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Are anthropic arguments, involving multiverses and beyond, legitimate?[1]

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25.1 Introduction

Though there has been much discussion of the Anthropic Principle (AP) over the last 35 years or so, it is still a very tantalizing and controversial subject, on the boundary between scientific cosmology and philosophy. As new scenarios and theories emerge for describing and explaining the origin of our observable universe, AP considerations inevitably surface. So, a critical review of the meaning and status of the AP – as well as of the directions anthropic arguments are now taking, their legitimacy and the fundamental philosophical issues involved – is perhaps warranted.

The anthropic idea was first introduced in 1961 by Robert Dicke, who noted the comparability of several very large numbers when fundamental physical constants are combined, and suggested that this might be connected with the conditions necessary for the presence of observers [1]. A decade later, Barry Collins and Stephen Hawking, realizing that the initial conditions for our universe seemed to be very special, suggested the following: 'The fact that we have observed the universe to be isotropic is therefore only a consequence of our own existence' [2]. One way of explaining this, they speculated, would be to have an 'infinite set of universes with all possible initial conditions' – thus anticipating the way many cosmologists now interpret the AP.

The following year, Brandon Carter – obviously stimulated by Dicke's seminal suggestion, since he referred to it several times in his paper – introduced the term 'anthropic principle'. His initial formulation of the AP was as follows: 'What we can expect to observe must be restricted by the conditions necessary for our presence as observers' [3]. Subsequently, Carter

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made a distinction between the 'weak' and 'strong' forms of the AP [4]. However, these terms have been used in many different ways, corresponding to similar but inequivalent formulations of the AP, which has led to considerable confusion. (In summarizing the origin and early history of the AP, I have followed ref. [5].)

First, it is important to recognize that the AP is not really a principle. Its fundamental content is that our universe *appears* to be fine-tuned for life and for consciousness – or perhaps, more precisely, for complexity. This appearance of fine-tuning originates from analysis of and reflection upon the results of a very broad range of experimental and theoretical investigations, indicating the extreme sensitivity of our universe's capacity for generating and sustaining complexity to very small changes in the laws and constants of nature, in the properties of the basic constituents of matter and in the initial conditions of our universe (for example the expansion rate or mass–energy density at some early time). A classical compendium on the AP, including a wide range of examples of fine-tuning, is given in ref. [6]. Changing the value of any of a large number of parameters even a little would so change our universe as to preclude the emergence of complexity – and therefore life and consciousness. The different formulations of the AP – and all the controversy which surrounds it – really trace back to the issue of what conclusions can be legitimately drawn from this apparent fine-tuning and what presuppositions are justifiable.

25.2 Weak and strong versions of the AP

From the earliest AP discussions, it was recognized that there are both weak (WAP) and strong (SAP) formulations. The weak versions assert that, since there are observers in our universe, its characteristics, including the values of the fundamental constants and the initial conditions, must be consistent with the presence of such observers (see ref. [5], p. 372). Thus the existence of observers acts *a posteriori* to select values of the fundamental constants and other important parameters. These versions of the AP just specify the conditions which have been fulfilled for complexity and life to arise – they do not explain how or why those conditions have been realized. In fact, some writers describe the WAP as just a selection effect.

Strong versions of the AP go much further: they asssert that our universe – right from the start – *had* to be such that the appearance of observers is inevitable. That is, they purport to account in a basic way for our universe being life-bearing. For instance, one version of the SAP would be as follows: 'The universe must be such as to admit the existence of observers within it at some stage' (see ref. [5], p. 376). Here, the words 'must be' indicate *a priori* necessity – not the consequence of there being observers now [5]. The eventual emergence of observers somehow explains why the universe possessed its initial characteristics – it has these characteristics *in order* that observers will appear.

From this, it is clear that some evidence or justification for the requirement of having observers must be provided. Many – but not all – such formulations do this by incorporating an explicit or implicit finality or purposiveness in our universe, which goes considerably beyond what can be concluded from the natural sciences themselves. Sometimes this is done on philosophical grounds, sometimes on theological ones.

25.3 Two principal versions of the SAP

Over the past decade, two very different – and certainly inequivalent – versions of the SAP have been discussed. The first is essentially the way it was first formulated: the characteristics of our universe are chosen to ensure the appearance of life and observers. But this raises the issue of what or who tailors the laws of nature and the fundamental constants in this way, which immediately goes beyond the domain of science.

Thus, a second version of the SAP has become popular, which – at first sight – keeps it within the realm of the natural sciences. This asserts that our universe – or our domain – is one of a large, actually existing, ensemble of universes or domains, each having different laws, fundamental constants and initial conditions. In fact, a frequent, but much less adequate, specification of this ensemble is that it contains all possible universes. The presupposition here is that there exist universes or domains representing the full range of possibilities [7]. There is then some probability that any one of the these really existing universes will allow the emergence of life and observers.

This, in one sense, *does* explain why our universe is life-bearing, providing the presuppositions can be justified and providing a meaningful probability measure can be defined on the space of the ensemble [7,8]. But this explanation is obviously incomplete. It immediately invites further understanding of the process by which this particular cosmic ensemble emerged and why it contains universes or domains which allow for the emergence of complexity. And if we can substantiate the operation of such a fertile cosmogonic process, then we may certainly want to seek an explanation for its origin, however we have come to understand and model its scientifically accessible underpinnings.

Thus, this formulation of the second version of the SAP clearly manifests its inequivalence with the first version, as well as the extraordinarily strong presuppositions on which it rests. In fact, if we use it to argue from the presence of observers in our universe to the existence of a certain type of ensemble of universes, then it seems to reduce to the WAP. However, the characteristic feature of this version – the existence of at least a large subset of possible domains, some of which are life-bearing – really takes us beyond the WAP. It solves the fine-tuning problem, but does not explain in any *a priori* way why our universe should have observers in it at some stage, much less why the ensemble of all existing universes should include some which admit their emergence.

It is certainly true that, if the ensemble exists, then our universe itself *must* exist. But this is obviously a very weak form of the SAP. The 'necessity' of the existence of our life-bearing universe rests on the presupposed existence of all possible universes, or at least of a large number of universes of a broad range of types. Clearly – to achieve equivalence with the first version of the SAP – we require an adequate explanation for the necessity of the encompassing ensemble – or at least some explanation or justification for its *de facto* realization. Anchoring this version of the SAP really requires some compelling cosmological account of the ensemble, which is by no means unique [8], or – even better – of why it *must* exist. This would make the multiverse version of the SAP equivalent to the first version. However, the multiverse version will never be able to go that far, since it strives to avoid scientifically inaccessible causes and explanations.

Another strong reason for stressing the multiverse version of the SAP is that we now recognize that there are a number of natural ways in which an ensemble of actually existing 'universes' could arise in quantum cosmology: for example, Andrei Linde's chaotic or eternal inflation scenario [9]. However, as we shall see later, such suggestions are not yet very secure. Furthermore, there are serious physical and philosophical issues which need to be resolved before they can be regarded as evidential [7, 8]. Until then, this version of the SAP, despite its popularity, must be relegated to the category of (at best) informed cosmological speculation.

In discussing the multiverse version of the SAP more fully, several points should be emphasized.

- As it now stands, it does not provide either an adequate or complete – let alone an ultimate – scientific explanation. Only strong evidence for – and an adequate description of – the process by which the ensemble emerges can do that. To constitute an ultimate explanation, that process must further be shown to be necessary, an understandable accident that was always a possibility, or intended by some transcendent agent for a specific reason. But the scenarios by which the ensembles may have originated are still very uncertain and *ad hoc*, so it is impossible to envision them as necessary or providing any fundamental or final philosophical explanation.

- Once we grant that the ensemble embracing our universe really does exist, then saying this ensemble explains how our universe is fine-tuned for life does have some meaning and validity – in terms of the probability of any one of the universes being like our own. But this requires that there be some well defined distribution function on the space of all possible universes, with an associated probability measure [7, 8].
- It is very difficult, if not impossible, to define a really existing ensemble of all possible universes in a meaningful way which avoids infinities [7, 8]. Also, in order for the ensemble idea to work, it cannot just be an ensemble of conceptually possible universes – it must really exist. Any power this version possesses relies on the universes or domains having a *bona fide* existence. Possible or potential existence has no *a posteriori* implications and explains nothing (see ref. [5], p. 371).

25.4 Scientific status of ensembles of universes

We have seen that the cosmic ensemble version of the SAP is not as strong as the original version. It is incomplete, requiring understanding of the process generating the ensemble. Furthermore, even with this understanding it cannot provide an ultimate explanation of the fine-tuning. Nevertheless, we can accept it such as it is, acknowledging that it may become more compelling as our understanding of the early universe improves. With this in mind, we shall reflect in more detail on what has come to be known as the 'multiverse' proposal [7].

First, as emphasized in Section 25.3, there are well supported but still preliminary indications that whatever process or event gave birth to our universe or domain also generated a large number of other universes or domains. This is why so many cosmologists and theoretical physicists are taking the idea seriously. Several lines of current research and speculation are probing, accumulating evidence for and attempting to model the primordial emergence of such an ensemble. Besides Linde's chaotic inflationary programme, there are a number of others, including those of Steven Weinberg [12, 13] and Jaume Garriga and Alex Vilenkin [14–16], who have suggested that random quantum fluctuations generated during inflation could have led to a large number of different cosmic regions, each with a different vacuum energy density. All of them would then evolve differently, with significantly different physics perhaps emerging in subsequent (GUT and electro-weak) spontaneous-symmetry-breaking transitions. Recently, superstring theory has provided prospects for generating multiverses. Some versions of it provide 'landscapes' populated by extremely large numbers of vacua, each of which could initiate a separate universe domain [17–20].

Ensembles of universes can also be generated in many other ways: for example, through decoherence from the mixed quantum gravity states which may have characterized the Planck era, or through the re-expansion into different domains of regions which had earlier collapsed to form black holes [21]. In the latter case, Lee Smolin envisions a type of natural selection operating on the resulting ensemble of expanding regions, rendering a significant subset of them bio-friendly. Finally, ensembles of universes can develop from the cosmic branching allowed by the Everett–Wheeler interpretation of quantum theory. In a recent popular article [22], Max Tegmark presents the case for multiverses and describes the different processes through which they may arise. All such scenarios are scientifically plausible. But, if they are to be taken seriously, they must continue to receive support from theoretical and observational advances in early and late universe research.

Even when such multiverse scenarios are better established, their deployment in anthropic arguments requires a proper characterization of the ensembles, with well defined (finite) probability distribution functions and meaningful probability measures [7]. If all these requirements are eventually fulfilled, there still remains the philosophical question of the legitimacy of appealing to ensembles whose existence is not testable. This raises the more fundamental issue of what kinds of testability are appropriate in the natural sciences. What concept of testability, if any, can legitimate reliance on cosmic ensembles for scientific conclusions? It is important in this regard to note that there is a general consensus that the acceptability of any appeal to multiverses depends on there being a testable theory which independently predicts their existence. This requirement is crucial and must be kept in mind in evaluating these theories and in contemplating their use in anthropic arguments.

That understood, are there concepts of testability which would enable multiverses to be scientifically legitimate? I believe that there are. One very compelling approach is that of 'retroduction' or 'abduction', first described in detail by the American philosopher of science C. S. Peirce [23, 24] and more recently emphasized by Ernan McMullin [25–28]. 'Retroduction' is inference from observed consequences of a postulated hypothesis to the explanatory antecedents contained in the hypothesis – that is, it is an inference based on the success or fruitfulness of an hypothesis in accounting for and better understanding a set of phenomena. Scientists construct hypotheses, which are then used to describe and probe the phenomena more profoundly. As they do so, they modify – or even replace – the original hypotheses in order to make them more fruitful and more precise in what they reveal and explain. As McMullin himself emphasizes, the hypotheses may often involve the existence of hidden properties or entities (like multiverses) which are basic to the explanatory power they possess. As the hypotheses become more fruitful in explaining a set of natural phenomena and their inter-relationships, and more central to the research of a given discipline, they become more reliable as accounts of reality. Even if the hidden properties are never directly detected, the success of the hypotheses which rely on them indirectly leads us to affirm that either they – or something very much like them – must exist. We can regard hypotheses as fruitful or successful if they: (1) account for all relevant data (empirical adequacy); (2) provide *long-term* explanatory success and stimulate productive lines of further enquiry (theory fertility); (3) establish the compatibility of previously disparate domains of phenomena or facts (unifying power); and (4) manifest consistency (or correlation) with other established theories [29].

This way of looking at how science works provides us with a criterion for testing theories which imply the existence of a multiverse. If such a theory successfully explains various aspects of what we see and measure in our universe, and continues to provide a secure basis for further cosmological understanding, then that strongly supports the existence of such universes, even though we may never be able to detect them directly. This critierion can be summarized as: Does the multiverse theory lead to greater intelligibity of the reality around us?

25.5 Using anthropic arguments in scientific cosmology

Setting aside for the time being the controversial SAP and multiverse ideas, we now turn our attention to a more modest application of anthropic arguments: their use in deciding purely scientific issues in cosmology. The extreme sensitivity of the character of our universe to slight changes in fundamental constants, the properties of fields and particles, initial conditions, etc. shows that – with enough knowledge – we can determine the values of these parameters on anthropic grounds.

The general form of such arguments is very straightforward. For life to exist in our universe, a given parameter A must be in the range A_1 to A_2. Life exists in our universe; therefore the value of A *is* between A_1 and A_2. However, it is important to recognize that this is a *necessary* but not *sufficient* condition for life. The main idea is that, using such anthropic arguments, cosmology can determine the values of key parameters without directly measuring them. This would be important whenever we did not have the capability of measuring the parameter A.

Three questions arise in considering such arguments: (1) Are they legitimate? (2) Do we need them in cosmology? (3) Do they suffice from a scientific point of view? The first question is easy to answer – the logic of the argument is clearly valid, so anthropic arguments are certainly legitimate. Establishing the major premise requires a great deal of theoretical work, however, and usually involves assumptions about what is essential for the emergence of life and how those essentials can be realized. Furthermore, as discussed below, such arguments demand a more complete understanding of the underlying 'laws of nature' which are at the basis of the parameter constraints.

Moving to the second question, we can say that, in some circumstances, we may 'need' such arguments or at least find them 'useful' until better scientific evidence is available. One of the drawbacks of anthropic arguments is that establishing that a given parameter must have a certain range of values for life normally takes a great deal of scientific investigation. The better and more reliable the underlying scientific theory enabling us to make that determination, the better and more reliable the anthropic arguments we can construct. But often, by the time we have reached that stage, we already know or have a good idea of what range of values a certain parameter has, independently of anthropic arguments. From this we might conclude that, whatever the state of our knowledge, anthropic arguments can always serve as consistency checks on conclusions we have reached by other means.

The answer to the third question – Are anthropic arguments sufficient? – is obviously no from a scientific point of view. The anthropic connection never stands by itself, but reflects a deeper and more fundamental set of relationships in the laws of nature – whether or not we understand them. Those deeper and more fundamental relationships will always be vulnerable to scientific determination or philosophical reflection, at least in principle.

25.6 Undermining anthropic arguments

The difficulty of reliably establishing the ranges of parameter values necessary for life in our universe is illustrated by the work of Anthony Aguirre [30]. He has demonstrated that there are more regions of cosmological parameter space which allow life than we had originally suspected. And some of these regions are isolated from each other.

This is true, for instance, for the cosmological parameter η, which is the ratio of the number density of baryons (protons and neutrons) to the number density of photons. This is a measure of the cosmological entropy density. In our universe, $\eta \approx 10^{-9}$, which indicates that the early universe was very hot. If we found $\eta \approx 1$ instead, our universe would have started out relatively cold. Such universes are referred to as 'cold big bang' models. Aguirre has shown that several classes of such models allow the formation of stars, and hence the production of heavy elements, and would therefore be open to the emergence of life. This set of bio-friendly cosmological models is disconnected in η-parameter space from the hot big bang models.

This unexpected development undermines anthropic arguments somewhat – or at least makes the conclusions we can draw from them less certain. We originally expected anthropic arguments to yield tightly constrained parameter ranges for life. But now, in at least some cases, we find that these ranges are somewhat broader and perhaps even disconnected from one another. We do not know if there are other cases of this sort. But if we are going to rely on such arguments, we have to be sure that we have theoretically explored the full range of cosmological parameter space for isolated bio-friendly islands.

Despite this uncertainty, we can still legitimately assert that: (1) the conditions for life have been fulfilled; and (2) the values of the parameters which characterize our universe must fall within certain relatively narrow ranges for these conditions to be maintained. However, given Aguirre's results, we need to be cautious in asserting precisely what these bio-friendly ranges are.

25.7 The SAP, final theories and alternative universes

Any version of the SAP presupposes that the laws of nature that characterize our universe could have been significantly different in terms of at least one of the following: initial conditions, particle properties (for example masses), fundamental constants (for example coupling parameters) and laws of nature (for example different fundamental interactions). The key point is this: if a 'final theory' or 'a theory of everything' specifies a unique universe – that is, a universe with precise laws, values of the fundamental constants and initial conditions – then there is no need for, or even the possibility of, anthropic arguments. The universe could not have been any different without violating the theoretical consistency 'imposed' by the final theory. However, even if this were the case, we would – from most philosophical points of view – still need a sufficient explanation for the existence of the universe and for its precise order.

The extreme consequence of a final theory that specified a unique universe, accounting for all its characteristics precisely and exhaustively, is difficult to imagine. It is just possible that a final theory could achieve this. However, it seems very unlikely that it would fully determine the conditions for the universe as it exited the Planck or inflationary era, for example its expansion rate at this point and the initial entropy. In other words, to make anthropic arguments unnecessary scientifically or vacuous philosophically, we would need an adequate theory of initial conditions. We would also need a theory to specify the parameter values after spontaneous symmetry-breaking transitions.

An alternative would be a process, or a combination of processes, which renders the universe which emerges from the quantum cosmological womb *insensitive* to initial conditions. If such processes operated in the early universe, there would be no need for us to know or to explain the initial conditions in order to model how our universe evolved to its present form. It would have done so, no matter what the initial conditions, due to the 'smoothing' action of these primordial processes. They would bring the infant universe to the primordial homogeneity, no matter how it 'began'. This attractive suggestion is sometimes referred to as the 'Cosmological Indifference Principle' (see ref. [5], p. 359).

Two proposals for such 'indifference-rendering' are the chaotic cosmology programme of Charles Misner [31] and the (now almost orthodox) inflationary scenarios. In chaotic cosmology, Misner envisaged viscous forces dissipating any initial anisotropies to yield an isotropic expanding universe with very smooth spatial sections. It was eventually realized that such processes cannot accomplish this, but inflation is now invoked to fulfil this function.

As long as inflation can be initiated, it severely attentuates all initial inhomogeneities and anisotropies, ensuring that the resulting domain is nearly flat, causally connected and smooth on very large scales. At the same time, it preserves the low-amplitude quantum fluctuations of the early universe. These gradually develop into galaxies and clusters of galaxies but within a large-scale, nearly homogeneous background. Although it now appears that inflation is also incapable of rendering our universe insensitive to initial conditions – because the onset of inflation itself seems to require very special initial conditions [32, 33] – attempts to realize the Cosmological Indifference Principle persist.

In fact, the multiverse idea may itself be interpreted this way (see ref. [5], p. 285). Taken alone, our universe requires very finely tuned initial conditions. Placing it in a really existing ensemble of other universes or domains seems, at first sight, to dispense with the need for that fine-tuning. However, as we have seen, they are certainly not uniquely specified. Accounting for the existence and specific character of our multiverse requires an adequate generating process or principle, which must explain the particular distribution function specifying it. This may itself require fine-tuning.

In comparing the two opposing philosophical perspectives represented by the anthropic and indifference principles, McMullin [5] points out that the first inevitably involves mind and teleology (see ref. [5], pp. 259–367). This always threatens to take us beyond the domain of natural science to philosophy and theology. The indifference preference studiously avoids any direct appeal to such influences, relying instead on the dynamics inherent in and emerging from the mass–energy distribution itself [8].

25.8 The SAP and transcendent explanations

We have considered the legitimacy and scientific potential of anthropic arguments and we have come to a number of conclusions about the philosophical reach of the two versions of the SAP. We summarize these in five statements.

- Leaving aside the issue of an ultimate explanation, as long as the selection of initial conditions and the fundamental constants cannot be explained by some physical process or relationship, or rendered indifferent by one, a 'transcendent' explanation – one that takes us beyond natural science – is needed *if the Principle of Sufficient Reason continues to hold.*[2] This may take the form of a divine creative agent or a really existing multiverse.
- If we do have good evidence, and an adequately specific model for, the multiverse to which our own universe belongs, thus providing some explanation for its bio-friendly characteristics, this would not be a complete – let alone an ultimate – explanation. We would still require an explanation for the existence and bio-friendly character of the multiverse itself (bearing in mind that there is no unique prescription for it) and for the process through which it emerged – as well as a philosophically ultimate explanation.
- If we have a final theory which uniquely specifies all the characteristics of our universe, including the initial conditions, we cannot employ the

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[2] The Principle of Sufficient Reason, which many philosophers maintain holds in all circumstances, requires that, for every state of affairs, event or outcome, there is an adequate reason or explanation. If, in some fundamental regime (for example quantum cosmology), this were not the case, then we might be able to forego searching for a further, deeper understanding. I personally do not believe this is the case, but it is a possible philosophical stance.

fine-tuning arguments of the SAP either scientifically or philosophically. There would then be only one way in which our universe could exist consistently. This is very unlikely, but we cannot rule it out at present.

- Even if the previous option applies, it would still not eliminate the need for an ultimate explanation or 'cause'. Nor would it invalidate philosophical arguments from contingency for the existence of God. (Here again we would be invoking the Principle of Sufficient Reason.)
- If we have a final theory that still allows some 'play' in the laws of nature, then a theological answer in terms of intentional action by a divine agent or Creator is certainly acceptable, as long as we are allowing ourselves to go beyond the natural sciences and admit a theological or metaphysical frame of reference. Science can neither support nor exclude such a conclusion. It cannot even adjudicate the question. However, in going beyond the sciences, we must avoid putting God in the 'scientific gaps'. Perhaps our final theory is not really final! We should ensure that the divine agent is always a primary or ultimate cause – not one that could conceivably be filled by some unknown secondary or created cause [34].

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