S & CB (2001), **13**, 5–24 0954–4194

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Fine-Tuning, Many Universes, and Design

In the light of the fine-tuning of the universe, I critique the postulation of the existence of infinitely many universes as an alternative to design. Among the problems identified with the hypothesis are (i) the existence of infinitely many universes depends critically on parameter choice; (ii) the probability that any universe in an ensemble is fine-tuned for life is zero; (iii) the physical realisation of any ensemble will exclude an infinity of possibilities; (iv) the hypothesis is untestable and unscientific; (v) the hypothesis is not consistent with the amount of order found in this universe, nor with the persistence of order. The explanatory power of the hypothesis is thus undermined. Even if this had been otherwise the hypothesis should be given a low prior probability on the grounds of lack of simplicity and economy. The design hypothesis then fares better on a simple probability comparison.

Keywords: Fine-tuning, many universes, cosmology, design.

1. Introduction: Fine-tuning and the invocation of many universes

Modern cosmology presents us with a universe remarkably 'finely-tuned' for life. The Big Bang theory utilises the laws of physics to describe how the universe has evolved from the first fraction of a second to the present day. It transpires that fine-tuning operates on two levels: both the fundamental constants which go into the laws, and the initial conditions at the earliest conceivable time, must take the values they do to remarkable degrees of accuracy in order for the universe to give rise to intelligent living beings.

The number of examples of this fine-tuning is legion. To set the scene we limit ourselves to three examples, two pertaining to the physical constants and one to initial conditions (two examples of the latter kind will form the bulk of our discussion later):

(i) One of the most important elements necessary for life, certainly life as we know it, is hydrogen – no hydrogen means no water and hence no life. If the weak nuclear force, the force responsible for radioactive decay, were not, apparently accidentally, related to the gravitational force in a rather special way, either all the hydrogen would be converted to helium within a few seconds of the Big Bang or none would.[1] In the former case, with the weak force somewhat weaker, one would end up with no possibility of water or life at any subsequent stage in the universe's history. Moreover, stars which burnt helium through nuclear reactions in their cores would be much shorter-lived than hydrogen-burning stars. Life would not have time to develop on the planets of such stars. Whilst no helium production in the Big Bang would not be so significant, it would appear that the requirement that massive stars explode in supernovae, so that the chemical elements they have manufactured in their cores through nuclear reactions can be made available for planet-building, constrains the relationship between the weak force and gravity in both directions (i.e. relative increase or decrease of the weak force relative to gravity).[2]

(ii) Life as we know it is based on the element carbon, and it is unlikely that any other element could give sufficiently stable compounds to produce alternative life forms. Oxygen is also essential. The chemical elements are built up inside stars, and carbon is one step on the way to manufacturing the other elements in the periodic table. We are required both to get as far as carbon in the first place and then, even more delicately, not to burn up all the carbon we have made to manufacture oxygen and the other elements. If the strong nuclear force, which binds nuclei together, and the electromagnetic force, which operates between charged particles, were not so very finely balanced as they are we would either get no carbon in the first place or have all the carbon burn making oxygen. This aspect of the anthropic argument is discussed both by Barrow and Tipler[3] and by Davies[4], in each case following an argument of Fred Hoyle.

Hoyle himself (an atheist) was so impressed by this particular coincidence, that he was moved to remark:

> I do not believe that any scientist who examined the evidence would fail to draw the inference that the laws of nuclear physics have been deliberately designed with regard to the consequences they produce inside the stars. If this is so, then my apparently random quirks have become part of a deep-laid scheme. If not then we are back again at a monstrous sequence of accidents[5].

1 J. D. Barrow and F. J. Tipler, *The Anthropic Cosmological Principle* (Oxford: Oxford University Press, 1986), p 399; P. C. W. Davies, *The Accidental Universe* (Cambridge: Cambridge University Press, 1982), pp 63-65. The actual constraint is that the strength of the weak force is roughly equal to the strength of the gravitational force to the power $1/4$, ie to 10^{-11} where these strengths are measured as appropriate dimensionless numbers. Decrease the weak force strength by a couple of orders of magnitude to 10^{-13} and the helium abundance increases from 25% to 95% with disastrous consequences for the possibility of life.
2 B. J. Carr and M. J. Rees, 'The Anthropic Principle and the Structure of the Physical World', *Nature* 278 (1979), pp 605-612.
3 Barrow and Tipler, *op. cit.*, pp 252-253.
4 Davies, *op. cit.*, pp 117-118.
5 F. Hoyle in *Religion and the Scientists* (London: SCM Press, 1959).

(iii) The universe at its earliest moments is endowed with a very small excess of baryons, a class of particles, including neutrons and protons, affected by the strong nuclear force, over anti-baryons, the anti-matter particles corresponding to baryons (the excess is 1 particle in 10^9). Baryons and anti-baryons annihilate to give photons. If the universe were baryon symmetric (i.e. having an equal number of baryons and anti-baryons) at the relevant time, there would be insufficient matter following annihilation for galaxies to form. The process of cosmic evolution – galaxies, stars, planets, life – would not even get going. Whilst it might be the case that this asymmetry can arise from physical processes occurring in an earlier symmetric state, as Grand Unified Theories (see later) predict, this would only push the question back a stage – namely to the parameter values taken by the GUTs. This 'pushing back the question' is a phenomenon we shall have occasion to refer to later.

One possible inference to draw from the data is that the constants and initial conditions were fixed by God who wished to create an anthropically fruitful universe. A counter strategy often adopted by those who wish to deny design is to postulate the existence of infinitely many universes in which the constants and/or the initial conditions take on all possible values. We should then not be surprised to find ourselves in a universe with the parameters ours has, since we could not find ourselves in, and hence observe, any universe whose parameters differed by more than the smallest amount from ours. The kind of opponent of design I am describing usually wishes to adopt the position that all physical events can be explained solely, and exclusively, in terms of other physical events. I shall call such a position 'scientific naturalism'.

In this paper I want to critique the many-universes idea as an alternative to design. However, the scope of the article is inevitably severely limited. I shall not have much to say about the design argument itself, which certainly needs some development. Then, I shall concentrate on only one particular mode of existence of many universes. This is the simultaneous existence of infinitely many sub-universes in a single overarching space-time (an hypothesis associated with the name of Brandon Carter). It seems to me that this is the least controversial means of obtaining many universes.[6]

A serious problem which pervades the whole discussion of the 'anthropic coincidences', whether trying to explain them in a single universe or by invoking many universes, is that it is difficult to assess the number of possible allowed combinations of free parameters and hence the proportion of them which allow life to develop. Dennis Sciama points out that, in order to determine whether or not our universe is 'super special' we require a 'still-to-be-con-

6 Thus I ignore the oscillating universe theory of John Wheeler, which is in any case now out of favour with cosmologists, and Everett's many worlds interpretation of quantum mechanics, which, though having found favour with a number of cosmologists, has not attracted many quantum theorists.

structured measure theory on the ensemble space of the universes'[7]. A measure is a mathematical function with certain properties, notably additivity, of which probability is a special case. Such a measure theory as advocated by Sciama would greatly improve the rigour of anthropic arguments by providing a basis for assigning probabilities to the parameters which describe the universes. Paul Davies has made a similar point to this in his book *The Mind of God*[8].

To see how the measure problem is manifested, suppose that a particular parameter λ could lie theoretically anywhere in the range 0 to n. If equal intervals of λ are equally likely, then the probability that λ lies between a and b, where b is greater than a, is $(b - a)/n$. This is the length of the interval $(b - a)$, multiplied by $1/n$, the probability density function.

Clearly, the larger the value of n the smaller the probability that λ lies within any particular finite interval (a, b). Naïvely one might expect that the probability $(b - a)/n$ would tend to zero as n tends to infinity. However, there is a problem about actually taking the limit as n tends to infinity because the probability density function would still have to integrate (ie add up) to 1, a property known as normalisation.

All this begs the question, 'Why should we take such a uniform distribution?' We could equally well take any function of λ and assign that a uniform distribution, or any distribution we please, and get an entirely different answer. What the normalized probability distribution for any of the parameters in question should actually be is simply unknown.

It is clear that we shall not be able to solve these deep-rooted problems in this article. Nevertheless we shall be taking account of statements of probability made by leading cosmologists. In so far as possible we shall take these statements at face value and explore their logic. Our contention is that such statements are in fundamental tension with the invocation by these same authors of many universes as an explanation for fine-tuning.

Our discussion focuses on two of the most important elements of fine-tuning. These both relate to initial conditions in the early universe rather than fundamental constants of physical theory. They are the initial density and isotropy of the universe. The analysis shows (i) that the existence of an infinite ensemble depends on critical assumptions which may not be probable; (ii) that the probability that any universe within the ensemble is finely-tuned might actually be zero, in which case the explanatory value disappears; and (iii) that the ensemble is in any case not physically realizable.

We go on to consider how the relatively new theory of inflation might impact on these conclusions.

7 D. W. Sciama, in F. Bertola and U. Curi (eds.), *The Anthropic Principle: Proceedings of the Second Venice Conference on Cosmology and Philosophy* (Cambridge: Cambridge University Press, 1989), pp 109-111.
8 P. C. W. Davies, *The Mind of God* (London: Simon and Schuster, 1992), pp 204-205.

Finally, we consider certain other general problems with the infinitely many universes hypothesis as an explanation for fine-tuning. These include the kind of explanation offered, its testability, and whether the amount of ultra-fine-tuning this universe actually possesses is explained.

2. Critical density

Standard cosmological theory informs us that the universe is either open, ie will expand forever, or closed, ie will eventually recollapse. Which alternative is realised depends on the mean density of energy in the universe, ρ. If ρ is less than a certain critical value ρ_c the universe is open; if it is greater than ρ_c the universe is closed. If $\rho = \rho_c$ the universe is just open. Present observations show that ρ is very close to ρ_c so that we cannot decide between these alternatives.

Now it turns out that ρ simply has to be very close to ρ_c in order to have a universe in which life evolves. This is because a universe with greater density would have recollapsed before stars had time to evolve and life had time to form, and one with smaller density would expand so rapidly that matter would never collapse into galaxies and stars.

One can trace the closeness required of ρ to ρ_c in order to yield a life-producing universe right back to the Planck time. This time, when the universe is a mere 10^{-43} seconds old, is the earliest about which we can sensibly speak, since an as yet unknown theory of quantum gravity is required to take us further back still.

Barrow and Tipler report that, in order for the universe to give rise to life[9], at the Planck time ρ must be equal to ρ_c to an accuracy of 10^{-56} to 10^{-60}. This represents a very tight constraint indeed on the initial conditions of the Big Bang. Why the density should be so tightly constrained has been dubbed the 'flatness problem' by Alan Guth, since a universe with density equal to the critical density has zero spatial curvature.[10]

We now examine how Barrow and Tipler attempt to evade the conclusion that ρ is designed to be very close to ρ_c by invoking many universes.

Barrow and Tipler state: '… because in an infinite universe there is a finite probability that an arbitrarily large region obeying [this constraint] will occur somewhere if the initial conditions are *random*, we would expect to observe [this constraint]'.[11]

9 Barrow and Tipler, *op. cit.*, p 411.
10 In Einstein's theory of general relativity, space is curved owing to the effects of gravity. Curved three dimensional space is hard to visualise, but its analogues in two dimensions can be imagined. The special case of $\rho = \rho_c$ gives rise to a 'flat', ie Euclidean, geometry, corresponding to a plane in 2 dimensions. $\rho > \rho_c$ and $\rho < \rho_c$ give positive and negative spatial curvature respectively, equivalent to the surface of a sphere and a saddle shape in 2 dimensions.
11 Barrow and Tipler, p 411.

We need to try and unpack the meaning of this very important statement, remembering the qualifications made in our introduction about probability statements. Barrow and Tipler give us no guidance.

At face value the statement would appear to mean that, in an infinite universe, there is a probability p lying strictly between 0 and 1, that a region with density satisfying the condition will occur. But what is meant by 'random initial conditions'? Presumably this means that ρ is chosen randomly, but from what probability distribution? Barrow and Tipler do not tell us, so we are left to fend for ourselves. Let us try some possibilities.

Suppose first that the initial value of ρ is a uniform random variable lying between 0 and ρ_c. Then there will be a finite probability, of order 10^{-57}, that a given universe with a single value of ρ would have the required density. How p relates to this latter probability is not made clear. If p is very low, the appeal to an infinite universe with regions of differing ρ is nugatory.

One might have expected the stronger claim that in an infinite universe, given random initial conditions, an arbitrary region satisfying the near-flatness condition is bound to occur, ie will occur with probability 1 – that is the usual motivation for the appeal to an infinite universe. If one could engineer more than 10^{60} universes, each with the initial value of ρ chosen from the above distribution, then p would indeed approach unity.

Were it possible to partition space into infinitely many regions with density randomly chosen between 0 and ρ_c (though see below), then the probability would indeed be 1 that one with density in the required range would exist. The anthropic reasoning of Barrow and Tipler would then be correct: we can only observe a region of this kind.

But why limit the random choice of ρ to the range 0 to ρ_c? We have been considering the value of ρ to be randomly chosen for each region. Now let us consider the density ρ_{tot} of the ensemble as a whole. There would seem to be no reason to restrict ρ_{tot} to the range $(0, \rho_c)$.

To avoid problems about an infinite range, suppose that ρ_{tot} has a physically realisable maximum value ρ_{max} (this may be physically realistic if we discount the existence of classical black holes with literally infinite density). Presumably it will be the case that $\rho_{max} >> \rho_c$. The probability that $\rho_{tot} < \rho_c$ is then very small, on the assumption that ρ_{tot} is drawn from a uniform distribution on the interval $(0, \rho_{max})$. Moreover, if $\rho_{tot} > \rho_c$ then the universe is finite. In fact it is overwhelmingly likely, given that ρ_{tot} is randomly chosen from such a uniform distribution, that the universe will be finite. But if the universe is finite, there are not infinitely many regions of arbitrary size! The argument from random choosing of ρ_{tot} to infinitely many universes in which the 'right' values for life will automatically occur breaks down. In other words, the many universes hypothesis already implies a very special condition (ie $\rho_{tot} < \rho_c$) on the system as a whole.

Let us summarize this argument. Postulate an infinite universe in which arbitrarily large regions exist whose density is chosen randomly between 0 and ρ_c. For the sake of argument assume that this implies that there exists with certainty a region with ρ satisfying the near-flatness condition. The anthropic explanation for our existence succeeds. However, *in order for there to be infinitely many regions the overall density of the universe* ρ_{tot} *must be below* ρ_c. But the probability that there actually exist infinitely many regions might well be low, since if ρ_{tot} is chosen randomly from the range 0 to ρ_{max}, then it is highly probable that the universe is finite.

Thus we are far from having eliminated the finely-tuned density of the universe as a 'cosmic coincidence'. ρ_{tot}/ρ_c for the universe as a whole must be less than unity, and the probability of this may well be extremely small.

Now the argument can of course be thrown back at us that we have assumed this uniform distribution for ρ without warrant. In fact we have no idea what the distribution for ρ should be. This is true. My point is that neither do Barrow and Tipler have a clue as to what this distribution should be. They certainly do not tell us, but just vaguely assume that an infinite universe with random drawings of ρ will automatically give some regions suitable for life. This assumption relies on the critical, but apparently arbitrary further assumption that ρ_{tot} for the whole ensemble is less than ρ_c.

There is a further point. Given an infinite universe, it is actually impossible to determine what the value of Ω_0 (the value of ρ_{tot}/ρ_c at the present time) is, and hence to extrapolate back to its tightly constrained value in the very early universe. To assign it a value is therefore to make a 'metaphysical' assumption. Without such a metaphysical assumption, the hypothesis of an infinite universe fails.

3. Isotropy

In a seminal paper, Collins and Hawking[12] showed that 'the set of spatially homogeneous cosmological models which approach isotropy at infinite times is of measure zero in the space of all spatially homogeneous models'.[13] Such models are known as asymptotically isotropic. Like Barrow and Tipler's statement about density, this too is a highly significant result, and we begin by examining the background to it.

The microwave background radiation bathing the universe is isotropic to a remarkably high degree. More precisely, the temperature and intensity of this

12 C. B. Collins and S. W. Hawking, 'Why is the Universe Isotropic?', *Astrophysical Journal* 180 (1973), pp 317-334.

13 Spatial homogeneity denotes the universe looking the same in every place, isotropy its looking the same in every direction. Homogeneity to the right degree has also posed problems for cosmologists (there must be some lumpiness for galaxies to form!), but we have no space for further discussion of this topic.

radiation appear independent of direction in the sky to 1 part in a thousand (Barrow and Tipler[14], but 1 part in 100,000 if the earth's motion is accounted for[15]). This is a deeply puzzling feature of the universe, indicating that widely separated regions of the universe, which, because of the limitation imposed by the speed of light, cannot have been in causal contact with each other, nevertheless seem highly co-ordinated. This is the so-called 'horizon problem'.

Isotropy is not just puzzling *per se*, however: it is apparently necessary for life, and therefore another seeming 'anthropic' coincidence. This is because any anisotropy, ie shear and rotational distortions, in the expanding medium of the Big Bang must die away quickly if density perturbations are to develop into galaxies. It is assumed (but see later) that a universe in which this is the case is asymptotically isotropic. As Collins and Hawking remark, 'The existence of galaxies would seem to be a necessary precondition for the development of any form of intelligent life.'

Charles Misner had introduced the 'chaotic cosmology' programme with a view to showing that the present large-scale structure of the universe, including its isotropy, is largely independent of initial conditions.[16] This is a case of what McMullin calls the 'indifference principle' – the idea that there is nothing 'accidental' about the universe.[17] Applied to the initial conditions of the Big Bang, this asserts that, whatever they were, the universe would evolve in the same way.

Collins's and Hawking's paper dealt the death blow to chaotic cosmology. They used the standard (Bianchi) classification of solutions to Einstein's equations of general relativity, and examined the stability of these solutions to perturbations in initial data. In practice, spatially homogeneous models may be grouped into three classes, as defined above at the beginning of section 2: those that are closed, 'just open' and open. Models in the first group do not last long enough to approach isotropy and those of the third group do not in general tend to isotropy. Collins and Hawking write:

> Those models of the second class which are sufficiently near to the Robertson-Walker[18] models do in general tend to isotropy, but this class is of measure zero in the space of all homogeneous models. It therefore seems that one cannot explain the isotropy of the universe without postulating special initial conditions.

14 Barrow and Tipler, *op. cit.*, p 419.
15 Alan H. Guth, *The Inflationary Universe: The Quest for a New Theory of Cosmic Origins* (London: Jonathan Cape, 1997), p 336, footnote.
16 Charles W. Misner, 'The Isotropy of the Universe', *Astrophysical Journal* 151 (1968), pp 431-457.
17 E. McMullin, 'Indifference Principle and Anthropic Principle in Cosmology', *Studies in History and Philosophy of Science* 24, No. 3 (August 1993), pp 359-389.
18 The Robertson-Walker models are an idealized class of solutions to Einstein's equations which are perfectly homogeneous and isotropic.

In other words, the set of asymptotically isotropic universes is a negligible fraction of the total set of possible universes.

Collins and Hawking are aware of possible criticisms of their finding. We are clearly not yet at time infinity, so perhaps we are in a universe which is still young, has been very nearly isotropic up to now, but may yet tend to anisotropy. They are simply 'unhappy' about believing this, finding it much more plausible that the universe is becoming more rather than less isotropic. This seems rather lame, but all I can do for the purposes of this paper is to assume that they are right, that we are necessarily in an asymptotically isotropic universe (because only so can we have galaxies), and follow through the logic of their position.

Collins and Hawking justify consideration of this measure zero set of cosmological models by appealing to a postulate of Dicke[19] and Carter[20], namely that 'there is not one universe but a whole infinite ensemble of universes with all possible initial conditions'. As in the case of finely-tuned density, this appeal is highly problematical – indeed much more so.

The appeal to a spatially infinite universe does not help in this case because the probability that any region within the ensemble is asymptotically isotropic is not just low, but zero (that is what 'measure zero' means). This destroys the explanatory power of an infinite number of universes (as noted by Earman[21]). A zero probability times an infinite number of possibilities is a mathematically indeterminate quantity. Thus there is absolutely no guarantee that a spatially infinite universe can provide a region of sufficient size with asymptotic isotropy, and hence, a fortiori, with life. If the properties of the various regions of the infinite universe are random, the number of suitable universes could be any finite number or zero.[22]

Moreover, the number of finite regions above a given size within an infinite

19 R. H. Dicke, 'Dirac's Cosmology and Mach's Principle', *Nature* 192 (1961), p 440.

20 cited by Collins and Hawking as B. D. Carter, Cambridge University preprint (1968), but eventually published as Brandon Carter, 'Large Number Coincidences and The Anthropic Principle in Cosmology', in Longair, M. S. (ed.), *Confrontation of Cosmological Theory with Astronomical Data* (Dordrecht: D. Reidel, 1974), pp 291-298; reprinted in J. Leslie (ed.), *Physical Cosmology and Philosophy* (New York: Macmillan, 1990), pp 125-133.

21 John Earman, 'The SAP also rises: a critical examination of the anthropic principle', *American Philosophical Quarterly* 24, No. 4 (1987), pp 307-317. Earman discusses a 1979 paper in which George Ellis postulates an infinite universe with many regions in different states of expansion and contraction and possessing different degrees of homogeneity and isotropy. Earman comments: 'But if the feature in question is unusual with a vengeance – measure zero – then the probability that it will be exhibited in some mini-world in the Ellis model is zero; …'

22 see J. F. C. Kingman and S. J. Taylor, *Introduction to Measure and Probability* (Cambridge: Cambridge University Press, 1966), p 269, for further discussion of 'measure zero'.

universe, although infinite, is only countably infinite.[23] This means that there will be an infinite number of possible universes that are *not* realized (just as there is an infinite set of numbers between zero and infinity which are not integers).

It is often blandly stated that if all possible universes existed the probability that one like ours would exist is 1. We should therefore not be surprised to live in one like ours, because only such an one would be observable. We now see that this claim is fallacious. Any subset of universes which exhibit the right properties to produce life is of measure zero in the space of all universes, and therefore occurs with zero probability, thus vitiating the explanatory value of the infinity. Furthermore, it is not possible that all possible universes co-exist, at least not as sub-universes in a single space-time overarching universe.[24]

4. A better physical theory?

The existence of infinitely many universes is often postulated as an alternative to 'design', the argument that the fine-tuning of the universe is evidence that the parameters in question were deliberately chosen by God with the express intention that the universe would give rise to life. Another strategy for avoiding design is the proposal that some better physical theory will sooner or later be found to explain the 'cosmic coincidences'.

The only viable candidate for a more comprehensive physical theory currently on offer is 'inflation'. Certainly this is gaining wide acceptance in the astrophysical community, so, to ground our discussion, inflation is the theory we shall concentrate on.

4.1 Inflation

Inflationary cosmologies began life in 1981 with Alan Guth's proposal that the universe underwent an early period of rapid, faster-than-light, accelerating expansion, as opposed to the deceleration of the standard model. On this picture, at about 10^{-35} seconds the size of the universe was about 10^{-25} cm. By 10^{-32} seconds it had expanded to at least 10 metres across. At that point inflation ended and the much slower classical, decelerating Big Bang expansion took

23 Mathematicians speak quite comfortably about varying 'degrees' of infinity. Indeed such degrees of infinity can be defined in a precise and rigorous way. The 'lowest' level of infinity is 'countable' infinity. A set is countably infinite if its elements can be put into one-to-one correspondence with the natural numbers, 1, 2, 3, … It turns out, rather counter-intuitively perhaps, that the rational numbers (fractions) can be put into such a one-to-one correspondence, but the real numbers (which include all non-recurring decimals like π and $\sqrt{2}$ as well as the fractions) cannot. In a well-defined sense there are therefore the same 'number' of fractions as natural numbers but more reals than fractions or natural numbers.

24 NB consideration here of the countability of finite regions strengthens Earman's earlier point about measure zero sub-universes – see Earman, *op. cit.*

over.[25] The expansion rate following the inflationary phase would settle very close to the critical value for a wide range of initial conditions, hence solving the flatness problem. Moreover, it is also claimed that inflation solves the horizon problem, because regions which might have interacted have been pushed very far apart. The universe visible to us is within a single co-ordinated region because any interactions took place at pre-inflationary times.[26]

Polkinghorne notes that it is still true that the inflationary universe only arises if the laws of physics follow a certain pattern, and that the 'anthropic fruitfulness' of such a universe is still to be explained.[27] Surely he is right. Those who believe that inflation removes the need for design seem to argue as follows:

(i) The initial conditions of the universe are very special, invoking our awe.

(ii) Theory X (in this case inflation) predicts the initial conditions.

(iii) Therefore, we are supposed to lose the awe which we had at the initial conditions.

Surely the right conclusion is instead

(iii) The awe which we had at the initial conditions is transferred to theory X.

Furthermore, whilst apparently, and impressively, solving the flatness and horizon problems, inflation does this at the expense of introducing other problems. First, the model needs fine-tuning! Inflation, and subsequent variants, rely on a choice among Grand Unified Theories (GUTs). GUTs seek to unite the fundamental forces of nature under conditions of high energy, such as obtain in the Big Bang, whilst allowing the forces to become physically separate in low energy conditions, such as result from the cosmic expansion (this process of force separation is also known as 'symmetry breaking'). These GUTs contain unknown parameters. The energy régime at which the GUTs apply is beyond that achievable in the laboratory, making it extremely difficult to choose between theories and to determine the parameters. Inflation gives rise to bubbles of the new phase of matter, in which the forces are differentiated, surrounded by the old phase (just like bubbles of steam in boiling water). In the original model the rate of bubble formation depends very sensitively on these unknown GUT parameters and it is assumed that the rate of bubble formation is very low.

25 G. Smoot and K. Davidson, *Wrinkles in Time* (London: Little, Brown and Company, 1993), p 180.
26 J. Leslie, *Universes* (London and New York: Routledge, 1989), p 30.
27 J. C. Polkinghorne, *Science and Creation: The search for understanding* (London: SPCK, 1988), p 23.

A far worse problem than the need for fine-tuning is the 'graceful exit problem', which leads to a fundamental conflict with observation. This concerns 'the difficulty of finding a smooth ending to the period of exponential expansion'.[28] This is because the energy in the bubbles is stored in the bubble walls and can only be released to fuel particle creation through many collisions of large bubbles. Unfortunately what happens, as pointed out by Stephen Hawking and others, is that the expansion speed is such that the bubbles remain in finite clusters in the expansion, rather than 'percolate' to form an infinite region. The result is that the universe is intolerably inhomogeneous and there is no mechanism for particle creation to start the big bang.

Andrei Linde[29] (and independently Andreas Albrecht and Paul Steinhardt[30]) realized that the graceful exit problem could be solved if the bubbles were so big that our universe is contained in a single bubble. This could be achieved by slower symmetry breaking. This model, known as the 'new inflationary universe', also needed fine-tuning! The 'slow roll-over' transition again depends on a special choice of parameters to achieve the required energy density function.

The new inflationary universe also had a serious problem pointed out by Hawking that the bubble would have to be bigger than the universe at the time.[31] Although this problem could in turn be resolved, a further one concerning too great variations in the temperature of the microwave background could not, and doubts were also raised about the kinds of phase transition required. And all this in addition to the model's need for fine-tuning![32]

Linde's 1983 'chaotic inflationary model'[33] seems to get round these problems by requiring no dubious phase transitions and it can also give satisfactory predictions for the microwave background temperature fluctuations.[34] It is chaotic because it starts from a random initial distribution of scalar fields.[35] These scalar fields determine the different modes of symmetry breaking (and hence different-looking laws of physics) in different domains. In this way we end up with a 'cluster of causally disconnected mini-universes' with (supposedly) every sort of universe existing somewhere, ie we are back to a many-

28 Alan H. Guth, 'Inflationary Universe: A Possible Solution to the Horizon and Flatness Problems', *Physical Review D* 23 (1981), pp 347-356.
29 A. D. Linde, 'A New Inflationary Universe Scenario: A Possible Solution of the Horizon, Flatness, Homogeneity, Isotropy and Primordial Monopole Problems', *Phys. Lett. B* 108 (1982), p. 389.
30 A. Albrecht and P. J. Steinhardt, 'Cosmology for Grand Unified Theories with Radiatively Induced Symmetry Breaking', *Phys. Rev. Lett.* 48 (1982), p 1220.
31 S. W. Hawking, *A Brief History of Time* (London: Bantam, 1988), p 131.
32 A. H. Guth and P. J. Steinhardt, 'The Inflationary Universe', *Scientific American* 250, No. 5 (1984), pp 90-102; E. McMullin, *op. cit.*, 385; Leslie (1989), *op. cit.*, pp 29-33.
33 Andrei Linde, 'Particle Physics and Inflationary Cosmology', *Physics Today* (September 1987), pp 61-68.
34 Hawking, *op. cit.*, p 132.
35 McMullin, *op. cit.*, p 385.

worlds type of scenario. Our type of universe will arise for particular choices of scalar field *Ø*.

In superstring theories, which pertain to the first 10^{-43} seconds of the universe and remain highly speculative, the fundamental particles are of higher dimension than we experience, but these dimensions get compactified to those we know. Linde speculates that compactification may lead to a variety of space-time dimensions in his mini-universes.

Inflation has developed into a quite massive industry, with many papers being produced – far too many, Alan Guth admits, even for him to keep up with! This is perhaps surprising when the observational evidence is lacking and the GUTs remain speculative hypotheses virtually untestable in the laboratory. Guth notes that even the standard model of particle physics needs the input of arbitrary parameters to ensure that the results come out right. For example, the ratio of 160,000:1 for the W^+-electron mass ratio and the ratio of the gravitational force to the electrostatic force between two protons of 10^{36}:1 are both rigged.[36]

The fine-tuning required by inflationary models is a serious drawback since inflation was meant to explain fine-tuning! In this context a significant example would be that of the cosmological constant, Λ. This is essentially a repulsive force originally introduced by Einstein into his equations of general relativity in order to give a static universe, but subsequently abandoned when the expansion of the universe was discovered by Hubble. Until recently physicists had assumed that Λ was zero, and observation certainly puts very severe limits on it. However, physicists now believe that the energy density of the quantum vacuum gives rise to a cosmological constant, which powers inflation. Unfortunately the calculated magnitude of Λ is 10^{120} times greater than is compatible with observation (and with a life-producing universe for reasons similar to other cases of fine-tuning).

Even Linde's chaotic 'eternal inflation' requires very specific, though highly speculative, assumptions about the physics which applies at extreme densities. It is beyond the scope of this paper to provide probability calculations for inflationary models comparable to those for density and isotropy we have discussed in detail for the standard Big Bang. However, it does appear from our limited discussion that freely assignable parameters in the Big Bang are merely transferred to free parameters in the inflationary model. Indeed Barrow and Tipler make just this point: 'Why should we bother conjuring up the *Ø* ≈ constant state necessary for inflation to occur? Why not argue that in a chaotically random, infinite initial data set there *must* exist a large, virtually homogeneous and isotropic region, expanding sufficiently close to flatness ($\Omega_0 = 1$) so that after fifteen billion years it looks like our universe?'[37] Whether the values of parame-

36 Guth (1997), *op. cit.*, pp 238-239.
37 Barrow and Tipler, *op. cit.*, p 431.

ters required for life in inflationary mini-universes form a subset of zero measure or finite measure within the set of possible values is a point worthy of further exploration. It would appear that my point about the set of realized universes above a given size being of measure zero applies equally well to Linde's chaotically produced universes as to the original Carter scheme.

Besides the profligacy of many world scenarios, in the case of inflation we also witness the *ad hoc* nature of much of the theorizing, seemingly in order to avoid design, though rationalized via the indifference principle.

Even if attempts to explain the coincidences in terms of some more fundamental theory were successful, as noted above, that would not vitiate the argument from design which the coincidences support: it would merely put the argument back a stage. For these fundamental laws are not necessary a priori. They could be different, so it is still equally valid to ask, 'Why are these fundamental laws so special that they have the consequences they do for the parameters we have been talking about?'

4.2 Observational problems with inflation

When it comes to predictions made by inflation, we are faced with a fundamental problem. Because inflation predicts that $\Omega_0 = 1$, it therefore seems to yield a value for the age of the universe of only about 8 billion years[38]. This is inconsistent with models of stellar evolution. In particular, there are globular clusters (galaxies of a particular kind) which are believed to be up to 15 billion years old. Including 'dark matter' of uncertain identity, current best estimates of Ω_0 come out at about 0.3.[39] It is only theory which might lead one to expect $\Omega_0 \sim 1$,[40] and even then some aspects of big bang theory imply a low value of Ω_0. Thus nucleosynthesis calculations of light element abundances yield a constraint on Ω_0 of $0.011 \leq \Omega_0 \leq 0.11$.

It is possible that inferences from recent observations of supernovae in very distant galaxies might modify the above. These seem to be further away than their redshifts would indicate.[41] One possible interpretation of this is that the expansion of the universe is accelerating with time, indicating a positive cosmological constant (though still vastly smaller than quantum vacuum calculations). The contribution this makes to Ω_0 (~ 0.6) might be consistent with flat space ($\Omega_0 = 1$).[42] An alternative strategy of inflationary theorists is to abandon one of the chief predictions of inflationary theory, namely flatness, and opt for

38 Guth (1997), *op. cit.*, p 53.
39 Lawrence M. Krauss (1999), 'Cosmological Antigravity', *Scientific American*, January 1999, pp 34-41.
40 Peter Coles, 'The quest for Omega', *Astronomy & Geophysics* 39, No. 5 (1998), pp 20-23.
41 Craig J. Hogan, Robert P. Kirshner and Nicholas B. Suntzeff (1999), 'Surveying Space-time with Supernovae', *Scientific American*, January 1999, pp 29-33.
42 Krauss (1999), *op. cit.*, p 36.

'open inflation'.[43] Again, open inflation depends on a particular choice of potential energy function in order to give a slightly curved, rather than strictly flat, space. None of these latest findings of observation or theory can be regarded as definitive.[44]

A further serious problem is that most GUTs predict that the proton is unstable with a half life of between 10^{27} and 10^{31} years. This is one of their few tangible predictions but proton decay is immensely difficult to detect. As Guth himself notes, the evidence is against proton instability, with one experiment reporting no certifiable decays, implying that the half life must be at least 2×10^{32} years.[45]

5. Further problems with the many-universes hypothesis

There are a number of problems of a more general, philosophical nature with regard to the postulation of infinitely many universes, and to these I now turn.

5.1 Testability

One of the problems associated with the many-universe hypothesis in its various forms is its lack of testability. Experimental or observational verification is at the heart of scientific method, yet this seems to be lacking in this case even in principle. In science such verification does not have to be direct. Some exotic particles are believed to exist because of their effects. For example the Higgs particle is predicted to exist in order to give mass to other particles, and its existence implies measurable effects in many high energy scattering experiments, even where the Higgs particle itself is not produced. Although not yet directly observed, the measurable effects already put limits on its mass.

In the case of many universes which are sub-universes in an infinite spacetime, there cannot even be indirect observational evidence of the other universes' existence. There is a barrier imposed by the finite speed of light which means that there is a natural horizon from beyond which signals cannot yet have reached us. This applies equally to the causally disconnected mini-universes produced by chaotic inflation. By definition a causally disconnected universe cannot cause any effects in our own universe.

43 Martin A. Bucher and David N. Spergel (1999), 'Inflation in a Low-Density Universe', *Scientific American*, January 1999, pp 42-49.
44 Research in this area is intense and ongoing. For results from the balloon-borne telescope BOOMERANG see A. Melchiorri et al, 'A Measurement of Ω from the North American Test Flight of BOOMERANG', preprint available at http://xxx.lanl.gov/archive/astro-ph where one chooses November 1999 and paper 9911445. These authors claim to constrain total Ω (including matter and cosmological constant contributions) to the range $0.85 < \Omega < 1.25$ at the 68% confidence level. This would be consistent with flat space.
45 Guth (1997), *op. cit.*, p 238.

As Polkinghorne points out, this means that the existence of many universes provides, not a scientific, but a metaphysical explanation of the fine-tuning of this universe. The reason he says this is that the existence of these worlds is completely insensitive to any empirical data – they are unobservable. The fact is that, whether we like it or not, we are faced with alternative metaphysical explanations, eg either the universe is unique and a brute fact, or there are infinitely many universes, or the universe is designed (we do not consider the logical possibility that God designed and created infinitely many universes).

5.2 The nature of the many universes and their plausibility

It is worth contemplating for a moment what we are being asked to swallow if we are to believe in infinitely many universes. Let us ignore for a moment the measure zero problem and assume that a finite fraction of universes are life-bearing. It is still the case that the vast majority of universes will be totally dead. Of the minute proportion bearing any resemblance to ours, there will be some in which an 'I', virtually identical with me up to now, fell under a bus before completing this paper; some where there is even more unimaginable evil and suffering than in this one; some where conditions are benign and Eden-like; some in which gorgons or unicorns or wyverns actually exist; and so on, and so on. Just simply trying to contemplate the infinitely many universes makes us realise how bizarre the hypothesis is.

5.3 What kind of explanation is provided by many universes?

Because of its lack of observable consequences, the appeal to many universes provides a metaphysical explanation for life rather than a scientific one. But the theory is also unscientific in another sense. This is because it provides a 'catch-all' kind of explanation.

Many world theories remind me of the argument put forward by Christian fundamentalist Philip Henry Gosse in the last century to reconcile a literal reading of Genesis with geology. Nature is really cyclical and God created it instantaneously in mid-cycle – Adam with a navel, trees in Eden appearing to be 50 years old, fossil birds with half-digested food in their mouths![46] Anything can be explained on this basis and no observation can possibly contradict the theory. Many worlds theories are equally sterile. Yes, they explain everything, by the simple formula, 'If it can happen, it will happen somewhere sometime, so don't be surprised!' But they cannot be falsified: they are completely insensitive to the empirical facts. This is a far cry from the normal kind of explanation sought in science. Scientific naturalist Richard Dawkins ought to reject it since this is precisely why he rejects religion, eg: 'Scientific belief is based on publicly checkable evidence. Religious faith not only lacks evidence; its inde-

46 B. Ramm, *The Christian View of Science and Scripture* (London: Paternoster, 1955), pp 133-134.

pendence from evidence is its joy, shouted from the rooftops…'[47]. But of course, as we have seen, one must adopt a metaphysical position of some kind, whether it be infinitely many universes, just one, or theism. However, there is yet a further problem with many-worlds.

Many-worlds theories provide a disincentive to do science. Any uncomfortable observation can be greeted with the cry, 'We just happen to be in a universe which has that feature.'

Sometimes the charge of providing a disincentive to do science has been levelled at the theistic hypothesis. However, in that case the charge does not stick. The theistic hypothesis might lead one to expect a universe with certain features, eg that it exhibits purpose and a moral order. Moreover, the idea that the universe is the good creation of God has historically led to a thoroughgoing motivation to do science.[48] The many-universes hypothesis gives us no reason to expect any particular features in this universe, apart from the fact that it should be a universe which we can observe.

5.4 How much fine-tuning is there in our universe and why does order persist?

If the many-worlds hypothesis is to be transformed from the realms of metaphysics to physics, the scientific naturalist must surely provide us with some observational consequences. Dennis Sciama has suggested that, under the many-universes hypothesis, 'we would not expect our universe to be a more special member of the ensemble than is needed for our development', whereas by contrast 'a unique universe might be expected to be very special indeed'[49]. This is a highly significant difference, albeit one which does not involve any causal contact with, or observation of, other universes.

Unfortunately for the scientific naturalist the news on this potential observational difference between theories is not good for multiple universe proponents, for Roger Penrose has suggested that our universe is indeed more special than would pertain on a many-universes hypothesis. Penrose notes that, regarding the initial entropy of the universe, ie the amount of order the universe started off with, a precision of

1 part in $10^{10^{123}}$

is required. However, the order required to manufacture the solar system and its inhabitants, simply from the random collisions of particles, is vastly less

47 Richard Dawkins, *Daily Telegraph Science Extra* (September 11th 1989), xi; this idea is often repeated in Dawkins's writings.
48 As argued for example by R. Hooykaas, *Religion and the Rise of Modern Science* (Scottish Academic Press: Edinburgh, 1972); and by Stanley L. Jaki, *Science and Creation: From eternal cycles to an oscillating universe* (Scottish Academic Press: Edinburgh, 1974).
49 Sciama, *op. cit.*, p 109-111.

than this, though still very great[50] – something like

1 part in $10^{10^{60}}$

Many worlds thus offers us an explanation of why there is a universe fine-tuned for life but the ultra-fine tuning our universe actually possesses is an unexplained brute fact. Possible ways round this problem include inflation, as discussed above, and about which Penrose is especially dismissive, and vague appeals to Mach's principle (which concerns the origin of inertia) to link local and global structure.[51]

A further problem concerns the persistence of order in this universe. Presumably in an infinite ensemble of possible universes, many will be identical to ours up to, say 31st October 2000, and then dissolve into chaos. The question, 'Why does the order our universe possesses persist?' is one which finds no answer from the notion that ours is simply a random selection from an infinite ensemble.

Imagine a monkey sitting at a type-writer for untold aeons. The animal is vastly more likely to produce 'To be or not to be' at some stage and then sink into chaos than to produce the whole of *Hamlet*. Similarly, random selection of universes from a vast ensemble is far more likely to produce a solar system embedded in chaos, or a finely-tuned epoch followed by chaos, than a universe with the order, and persistence of that order, which our universe actually possesses. In contrast theism offers us the explanation that total order, in both space and time, is to be expected from the creation of a good God.

5.5 Prior probability of the existence of many universes

We have seen that the many-universes hypothesis is defective in explanatory power. But let us for the moment ignore this and assume that it provides an unimpeachable explanation for the existence of this life-bearing universe. Supposing theism also to provide an explanation, in comparing the hypotheses one would have to evaluate their prior probabilities. Richard Swinburne argues that God is a simple hypothesis and of high prior probability.[52] We do not have space to critique this thesis here in detail; as stated in our introduction, we are more concerned in this paper to critique the many-universes hypothesis. Naïvely, it would seem that the hypothesis of many-universes is distinctly non-simple and uneconomical – and this has been argued by Swinburne, Polkinghorne, Leslie and other authors. I would argue that it is not an hypothesis which ought to commend itself to scientists, for whom the Ockham's razor

50 R. Penrose, *The Emperor's New Mind: Concerning Computers, Minds and the Laws of Physics* (Oxford: Oxford University Press, 1989), p 354.
51 Davies (1982), *op. cit.*, p 129.
52 R. G. Swinburne, *The Existence of God*, Revised Edition (Oxford: Oxford University Press, 1991).

principle has been a valuable tool in comparing hypotheses. Roger Penrose is a scientist who recognises the de-Ockhamite nature of Everett's many worlds interpretation of quantum theory, and presumably Carter and Wheeler-type theories suffer similarly.

If on these grounds the many-universes hypothesis is rendered immensely improbable, and the God hypothesis much less improbable, and both are taken to have equal explanatory power, a simple Bayesian analysis[53] would lead us to believe that the existence of God given fine-tuning of the universe and other background knowledge is greater than the existence of many-universes given the same evidence.

6. Conclusions

I believe that the above considerations, taken together, mount a cumulative case against the postulation of infinitely many universes as an alternative to design. First, the infinitely many universes are invoked to explain the fine-tuning of this one. They fail to do so because (i) the existence of infinitely many universes may itself be improbable; (ii) the probability of the occurrence of fine-tuning in any universe or sub-universe of an ensemble would appear to be zero; and (iii) the realisation of all possible universes in an ensemble is impossible.

Inflation does not solve the problem because (a) the awe one felt at the finely-tuned initial conditions of the universe is now transferred to the theory which produced those numbers automatically; (b) inflation needs fine-tuning anyway; and (c) the infinitely many universes produced by inflation suffer from the same problems as those in the original scheme. In any case physicists in the inflation industry seem to be pursuing metaphysics rather than physics, since the GUTs which are utilised in inflation are untestable in the laboratory, and inflation seems to be contradicted by some fundamental observations.

That brings us to further philosophical problems suffered by many worlds theories. The many worlds are unobservable. Therefore the postulation of their existence is immune to empirical investigation, ie this is a metaphysical rather than scientific hypothesis.

Consideration of the bizarre nature of the universes which we are expected to believe exist in the ensemble further adds to the implausibility of the hypothesis. Furthermore as a 'catch-all' type of explanation they could potentially discourage scientific progress. Hard-nosed scientific naturalists should reject their existence.

One suggestion for a difference between a unique universe and a universe which is a member of an infinite ensemble is that the former would not be

53 Bayes's theorem in probability theory essentially enables one to calculate the probability of an hypothesis given certain evidence in terms of the prior probability of the hypothesis and its (mathematically well-defined) explanatory power in relation to the evidence.

expected to be more finely-tuned than is necessary for life. Ours seems to be vastly more special than required. Moreover the persistence of order in our universe is unexplained on the many-universes hypothesis.

Finally, even discounting the above, considerations of simplicity and economy would lead one to assign the existence of infinitely many universes a low prior probability compared with the existence of God. A simple Bayesian analysis would then lead one to conclude that the probability that God exists given fine-tuning and other background knowledge is greater than the probability that infinitely many universes exist given the same evidence.

Acknowledgement

I am grateful to an anonymous referee for providing detailed and helpful comments on an earlier draft of the paper.

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