sec.2.6) of Darwinian adaptation when collapse to black holes is followed by re-expansion, but with an alteration of the constants of physics each time, so as to allow for evolutionary selection towards those regions that produce the maximum number of black holes. The idea needs development, but is very intriguing:

Thesis H4: The underlying physics paradigm of cosmology could be extended to include biological insights. *The dominant paradigm in cosmology is that of theoretical physics. It may be that it will attain deeper explanatory power by embracing biological insights, and specifically that of Darwinian evolution. The Smolin proposal for evolution of populations of expanding universe domains [23] is an example of this kind of thinking.*

The result is different in important ways from standard cosmological theory precisely because it embodies in one theory three of the major ideas of the last century, namely (i) Darwinian evolution of populations through competitive selection, (ii) the evolution of the universe in the sense of major changes in its structure associated with its expansion, and (iii) quantum theory, underlying the only partly explicated mechanism supposed to cause re-expansion out of collapse into a black hole. There is a great contrast with the theoretical physics paradigm of dynamics governed simply by variational principles shaped by symmetry considerations. It seems worth pursuing as a very different route to the understanding of the creation of structure.

[3]This contrasts strongly, for example, with Lewis's defence of the concept [18]. Lewis defends the thesis of "modal realism": that the world we are part of is but one of a plurality of worlds.

[4]As opposed to consideration of an explicitly hypothetical such ensemble, which can indeed be useful).

4 Issue I: Natures of Existence

Underlying all this is the issue of natures of existence, which has a number of aspects, relating from the purely physical to more metaphysical issues.

4.1 Existence of Infinities

The nature of existence is significantly different if there is a finite amount of matter or objects in the universe, as opposed to there being an infinite quantity in existence. Some proposals claim there may be an infinite number of universes in a multiverse and many cosmological models have spatial sections that are infinite, implying an infinite number of particles, stars, and galaxies. However, infinity is quite different from a very large number! Following David Hilbert [14], one can suggest these unverifiable proposals cannot be true: the word 'infinity' denotes a quantity or number that can never be attained, and so will never occur in physical reality. He states

"Our principal result is that the infinite is nowhere to be found in reality. It neither exists in nature nor provides a legitimate basis for rational thought . . . The role that remains for the infinite to play is solely that of an idea . . . which transcends all experience and which completes the concrete as a totality . . ." ([14], p. 151).

This suggests "infinity" cannot be arrived at, or realized, in a concrete physical setting; on the contrary, the concept itself implies its inability to be realized!

Thesis I2: The often claimed physical existence of infinities is questionable. *The claimed existence of physically realized infinities in cosmology or multiverses raises problematic issues. One can suggest they are unphysical; in any case such claims are certainly unverifiable.*

This applies in principle to both small and large scales in any single universe:

- The existence of a physically existing spacetime continuum represented by a real (number) manifold at the micro-level contrasts with quantum gravity claims of a discrete spacetime structure at the Planck scale, which one might suppose was a generic aspect of fully non-linear quantum gravity theories. In terms of physical reality, this promises to get rid of the uncountable infinities the real line continuum engenders in all physical variables and fields. There is no experiment that can *prove* there is a physical continuum in time or space; all we can do is test space-time structure on smaller and smaller scales, but we cannot approach the Planck scale.
- Infinitely large space-sections at the macro-level raise problems as indicated by Hilbert, and leads to the infinite duplication of life and all events [9]. We may assume space extends forever in Euclidean geometry and in many cosmological models, but we can never prove that any realised 3-space in the real universe continues in this way — it is an untestable concept, and the real spatial geometry of the universe is almost certainly not Euclidean. Thus Euclidean space is an abstraction that is probably not physically real. The infinities supposed in chaotic inflationary models derive from the presumption of pre-existing infinite Euclidean space sections, and there is no reason why those should necessarily exist. In the physical universe spatial infinities can be avoided by compact spatial sections, resulting either from positive spatial curvature, or from a choice of compact topologies in universes that have zero or negative spatial curvature. Machian considerations to do with the boundary; and if one invokes string theory as a fundamental basis for physics, then 'dimensional democracy' suggests the three large spatial dimensions should also be compact, since the small ('compactified') dimensions are all taken to be so.
- It applies to the possible nature of a multiverse. Specifying the geometry of a generic universe requires an infinite amount of information because the quantities necessary to do so are fields on spacetime, in general requiring specification at each point (or equivalently, an infinite number of Fourier coefficients): they will almost always not be algorithmically compressible. All possible values of all these components in all possible combinations will have to occur in a multiverse in which "all that can happen, does happen". There are also an infinite number of topological possibilities. This greatly aggravates all the problems regarding infinity and the ensemble. Only in highly symmetric cases, like the FL solutions, does this data reduce to a finite number of parameters, each of which would have to occur in all possible values (which themselves are usually taken to span an infinite set, namely the entire real line). Many universes in the ensemble may themselves have infinite spatial extent and contain an infinite amount of matter, with all the problems that entails. To conceive of physical creation of an infinite set of universes (most requiring an infinite amount of information for their prescription, and many of which will themselves be spatially infinite) is at least an order of magnitude more difficult than specifying an existent infinitude of finitely specifiable objects.

One should note here particularly that problems arise in the multiverse context from the continuum of values assigned by classical theories to physical quantities. Suppose for example that we identify corresponding times in the models in an ensemble and then assume that *all* values of the density parameter and the cosmological constant occur at each spatial point at that time. Because these values lie in the real number continuum, this is a doubly uncountably infinite set of models. Assuming genuine physical existence of such an uncountable infinitude of universes is the antithesis of Occam's razor. But on the other hand, if the set of realised models is either finite or countably infinite, then almost all possible models are not realised. And in any case this assumption is absurdly unprovable. We can't observationally demonstrate a single other universe exists [11], let alone an infinitude. The concept of infinity is used with gay abandon in some multiverse discussions [16], without any concern either for the philosophical problems associated with this statement [14], or for its completely unverifiable character. It is an extravagant claim that should be treated with extreme caution.

4.2 The Nature of the Laws of Physics

Underlying all the above discussion is the basic concept of ordered behaviour of matter, characterized by laws of physics of a mathematical nature that are the same everywhere in the universe.[5] Three interlinked issues arise.

(i) *What is the ontological nature of the laws of physics*: descriptive, *just characterizing the way things are, or* prescriptive, *enforcing them to be this way*?. If they are descriptive, the issue arising is, *Why does all matter have the same properties wherever it exists in the universe*? Why are all electrons everywhere in the universe identical, if the laws are only descriptive? If they are prescriptive, then matter will necessarily be the same everywhere (assuming the laws themselves are invariable); the issue arising then is, *In what way do laws of physics exist that enforce themselves on the matter in the universe*? Do they for example have an existence in some kind of Platonic space that controls the nature of matter and existence? One can avoid talking about the laws of physics *per se* by instead considering the *space of possibilities* underlying what exists physically, rigorously constraining the possible natures of what actually comes into existence [6]. This space is more or less uniquely related to the underlying laws in the same way that the space of solutions of differential equations is related to the nature of the equations. This enables one to avoid the issue of the ontology of the laws of physics, but does not solve it.

(ii) *Why are the laws of physics so well explained by mathematical descriptions*? If they are prescriptive, this deep issue might be related to the suggested Platonic nature of the space of mathematical reality [19]. If they are descriptive, then the mathematical expressions we use to encapsulate them are just a convenient description but do not reflect their ultimate nature. Many writings in physics and cosmology seem to assume that their ultimate existential nature is indeed mathematical — perhaps a confusion of appearance and reality (see Sec.5.2).

(iii) *Do they pre-exist the universe and control its coming into being, or do they come into being with the universe*? This is where this issue relates deeply to the nature of cosmology, and is clearly related to the other two questions raised above. Many theories of creation of the universe assume that all these laws, or at least a basic subset, pre-exist the coming into being of the physical universe, because they are presumed to underlie the creation process, for example the entire apparatus of quantum field theory is often taken for granted as pre-existing our universe. This is of course an unprovable proposition

Thesis I3: A deep issue underlying the nature of cosmology is the nature of the laws of physics. *The nature of the possibility space for physical existence is characterized by the laws of physics. However it is unclear if these laws are prescriptive or descriptive; whether they come into being with space-time and matter, or pre-exist them.*

4.3 'Ultimate Reality'

Philosophers have debated for millennia whether the ultimate nature of existence is purely material, or embodies some form of rationality ('Logos') and/or purpose ('Telos'). *What in the end underlies it all*? Is the ultimate nature of the universe purely material, or does it in some way have an element of the mental? (cf. Sec.2.6). That profound debate is informed by physical cosmology, but cannot be resolved by the physical sciences alone (Sec.2.7). Here, I will make just two comments on this deep issue.

Firstly, even in order to understand just the material world, it can be claimed that one needs to consider forms of existence other than the material only — for example a Platonic world of mathematics and a mental world, both of which can be claimed to exist and be causally effective in terms of affecting the material world [6, 19]. Our understanding of local causation will be incomplete unless we take them into account.

Secondly, in examining these issues one needs to take into account data about the natures of our existence that come from our daily lives and the broad historical experience of humanity (our experiences of ethics and aesthetics, for example), as well as those discoveries attained by the scientific method. Many writings claim there is no purpose in the universe: it is all just a conglomerate of particles proceeding at a fundamental level in a purposeless and meaningless algorithmic way. But I would reply, the very fact that those writers engage in such

[5] The effective laws may vary from place to place because for example the vacuum state varies [25]; but the fundamental laws that underlie this behaviour are themselves taken to be invariant.

discourse undermines their own contention; they ignore the evidence provided by their own actions. There is certainly meaning in the universe to this degree: *the fact they take the trouble to write such contentions is proof that they consider it meaningful to argue about such issues*; and this quality of existence has emerged out of the nature of the physical universe Indeed the human mind is causally effective in the real physical world precisely through many activities motivated by meanings perceived by the human mind. Any attempt to relate physics and cosmology to ultimate issues must take such real world experience seriously [7, 8], otherwise it will simply be ignoring a large body of undeniable data. This data does not resolve the ultimate issues, but does indicate dimensions of existence that indeed do occur.

5 Issue F: The Explicit Philosophical Basis

Thesis F1: Philosophical choices necessarily underly cosmological theory. *Unavoidable metaphysical issues inevitably arise in both observational and physical cosmology. Philosophical choices are needed in order to shape the theory.*

There is of course always a philosophical basis to any scientific analysis, namely adoption of the basic scientific method and a commitment to the attempt to explain what we see as far as possible simply in terms of causal laws, ultimately based in physics. This will clearly be true also in cosmology. However we need further explicit philosophical input in order to attain specific geometric models — for example a Copernican principle — and to determine what form physical cosmology should take in the very early universe, for example deciding which physical principle to use as the core of one's extrapolation of known physics to the unknown. Underlying both sets of choices are criteria for satisfactoriness of a cosmological model, which help decide which feature to focus on in formulating a theory. Of particular importance is the scope chosen for our cosmological theory; together with the choice of criteria for a good theory, this is a philosophical decision that will shape the rest of the analysis. Some cosmologists tend to ignore the philosophical choices underlying their theories; but simplistic or unexamined philosophical standpoints are still philosophical standpoints!

5.1 Criteria for theories

As regards criteria for a good scientific theory [17], typical would be the following four areas of assessment:

1. *Satisfactory structure*: **(a)** internal consistency, **(b)** simplicity (Ockham's razor), and **(c)** aesthetic appeal ('beauty' or 'elegance').

2. *Intrinsic explanatory power*: **(a)** logical tightness, **(b)** scope of the theory — the ability to unify otherwise separate phenomena, and **(c)** probability of the theory or model with respect to some well-defined measure;

3. *Extrinsic explanatory power, or relatedness*: **(a)** connectedness to the rest of science, **(b)** extendability — providing a basis for further development;

4. *Observational and experimental support*, in terms of **(a)** testability: the ability to make quantitative as well as qualitative predictions that can be tested; and **(b)** confirmation: the extent to which the theory is supported by such tests as have been made.

It is particularly the latter that characterizes a scientific theory, in contrast to other types of theories claiming to explain features of the universe and why things happen as they do. It should be noted that *these criteria are philosophical in nature in that they themselves cannot be proven to be correct by any experiment.* Rather their choice is based on past experience combined with philosophical reflection. One could attempt to formulate criteria for good criteria for scientific theories, but of course these too would need to be philosophically justified. The enterprise will end in infinite regress unless it is ended at some stage by a simple acceptance of a specific set of criteria.

Thesis F2: Criteria of satisfactoriness for theories cannot be scientifically chosen or validated. *Criteria of satisfactoriness are necessary for choosing good cosmological theories; these criteria have to be chosen on the basis of philosophical considerations. They should include criteria for satisfactory structure of the theory, intrinsic explanatory power, extrinsic explanatory power, and observational and experimental support.*

The suggestion here is that the above proposed criteria are a good set to use in investigating cosmology; they include those most typically used ([17]; and see [19, 25] for comments on such criteria).

5.1.1 Conflicts between criteria.

These criteria are all acknowledged as desirable. The point then is that generally in pursuing historical sciences, and in particular in the cosmological context, they will not all be satisfied to the same degree, and may even lead to opposing conclusions:

Thesis F3: Conflicts will inevitably arise in applying criteria for satisfactory cosmological theories. *Philosophical criteria for satisfactory cosmological theories will in general come into conflict with each other, so that one will have to choose between them to some degree; this choice will shape the resulting theory.* .

The thrust of much recent development has been away from observational tests towards strongly theoretically based proposals, indeed sometimes almost discounting observational tests. At present this is being corrected by a healthy move to detailed observational analysis of the consequences of the proposed theories, marking a maturity of the subject. However because of all the limitations in terms of observations and testing [criteria **(4)**], in the cosmological context we still have to rely heavily on other criteria, and some criteria that are important in most of science may not really make sense. This is true of **2(c)** in particular; nevertheless many approaches still give the idea of probability great weight. At a minimum, the ways this can make sense needs exploration and explication. Furthermore the meaning of some of the criteria may come into dispute. **1(b)** is clearly a case in point : for example, is the idea of an existent ensemble of universes displaying all possible behaviours simple (because it is a single idea that can be briefly stated), or immensely complex (because that statement hides all the complexities and ambiguities involved in the idea of an infinity of possibilities)? **1(c)** is also controversial('beauty is in the eye of the beholder'), see [25] for a discussion.

The tenor of scientific understanding may change, altering the balance of what is considered a good explanation and what is not. An example [5] is the way cosmologists strongly resisted the idea of an evolving universe in the 1920's, at a time when biological evolution was very well established but the idea of continental drift was also being strongly resisted. The change to an appreciation of the explanatory power of an evolving model came later in both cases; but even then in the cosmological case, for either aesthetic or metaphysical reasons, some still sought for a steady state description, resisting the implication of a beginning to the universe. That tendency is still with us today, in the form of models that are eternal in one way or another (e.g. some forms of chaotic inflation). Another example is the change from supposition of underlying order, expressed in the idea of a Cosmological Principle, to a broad supposition of generic disordered conditions, embodied in the ideas of inflation. Associated with this is a shift from making geometric assumptions to providing physical explanatory models. It is this shift that underlies the major present support for inflation:

Thesis F4: The physical reason for believing in inflation is its explanatory power as regards structure growth in the universe. *Inflation predicts the existence of Gaussian scale-free perturbations in the early universe thereby (given the presence of cold dark matter) explaining bottom-up structure formation in a satisfactory way. This theory has been vindicated spectacularly through observations of the CBR and matter power spectra. It is this explanatory power that makes it so acceptable to physicists, even though the underlying physics is neither well-defined nor tested, and its major large-scale observational predictions are untestable.*

The physical explanatory power of inflation in terms of structure formation, supported by the observational data on the fluctuation spectra, is spectacular. For most physicists, this trumps the lack of identification and experimental verification of the underlying physics. Inflation provides a causal model that brings a wider range of phenomena into what can be explained by cosmology (Criterion **2(b)**), rather than just assuming the initial data had a specific restricted form. Explaining flatness ($\Omega_0 \simeq 1$ as predicted by inflation) and homogeneity reinforces the case, even though these are philosophical rather than physical problems (they do not contradict any physical law; things could just have been that way). However claims on the basis of this model as to what happens very far outside the visual horizon (as in the chaotic inflationary theory) results from prioritizing theory over the possibility of observational and experimental testing [4]. It will never be possible to *prove* these claims are correct.

The basic underlying cosmological questions are:

(1) *Why do the laws of physics have the form they do?* Issues arise such as what makes particular laws work? For example, what guarantees the behaviour of a proton, the pull of gravity? What makes one set of physical laws 'fly' rather than another? If for example one bases a theory of cosmology on string theory [25], then who or what decided that quantum gravity would have a nature well described by string theory? If one considers all possibilities, considering string theory alone amounts to a considerable restriction.

(2) *Why do boundary conditions have the form they do ?* The key point here, is how are specific contingent choices made between the various possibilities, for example whether there was an origin to the universe or not.

(3) *Why do any laws of physics at all exist ?* This relates to unsolved issues concerning the nature of the laws of physics: are they descriptive or prescriptive? (Sec.4.2). Is the nature of matter really mathematically based in some sense, or does it just happen that its behaviour can be described in a mathematical way?

(4) *Why does anything exist ?* This profound existential question is a mystery whatever approach we take.

Finally the adventurous also include in these questions the more profound forms of the contentious Anthropic question [2]:

(5) *Why does the universe allow the existence of intelligent life?* This is of somewhat different character than the others and largely rests on them but is important enough to generate considerable debate in its own right.

The status of all these questions is philosophical rather than scientific, for they cannot be resolved purely scientifically.

5.2 Limits of Representation and Knowledge of Reality

It follows from the above discussion that there are limits to what the scientific method can achieve in explanatory terms. We need to respect these limits and acknowledge clearly when arguments and conclusions are based on some philosophical stance rather than purely on testable scientific argument. If we acknowledge this and make that stance explicit, then the bases for different viewpoints are clear and alternatives can be argued about rationally.

A crucial underlying feature here is relating the nature of epistemology to ontology: how do we relate evidence to our theories of existence? A further key issue is the relation of models to reality:

Thesis F6: Reality is not fully reflected in either observations or theoretical models. *Problems arise from confusion of epistemology (the theory of knowledge) with ontology (the nature of existence): existence is not always manifest clearly in the available evidence. The theories and models of reality we use as our basis for understanding are necessarily partial and incomplete reflections of the true nature of reality, helpful in many ways but also inevitably misleading in others. They should not be confused with reality itself!*

The confusion of epistemology with ontology occurs all the time, underlying for example the errors of both logical positivism and extreme relativism. In particular, it is erroneous to assume that lack of evidence for the existence of some entity is proof of its non-existence. In cosmology it is clear for example that regions may exist from which we can obtain no evidence (because of the existence of horizons); so we can sometimes reasonably deduce the existence of unseen matter or regions from a sound extrapolation of available evidence (no one believes matter ends at or just beyond the visual horizon). However one must be cautious about the other extreme, assuming existence can always be assumed because some theory says so, regardless of whether there is any evidence of existence or not. This happens in present day cosmology, for example in presentations of the case for multiverses, even though the underlying physics has not been experimentally confirmed. It may be suggested that arguments ignoring the need for experimental/observational verification of theories ultimately arise because these theories are being confused with reality, or at least are being taken as completely reliable total representations of reality. This occurs in

- Confusing computer simulations of reality with reality itself, when they can in fact represent only a highly simplified and stylized version of what actually is;
- Confusing the laws of physics themselves with their abstract mathematical representation (if indeed they are ontologically real), or confusing a construction of the human mind ('Laws of Physics') with the reliable behaviour of ponderable matter (if they are not ontologically real);
- Confusing theoretically based outcomes of models with proven observational results (e.g. claiming the universe necessarily has flat spatial sections: $\Omega_0 = 1$, and so this can be taken for granted, when the value of Ω_0 can and should be observationally determined precisely because this then tests that prediction).

No model (literary, intuitive, or scientific) can give a perfect reflection of reality. Such models are always selective in what they represent and partial in the completeness with which they do so. The only model that would reflect reality fully is a perfect fully detailed replica of reality itself! This understanding of the limits of models and theories does not diminish the utility of these models; rather it helps us use them in the proper way. This is particularly relevant when we consider how laws of nature may relate to the origins of the universe itself, and to the existence and nature of life in the expanding universe. The tendency to rely completely on our theories, even when untested, seems sometimes to arise because we believe they are the same as reality — when at most they are *descriptions* of reality.

6 Conclusion

What is crucially needed in developing the multiverse idea as a theory about the real universe is a serious attempt to engage with the philosophy of science, developing an approach to theory validation that is adequate for this kind of context where insubstantial evidential support has to be supplemented by other inferential principles. This has not been undertaken so far. One can then compare this with the idea of validation in the religious context, and see how the multiverse and religious versions of explanation hold up relative to each other in the light of such criteria - remembering that these options are not in fact mutually exclusive.

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