Copernicus, Kant, and the anthropic cosmological principles

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Abstract

In the last three decades several cosmological principles and styles of reasoning termed 'anthropic' have been introduced into physics research and popular accounts of the universe and human beings' place in it. I discuss the circumstances of 'fine tuning' that have motivated this development, and what is common among the principles. I examine the two primary principles, and find a sharp difference between these 'Weak' and 'Strong' varieties: contrary to the view of the progenitors that all anthropic principles represent a departure from Copernicanism in cosmology, the Weak Anthropic Principle is an instance of Copernicanism. It has close affinities with the step of Copernicus that Immanuel Kant took himself to be imitating in the 'critical' turn that gave rise to the Critique of Pure Reason. I conclude that the fact that a way of going about natural science mentions human beings is not sufficient reason to think that it is a subjective approach; in fact, it may need to mention human beings in order to be objective.

1. Introduction

Physics prides itself on seeking and offering objective explanations of natural phenomena, explanations that are independent of the prejudices, interests, and restricted points of view of human beings. Physics tries to say how things are, and why they are as they are, in the physical world that exists independently of us, with whatever concepts are required for this task, however alien those concepts might be to ordinary human experience. Its scrupulousness about overcoming what is parochial in the human point of view on the world is evident even in seemingly minor things: physics searches for units that have some significance in nature ('natural

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units' like a Planck's constant worth of radiation energy) even if such units will not turn out to be the ones chosen for their convenience in many practical pursuits. The scale of a human being's ordinary concerns—the world of middle-sized dry goods, as J. L. Austin called it—does not restrict the interest of the physicist: she investigates the indiscriminably small electron, and the unfathomably large universe. Above all, the goal of physics is not to describe the world in such a way as to make human beings feel they are significant to it. Some would say its goal has been the opposite. When we speak of this tendency approvingly, we often hark back to the idea that Copernicus corrected human beings' egregiously self-serving tendencies when he proposed that the Earth was not in the center of the universe.

It must, therefore, have been with some dismay that any physicist read the climactic final sentence of a 1973 paper of C. B. Collins and S. W. Hawking purporting to explain why the universe is isotropic (the same in all directions) at a large scale:

> Since it would seem that the existence of galaxies is a necessary condition for the development of intelligent life, the answer to the question ''why is the universe isotropic?'' is ''because we are here.'' (Collins & Hawking, 1973, p. 334)

Collins and Hawking's capacity for humor should not be underestimated, but they also appear to have been summarizing a serious proposal. How did it come to be that a proposal apparently ascribing significance to human beings in an explanation of the physical world could be taken seriously? How deep a transformation in the outlook of physics would taking such things seriously represent? How could it even make sense to say that our existence is the reason the universe is as it is—wasn't the universe there long before we were?

The answer to the first question is clear: the phenomena of fine tuning first discovered in the early 1970s set some physicists on a search for explanations. It may be that the difficulty of the problem explains why some physicists made the unusual move of appealing to facts about our species for insight about the universe. However, there are also aspects of the fine-tuning situation that particularly encourage thoughts about human beings. I will discuss fine tuning and the questions it raises below. The answer to the second question depends very much on what kind of relevance human beings are taken to have in a given anthropic strategy. Accordingly, I will discuss each of the primary principles that take human beings to be relevant to the way the universe is or appears ('Anthropic Principles') with an eye to identify the associated argument style closely. Thereby we will be able to judge the extent to which, and ways in which, each strays from the physics tradition defined by the invocation of Copernicus and the avoidance of teleology (explanation of things in terms of goals, often goals of intelligent beings). Understood charitably, I will argue that Collins and Hawking's use of a reference to human existence in fact stands squarely within the Copernican tradition in physics. However, this is only because or to the extent that—contrary to appearances—they are not explaining why the universe is isotropic by appeal to the existence of human beings.

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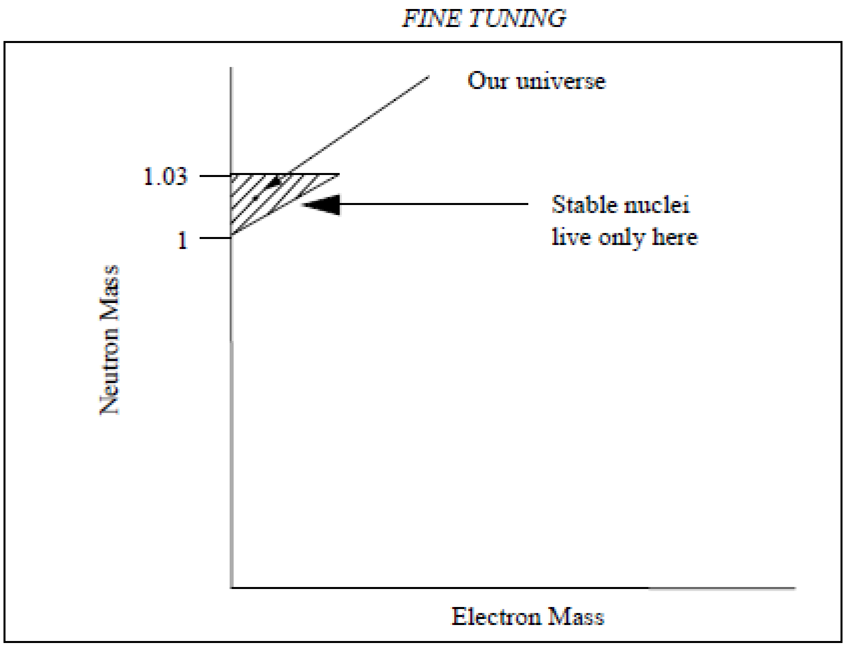
I will conclude by discussing elements of the Copernican tradition more pointedly, and locating each anthropic approach with respect to them. I will argue that one of the lessons of Copernicus is not flouted but extended by the Weak Anthropic Principle (WAP), and it is the same lesson Immanuel Kant took from Copernicus in his critical philosophy.

2. Fine tuning: what is it, and why is it a problem?

Musical instruments are finely tuned when they produce sounds that are as close as possible to certain pure tones. When an instrument is tuned so that it is only slightly off the intended tone, the result can be disappointing by itself, and is often painful to our ears when that tone is combined with the others it was intended to harmonize with. The range around the pure tone to which an instrument may be tuned and still produce a sound that is pleasant in combination with the other tones expected is rather narrow.[1] Vary a tone as far as the next pure tone or a higher register and the results are passable or even good; vary it only slightly around the intended tone, and cacophony frequently results.

It is similar with the effects of adjusting the knobs on a radio. Turn the knob as far as the next station, and the sound that results will be relatively coherent, even if it is a musical style you despise. Turn the knob ever so slightly away from your favorite station, and a ‘style’ of sound will result that no one could listen to for very long. This notion of tuning, borrowed from the realm of coherent sound, is apt for characterizing what physicists have been seeing in their theories and models since the early 1970s, because of the similarly sensitive dependence of gross (and pleasing) features of the physical world on very fine adjustments of parameters and initial conditions. Consider an example depicted in Fig. 1.



Source: Lee Smolin, *The Life of the Cosmos*, 1997

Fig. 1.

There are two ways of using this graph to see that the way the world is depends sensitively on the relation between the mass of the electron and the mass of the neutron (measured in units of proton mass). The first involves imagining that a knob controls where we go on the axis marking the electron mass, that is, the electron mass is greater the further the knob is turned to the right. Imagine a similar knob for controlling the neutron mass. As we turn it to the right we designate a point on the vertical axis that is further up, at which the neutron mass is greater. The actual universe can be plotted as a point in this two-dimensional plane, the point labeled 'Our Universe,' corresponding to the actual mass of the electron and the actual mass of the neutron.

How far could we 'tune' the universe away from these particular values of those masses (leaving everything not dependent on those masses just as it is) and still get a similar universe? The answer is dramatic. Turn the knob to make the neutron heavier

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1 This range fails to be as narrow as a mathematical point, because in every sense modality, including the auditory, human beings have limited ability to discriminate. However, our discrimination is still very impressive: we can typically tell the difference between a pitch of 1000 and 1001 cycle/s.

than it actually is, and very soon you will be out of the shaded region where stable nuclei can be supported. Turn the electron knob to the right, and quickly you come to a region where no mass for the neutron will give rise to stable nuclei with that value for the electron mass. Stable nuclei are a very basic feature of our actual universe—there would be no tables and chairs, or even planets or stars, without them—so if a universe did not have stable nuclei, but only, say, subatomic particles and radiation, it would surely count as dramatically different from the world we have grown accustomed to.

Let us say that a universe is fine tuned for X whenever (1) its unexplained parameters or initial conditions have values allowing for X in that universe, (2) if the values of those parameters or initial conditions were slightly different, then that universe would not have (or be) X; and (3) X is a significant, or gross, or qualitative feature. Thus, when I say that our universe is 'fine tuned' for stable nuclei, I will imply nothing about how it got the way it is. I do not presume that some intelligent being tuned it; to do so would beg some important questions.2 I refer only to the fact that it has certain gross features whose dependence on parameters is sensitive.

Why is the actual universe tuned to just these values of the mass parameters? Why is it tuned to have the gross feature of stable nuclei? The poignancy of that question

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2 There is a related use of the term 'fine tuning': a theory is fine-tuned if the scientist writes in the value of a parameter by hand and the value he or she gives to it must be within a very narrow range if the theory is to predict known features of the universe. If a universe is fine-tuned according to a theory, then the scientist must finely tune the parameters of the theory to make it fit the world.

can be appreciated by thinking about the graph in another way, and attempting to dissolve the problem by supposing that the values of the electron and neutron masses of the actual universe are a product of chance. Think of the diagram as representing the set of possible universes generated by varying the values of the electron mass and neutron mass. Let us arbitrarily restrict our attention to the set of possible universes you get when the axes are extended only to the larger rectangle. (This will make our result conservative in a sense I will explain.) Then we can judge the probability that a universe like ours in having stable nuclei could have arisen by chance, by imagining throwing darts randomly at this graph, and asking for the probability that a given dart would land in the shaded region. That probability is quite low, as we can measure by means of the area of the shaded region compared to the total area of the graph. Chance processes alone are not very likely to have produced a universe like the actual one, because that region of the graph is a very small part of the graph's total area. That area occupies roughly the proportion of the graph that a bull's-eye occupies on a dartboard, and bull's-eyes are fairly hard to get even when we are aiming (a non-random process). Having restricted our dartboard to the larger rectangle made our result conservative because it made the measure of possible ways of failing to get a universe like ours smaller than it might have been, and thus the probability of succeeding greater, because the latter is measured as a fraction of the size of the space of possible outcomes.

There are many such situations in contemporary physics and cosmology.[3] Parameters that determine such things as the strengths of fundamental forces and the masses of fundamental particles thereby determine gross features of the universe such as its size and lifespan, and whether or not stars will exist and their lifespan. Whether or not there are stable nuclei in the universe depends, not only on a balance between the masses of the electron and the neutron, but also on a delicate harmony between the strengths and ranges of the electrical and strong and weak nuclear forces. If the strong force that holds nuclei together by overcoming the electrical repulsion between positively charged protons were weaker by a half, most nuclei would become unstable. If the strong force had a larger range, it could pull all the protons and neutrons in the world together into one big nucleus. If any of the parameters in question were a bit different than it actually is, then the universe could have collapsed under its own gravity after a nanosecond, or expanded too fast for any clumping of matter into what we think of as objects to occur, or remained a sea

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3 The cases I allude to involve sensitivity of the universe's features to values of parameters in the Standard Model of particle physics. The concept of fine tuning was invoked earlier in response to the horizon and flatness problems in cosmology where it was hard to see how to get the actual world without carefully setting initial conditions (a case similar to the problem Collins and Hawking announce). Thus, there may be fine tuning of parameters or of initial conditions, both of which are the non-law-like, or contingent, portions of physical explanations. I have discussed the more recent fine tuning in parameters for ease of exposition. It should be noted that the inflationary scenarios which in their chaotic form overcame the fine tuning phenomena associated with the flatness and horizon problems depend for their basic inflation mechanism on the Standard Model of particle physics whose fine tuning problems I am discussing here. No mechanism explaining the Standard Model's fine tuning automatically comes from the latter's apparent successor String Theory. (See, e.g., Linde, 1994, pp. 37–38).

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of elementary particles and radiation, or become one giant tightly bound nucleus.[4] It has been estimated that the probability of getting a universe reasonably similar to the one that we have—i.e., large, old, with gravitational clumping and stable nuclei—by fixing the relevant independent parameters by chance is approximately 1 in 10229 (see Smolin, 1997, pp. 6–46).

This dramatic contingency of gross features of the universe would be less troubling, of course, if we knew how to explain why the relevant parameters take the particular values they do. However, the Standard Model of particle physics leaves those as free parameters to be written in by hand, with whatever values match the way we find that the world happens to be. This leaves the values, and thereby gross features of the universe, with no law-like explanation. We might wonder why it would not be satisfactory to leave things at that, to accept the values of these parameters as brute facts and demand no further explanation. Those parameters have to have some values or other, after all. Why not the ones they happen to have? Those values are no less likely, surely, than any other set of values. We could find a particular (uninteresting, mismatched) set of playing cards that we would be as unlikely to be dealt as a royal flush. We would probably be more surprised actually to be dealt a royal flush than to be dealt the mismatched hand, but we would have no right to be if they were equally unlikely.

There are certainly combinations of the values of the parameters that are different from the actual combination but equally unlikely. However, just as in the game of cards, a royal flush is singled out for attention (and points), so too the 'game' of physics involves the aim of explaining not merely what is unlikely to be the product of chance alone, but also what is a fundamental feature of the physical world. This should figure in our response to the fine tuning that is present in physical theories. Considering our actual universe, the gross features in question—size, age, stable nuclei, gravitational clumping—are basic, and universal physical properties. Gravitational clumping is not something that happens in only one corner of the universe, but everywhere. Features that are universal ought, arguably, to be given a law-like explanation whenever possible. The size and age of a universe characterize it as distinct from many others, and are not merely cosmetic properties, as the founders of early modern physics took properties like color and smell to be, thus banishing them from the proper subject matter of physics. Stable nuclei make up the objects whose motion physics got its start by trying to understand. If it turns out that physics cannot explain so-called emergent properties (like consciousness), then that

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4 What counts as a small or big change in a parameter? Can we not manipulate how surprising the actual universe appears to be by manipulating the units in which we judge the size of a parameter change? The results are always relative to the units we express them in, but in most of these cases units can be chosen that are natural, in the sense that the unit corresponds to the scale of the phenomena in question. For example, we do not report the sensitivity of stable atomic nuclei to the masses of the electron and neutron in units of kilogram, though that would make the result more dramatic, since the difference in these masses that would lead to the same big difference in the universe would be much smaller when reported in larger units. The result is reported instead in units of proton mass (roughly the same as neutron mass). In those terms, the result is that the electron must have a mass almost exactly the same as the (tiny) difference between the proton and neutron masses if there are to be stable nuclei.

will not be a failure for physics, but only for an ambitious reductionist philosophical program. But if we find that physics has not explained gross features of the physical world, then we must conclude that it has not finished its task.

Note that this approach to understanding why we should not be satisfied without an explanation for the fine tuning is distinct from one which would claim that our world is special among possible worlds because it has 'interesting' properties (e.g. largeness and oldness).5 My claim is rather that properties that are distinctively physical and significant to physics ought to be explained whichever way they turned out. Thus, size and age need to be explained whether the universe is big or small, old or young. Objects or their absence is the sort of thing about a universe that physics should explain. What the fine tuning shows is that these gross, and distinctively physical, features of the world depend sensitively on values of parameters that we have no explanation for.

A bit more is needed to defend thoroughly the claim that physics needs to explain the values of these parameters. For consider that we regard the height of a projectile and the distance of its flight as physical properties, properties that physics has some obligation to explain. However, when physics explains these things only part of the answer is law-like—the laws of motion for projectiles. We must also appeal to the initial conditions of the situation—the angle and speed at which a projectile was launched. We cannot explain the resulting height and distance of the projectile flight without the initial conditions, but we do not require ourselves to explain why the initial conditions are as they are in order to take ourselves to have given an explanation of the flight of the projectile. Why, one might ask, can we not take the same attitude toward these parameters on which features of the universe depend as we take toward those initial conditions of the projectile? Why is it clear that a further level of explanation would be valuable?

Comparison with the projectile is not apt for a reason that helps make explicit what is special about a fine-tuning situation. With the projectile, the initial conditions and the resulting height and distance of the projectile flight vary proportionally: vary the initial conditions a little and the height and distance of the flight will change a little. In any case of fine tuning, the way in which the world varies under changes of the parameter is between states that are in some way qualitatively different: e.g. a universe with objects or a universe with none. If the variation were quantitative—say, everything in the universe got a little bigger when the parameter got bigger—one should feel less inclined to call for explanation of the parameter's value. (Well, if everything were a little bigger by the same amount, we would not notice it anyway.) However, the situation we are in is one where which of two qualitatively different states results depends on the value of a parameter in a very sensitive way. Prima facie, a small quantitative change should not result in a large qualitative change, suggesting that there is something that our mere ability to name the value of the parameter is not sufficient to explain.

On the question of whether we should try to explain the parameters, there are also physicists' own testimony and historical precedent to consider. Sheldon Glashow,

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5 In this I disagree with the view of Parfit (1998).

one of the architects of the Standard Model, has said that the theory wears on its face the fact that it is not the final theory, because of its 19 or 20 adjustable parameters.6 We know, in addition, that there is precedent for raw values for some time taken as brute, unexplained facts, to be later explained by, or at least derived from, a deeper, richer theory. For example, the value of the ideal gas constant, merely observed in classical thermodynamics, gets derived and explained in statistical thermodynamics. Such examples make it clear why a physicist would not so easily be willing to give up entirely on the search for an explanation of the values of parameters; for, in so doing, she might be giving up on the next new theory.

The fact that all fine tuning results are based on features of our current physical theories should give pause to anyone thinking of drawing strong metaphysical conclusions from them .7 The existence of stars, at least in our region, is something that will probably figure in any future theory of the universe, but fine tuning will diminish as physicists are more successful at what they are trying to do. Fine tuning is thus more of a lack than a positive result of physics. The hope is that the reason certain parameters and initial conditions must be written in by hand is that there are deep laws that we do not yet understand. Such laws could tell us why any possible universe would end up with a certain value of a parameter, or they could tell us why any set of initial conditions or parameters would lead to a universe with gross features like ours has. In both cases, there would no longer be fine tuning according to my definition, in the first because the parameter’s value would have an explanation, and in the second because the gross features would no longer depend sensitively on the values of the parameters or initial conditions.

3. The strong anthropic principle

I have argued that the phenomenon of fine tuning shows that physics has some explaining to do, without so far mentioning human beings or living things at all. I cannot emphasize enough the fact that we do not have to be interested in human beings or import them into our considerations, in order to think that fine tuning presents a problem, and that the task of physics is not completed if we do not explain the values of the free parameters alluded to. However, adding human beings to our considerations of the fine-tuning problem will make that problem more vivid, especially for non-physicists. Some think it will also show how to solve the problem. In this section, I explain why fine tuning prompts some to flirt with, or even to endorse, the Strong Anthropic Principle (SAP). I discuss its more specific versions—the God hypothesis and the SAP many-universe hypothesis—and argue that physics has no use for these, though it may have a use for a non-SAP many-universe hypotheses. Finally, I use this analysis to give the only charitable interpretation I think there can be of Collins and Hawking’s cryptic invocation of human existence.

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6 Conference on Quantum Field Theory, Boston University, Spring 1996.

7 Leslie (1989) seems to me insufficiently concerned about this. On the other hand, it has been argued by Hogan (2000) that three particular adjustable parameters will have to remain fine tuned in any Grand Unified Theory since they will not be derivable from first principles alone.

Stable nuclei are required in a world, not only if it is to have planets, but also if it is to have living things like trees, lions, and human beings. Living things of our kind are made of stable nuclei of a wide variety of sorts: carbon, oxygen, hydrogen, phosphorus, sulfur and many more elements, including traces of heavy metals. These elements are made in stars, which would not exist if there were no gravitational clumping. In a universe that lasted less than a second, there would be no time for evolution to give rise to even simple organisms. And so on. The existence of life and human beings as they are depends on the precise values of the free parameters of the Standard Model as sensitively as the physical features of the universe I canvassed above.8 If those values had been slightly different, we would not be here to notice the fact. Thus, according to the definition of fine-tuning given above, the universe is fine tuned for life.

An analogy will give us a better feel for this situation: imagine that when he was a young man your father faced a Nazi who determined whether to shoot your father to death on the basis of a single roll of a roulette wheel. The Nazi chose one color and one number as the outcome that must occur if your father was to survive. Your existence today thus, in the story, depends on the fact that against all odds the roulette wheel produced just the right result for your father's survival. Similarly, only a very small measure of the sets of possible values for the parameters would allow the possibility of life, and we are faced with the fact that one of those sets was the outcome.

For some this tight dependence of our existence on the values of parameters, and the fact that chance does such a bad job of explaining why this was the outcome among all the possibilities, engenders the spooky suspicion that the goal of bringing life and human beings into existence was the reason the parameters got the values they did. It would be as if in response to learning of my father's encounter with the Nazi I concluded that my existence (or, at any rate, the existence of some child of my father) was somehow 'meant to be'. The improbability of the actual outcome is supposed to be evidence for a conclusion that in the case of the universe would be framed more or less as follows:

> … the Universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers in it at some stage. (Carter, 1974, p. 294)

This claim, and claims like it but that substitute 'life' where we have 'observers,' has been called the SAP by Brandon Carter, a cosmologist who christened the anthropic principles and was the first to formulate many of them. SAP makes it more probable than if the result of a chance process that the universe would have turned out as it has, and the fact that a hypothesis makes a phenomenon more likely than it otherwise would have been is a rough indication that the phenomenon is positive evidence for the hypothesis.

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8 Note that nothing we have seen implies that if a universe does have those values, then life and human beings will definitely arise, but only that if the universe had not had those values, then life certainly would not have arisen. Those values are a necessary condition for life and human beings, but are not claimed to be sufficient.

Understood as charitably as possible, the SAP hypothesis offers to explain the fine tuning of the parameters in terms of a claimed necessity that intelligent observers be possible.9 This effort at explanation is almost entirely uninformative, though, because it amounts to little more than the claim that the possibility of intelligent observers is not the result of chance. Since the possibility of intelligent observers at some stage in a universe is very nearly the same fact as the universe having nearly the parameters that ours has, the putative explanation is very nearly the mere claim that the parameter values must be as they are. We have not explained why the parameters have the values they have when we say that their having those values is not a matter of chance and must be as it is. At most, we have claimed that an explanation exists. We have achieved little more than the inchoate sense of the Nazi-survivor's child that its existence was 'meant to be'.

The problem of uninformativeness can be addressed to some extent by more articulated versions of the SAP: the God-hypothesis and the many-worlds hypothesis. According to the God-hypothesis, God chose that the world should be such that it could have intelligent living things of our sort. The only way that was possible was to choose the parameter values to be almost exactly what they are, so that is what he did.10 In this case, we do not merely deny that the parameter values were a product of chance and intone that they were necessary. We say what they were a product of God's choice. The strategy of using a many-worlds hypothesis is different, in that adoption of this sort of hypothesis removes the need to explain why of all possible worlds this one was singled out to exist, because the hypothesis says that this one was not singled out; worlds corresponding to all values of the parameters exist. Of course, a many-worlds hypothesis would properly be an articulation of the SAP cited above only if the supposed reason all those universes exist was in order that intelligent life be possible in at least one of them. A presumption that human beings are the telos of the universe would not be the reason we should think all those universes exist on the many-worlds view, for that would be using our hypothesis as evidence for itself. The reason we should think either the many-worlds or the God-hypothesis is true is supposed to be the evidence of fine tuning.

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9 A stronger version of the SAP also gets discussed, in which what is necessary about observers is not that they be possible, but that they be actual in a universe (Tipler, 1982, p. 37). Many of my comments apply to this principle as well. Also, it is important to bear in mind that the 'must' in the SAP claim needs to be an ontological 'must' in order to be explanatory of the parameters' values. It cannot be the epistemic 'must have been so on the basis of what we know', or a tautological 'must' as in 'Human beings are actual so they must be possible.' This is what makes the principle strong.

10 How do we know that choosing the parameter values to be exactly as they are was the only way to make life of our sort possible? How do we know that there are not different schemes altogether (different laws) for making physical worlds, some of which would not even use these parameters, and in which life of our sort was possible? In making these judgments we can do no better than rely on our current best estimate of physical possibility. Thus, we should always be on the lookout for ways in which the claims of fine-tuning themselves would change with a change of the laws or other assumptions. For example, recent work says that a cold big-bang

cosmological model allows an order of magnitude of latitude in cosmological parameters while maintaining the possibility of life in a world (see Aguirre, 2001).

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The God-hypothesis is not a viable option for physics, for reasons that are worth spelling out. Lee Smolin rejects this alternative on the ground that it is irrational, apparently meaning that it involves faith (Smolin, 1997, p. 45), but this is not the best way of explaining the inappropriateness of the alternative, since claims of irrationality and rationality may be too strong or too weak to make the God hypothesis and standard physics come out on the intended sides. On permissivist conceptions of rationality, beliefs (faiths) that do not positively contradict the evidence are counted rational. Thus, the God-hypothesis will be rational, if, as is plausible, going beyond the evidence is its only fault. On the other side, it is hard to distinguish beliefs scientists have in hypotheses that go beyond current evidence—as any interesting hypothesis does—from faith in the sense that Smolin appears to be rejecting. Thus, scientific hypotheses may be irrational if the God-hypothesis is.

There are several reasons why the God-hypothesis is inappropriate as an answer to the questions physics faces about why the parameters are fine tuned. The hypothesis is clearly teleological: it appeals to a goal or purpose to explain why things happened as they did before the goal was realized. In this case, the goal was intelligent life, a goal that an especially powerful intelligent being achieved by means of choosing certain values of the parameters. Since its inception in early modern times, physics as a discipline has avoided such explanations like the plague. This is not, I think, primarily because of doubt that such a being exists, but because of the nature of the explanation that would result from the assumption that it does. At the most elementary level, the problem is that neither God, nor the goals or intentions invoked, are taken even by their proponents to be physical entities. What results from these concepts is thus not a physical explanation, and does not answer the physical question that was posed. Accordingly, the God-hypothesis would deserve a different standing if a physical theology were offered, consisting of a conception of God and of intentions as physical, and physically effective, entities.

There is further trouble for physics with invoking God and the goal of human existence. As for God, if it were appropriate and satisfying for physics to appeal to God as the reason for values of parameters we discovered ca. 1970, then it seems that it would have been appropriate to appeal to God as the reason for any physical phenomenon. But it was not appropriate or satisfying to explain, say, the phenomena of electromagnetism by appeal to God—even if one thought God was in some sense responsible for everything in the universe. What was wanted was physical understanding of events, which is obviously not provided by appeal to something non-physical. The only exception I can see to this line would be if our present theories were the end of physics, at which point it might become appropriate to move to a different register of explanation. However, as I have argued above, the theories in which parameters or initial conditions are fine tuned are pretty clearly not the final theories, even if they are the final theories human beings will discover.

The God-hypothesis, in which human beings are the goal of the cosmos, offends against the tradition of physics in another way. The lesson many take Copernicus to have taught us when he proposed that our planet was not at the center of the universe was something like: never substitute self-aggrandizement for evidence. So,
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to suppose that the answer to our physics question was that human beings are special in the scheme of things seems, from the point of view of the practice of physics, not only to change the question as I have indicated, but also to be the product of self-serving psychological impulses. This is not to deny that there could be practices in which and goals for which the God-hypothesis played an explanatory role. It is just to say that such a practice would not be physics.

However, forced to choose between the God-hypothesis and the SAP many-worlds hypothesis, it seems to me the God-hypothesis would be preferable on grounds of simplicity. For notice that a many-worlds hypothesis that is an articulation of the SAP will rest its explanatory case on a claim that the physical possibility of intelligent observers was a goal for the sake of which all those worlds, including ours, became actual. If the explanatory force really lies in the overriding goal of making intelligent observers possible, then it seems simpler ontologically to call on God to choose the one world that fits the bill, than to suppose that all of them happened. Moreover, it seems that if the explanatory force resides in the overriding goal of bringing intelligent beings into existence, then the many-worlds hypothesis is itself incomplete without some mention of God, or something like God. Otherwise, how does the goal of bringing intelligent beings into existence bring it about that the many worlds exist?

When one adopts a many-worlds hypothesis, on behalf of SAP or otherwise, the question of explanation changes: there is not anything to explain about why this universe exists that is not something to explain about why any of the worlds exist, because this world's existing is not a property that distinguishes it from the other possibilities. It is as if a new mother asked her doctor in alarm why the top of her baby's skull was soft. The doctor would reply that all newborns have soft skulls and must accordingly be handled with care, leaving the mother (probably) with little further curiosity about the matter. But although there is no question about the softness of this baby's skull that is not also a question about every other baby's skull, a further question remains about why all babies are born with soft skulls. Similarly with the worlds, there remains a question about why all those worlds exist, if they exist. This leaves any many-worlds strategy with two questions about those worlds: Why do they exist? and Why should we believe that they exist?

The SAP many-worlds hypothesis appeals at this point to the necessity for human beings to come into existence as the reason why those worlds exist (via God's will in the most explanatory version), and the fine-tuning as a reason why we should believe it. What if we gave no answer to the question why all those worlds exist? In that case, provided we have given evidence that all the worlds do exist, we have explained why

this one exists in the same sense as the doctor has explained why this mother's baby has a soft skull, which is not impressive. What the doctor has done is allayed the mother's fear that her baby is abnormal—there is no question to be asked about the softness of her baby's skull that could not be asked about any baby's skull. He has not explained why the skull of this baby, or any other, is as it is. The bare hypothesis of the existence of all those many worlds does nothing to explain why this one exists, even if the hypothesis is true. This is so despite the fact that the former implies the latter.
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There are hypotheses of the existence of many worlds that do not share with the SAP the claimthat intelligent observers were 'meant to be,' but also do not leave the question of why all those worlds exist unanswered. I will call these 'non-SAP many-universe hypotheses'. For example, Smolin (1997) has proposed that universes are born of black holes. At each black hole in any given universe a new universe grows out the other side. The characteristics (parameters) of the baby universe are similar but not identical to those of its parent—there is something analogous to inheritance rather than cloning or budding in the process through which offspring universes are produced. One of the heritable traits of universes is black hole concentration, and as a consequence it is no surprise that in the space of universes so produced the universes with many black holes (and thus many stars) will come to dominate the population; they reproduce more (since they have more wombs) and they pass on their propensity to reproduce. Concentration of black holes in a universe is correlated with concentration of galaxies and stars, which is correlated with the possibility of life, so we get for free an explanation of why the universe is habitable. Now that is a story, and a physical theory. If it is an acceptable hypothesis, then it explains why there are many universes by giving a physical mechanism through which universes come into existence. It would also explain why a universe like ours, in having many stars is a commonplace, a likely outcome.

Another physical proposal for why many universes or many different regions of this universe would exist is the acclaimed chaotic inflationary cosmology of Andrei Linde and others. In inflationary models, the universe undergoes fantastically rapid expansion in a very early phase, an expansion which removes the need to postulate a geometry finely tuned to be nearly perfectly flat, as we find it to be. In chaotic versions of this, the initial conditions of the universe do not make a difference to the probable outcome. All possible kinds and values of scalar fields may have existed in the early universe, and even if the fraction of them that would undergo inflation were few, those few would dominate the outcome, because while the others remained small, they would become exponentially large and dominate the total volume of the multiverse. The difference between these physical hypotheses of the formation of many universes and the blank hypothesis of the mere existence of many universes is clear. The latter, minimalist, many-worlds hypothesis has received more attention from philosophers, but hypotheses that have a picture of how universes come into existence physically are the only sort of many-worlds hypotheses that could explain fine-tuning for physics.

Why should we believe that many universes exist? This is distinct from the question why they exist (if they do exist); it is a question about evidence. Many of the substantive, physical, many-universe hypotheses have the peculiarity that all of the universes distinct from ours are also causally disjoint from ours. This circumstance makes it hard to see how we could get empirical evidence about their existence, since there would be no way that anything happening in those other worlds could have an effect noticeable in this one. This is not a wholesome property for a hypothesis to have, since it suggests that the hypothesis is not testable against the experience that provides our only access to the external world, and thus that the hypothesis is idle speculation. However, it does not follow from the current causal disjointness of
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those other worlds from ours that the theory that says how they were produced has no consequences in this world. The more details a hypothesis has about the mechanism of formation of universes, the more likely that empirical evidence can be brought to bear on it. Smolin (1997, pp. 301–315) thinks that his proposal about black holes giving rise to universes makes falsifiable predictions in this universe. Though inflationary models make claims about unobservable (mini-)universes, they also make predictions in this (mini-)universe that have been fulfilled, such as those of anisotropies in the cosmic microwave background, and predictions that may not be, such as characteristic acoustic oscillations that should be in those anisotropies if they were caused by inflation.

A many-universe hypothesis can also get indirect evidential support by being part of a larger theory that is well-supported or has some virtues in its favor. The inflationary scenario is 'natural' rather than ad hoc, because the mechanism for it can be derived from the Standard Model of particle theory. Of course, dependence on another theory can be double-edged, and is in this case since the Standard Model is the theory whose own fine-tuning problems I have discussed earlier. Not every way of deriving many universes from another theory looks promising, though. Some looking for a many-universe type explanation of fine tuning apparently hope that interpreting quantum mechanics in the many-worlds style of Hugh Everett III will give them for free the many worlds they would like to use to solve the problems of fine tuning (see, e.g., Earman, 1987, p. 312 for a brief discussion). Everett's many worlds are generated by taking all the possible outcomes of a measurement to be actual, each corresponding to a world. Unfortunately, the plan to use these worlds to explain the parameters is misguided, since the way that many worlds come about on Everett's view gives no particular reason to think the many worlds should get different values of the parameters of the Standard Model.

Our situation with universes is different from the one we had with babies' heads, since when someone proposes that all newborns have soft skulls we can (in principle) go out and check his claim directly, by softly touching the top of the head of every baby in the world. Even if we can have empirical evidence in this world supporting the existence of other worlds, it is not likely to be as easy to obtain or as directly related to the hypothesis at issue, as the touching of babies' heads. Many have thought that the fine tuning of this world counts *in itself* as evidence for the existence of many universes, allowing us not to fret about the difficulty of finding direct evidence for those other worlds. The most convenient set of many universes, and the one usually considered in philosophical literature, is just the set of universes you would get by allowing the parameters at issue to have all possible values. The fine tuning is taken as evidence for the existence of these many universes because of a belief that the existence of many universes would make more likely the existence of this fine tuned one which is a priori so unlikely.

Whether that hypothesis makes this fine tuned universe more likely, and whether as a consequence the fine tuning makes the hypothesis of many universes more likely, are topics of debate, with some alleging, for example, that we could think so only if we committed an inverted form of the gambler's fallacy (Hacking, 1987). The gambler makes a fallacious inference when he concludes after seeing a run of bad

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throws of the dice that the next roll is more likely than chance to be good. We make a similarly fallacious inference, the argument goes, when we conclude from seeing an especially good roll of the dice that the game must have been going on for some time, with many rolls already having been made. It is a fallacy, of course, if the game is such that each new roll (universe) is independent of every previous one. What was rolled before cannot make this roll we got more or less likely if our roll was determined by the chance odds.[11] Whether there is some way of taking the fine tuning as evidence of a hypothesis of many universes without committing a gambler-type fallacy is a matter of continuing debate.

However, even if the fine tuning did make a many-universe hypothesis more probable than it otherwise would have been, that would not, I think, be sufficient to take fine tuning as significant evidence for many universes, because a hypothesis whose only evidence is the fine tuning, and whose only content is the claim of many universes, looks like it must be what has been called *use-constructed*. That is, the only evidence for it will have been the evidence used to construct it, the evidence it was designed to fit. Not all use-constructed hypotheses are ill-supported, but the bare many-universe hypothesis meets a further criterion that tends to render the support dubious: the method through which the hypothesis was constructed from the evidence is unreliable.[12] That is, the method of supposing all types of a thing (in this case universes) exist when your evidence is that one type exists does not have a good track record. Should I suppose that tomatoes of all possible colors exist when my observation is that the tomatoes I see are red (and I do not know why they are red)? The support the evidence of fine tuning alone can lend to a many-universe hypothesis is very weak if it exists at all, because that evidence does not represent a severe test: because of the method through which the hypothesis was constructed from the evidence, the evidence would be likely to match the hypothesis *even if the hypothesis were false*.

While non-SAP many-universe hypotheses are frequently a response to some fine tuning or other, they are not anthropic. This is evident from the fact that intelligent observers play no role in Smolin's or Linde's many-worlds type of explanation of why this or other worlds exist, or are as they are. Moreover, the fine tuning problem each of these physicists is responding to can be described without mention of observers, as I illustrated earlier. The teleological SAP discussed above, whether via God or via God plus many worlds, thus appears to be the only strong approach to fine tuning that deserves the name 'anthropic.' However, because teleology and a non-physical God play an essential role in these approaches, the discipline of physics has no use for the SAP.

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11 See also Leslie (1988, 1989), McGrath (1988), Dowe (2000), and White (2000).

12 Bayesians have argued that use-novelty (non-use-constructedness), a criterion that has been popular among error statisticians, is not a necessary condition for a hypothesis to be supported by evidence. Some replies in defense of the use-novelty criterion have been unconvincing. However, Mayo (1996, pp. 251–274) has isolated the further criterion that the method of hypothesis generation was reliable, and putting this criterion together with use novelty does seem to capture the sound intuition behind the original use novelty requirement. I employ her two criteria in this example.

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There is a minor, non-explanatory role for consideration of human beings in any many-worlds hypothesis designed for addressing fine tuning, that will help us see how to understand Collins and Hawking. Faced with their own elegant results about fine tuning—only a small set of initial conditions for the universe would give rise to a universe isotropic to the extent that ours is observed to be—these authors propose that an infinite number of universes exist, with all possible initial conditions. This way a universe with the initial conditions that lead to isotropy will be guaranteed to exist. The title these authors choose—Why is the Universe Isotropic?—suggests that their paper explains something, but we must be careful about what it is they can explain with their proposal. That an isotropic universe exists is not explained, since no account is given of why all, and therefore any, of those universes exist, or how the mechanism through which universes come into existence makes it more likely that there would be many cases of universes or isotropic universes happening. It is just as if we had been told that all babies have soft skulls, without being told why any of them do. If the question was why a universe with the properties ours has exists, then we get no answer, and this is despite the fact that the hypothesis of many universes *implies* the existence of this isotropic universe.

If the question was why the universe that exists is isotropic, then we can be comforted that these authors' proposal makes that question count as ill-formed: 'the universe that exists' does not pick out something uniquely since there are many universes that exist. Many of those are not isotropic, so there is nothing of the phenomenon we stated that is left to explain. Another way to state the same fact would be to say that if 'universe' means all that exists, then on the authors' hypothesis the question's phrase 'the universe' does not refer to something isotropic, so again there is nothing of what we asked about that is left to explain. In these ways, the mere adoption of a many-universe hypothesis adjusts the explanatory questions we began with. Those adjustments will be legitimate if and only if our adoption of the hypothesis was legitimate. The hypothesis thus has the potential to affect the explanatory game, while not itself giving an explanation.

Collins and Hawking's proposal that many universes exist does not make any reference to intelligent beings, but their parting salvo does. It is possible that this is a gesture toward a teleological and theological ingredient for closing the explanatory gap I have just noted. To be charitable by my lights I will ignore that possibility, since I have argued above that it cannot give an explanation for physics. Why then do these authors mention human beings? It is easy to be misled into thinking that mention of human beings explains something about why we *observe* a certain kind of universe even though it cannot explain for physics why that universe is the way it is. After all, it will be said, of all the universes this is the only kind we *could* observe. However, that we require certain things for our existence does not explain why we observe the kind of universe we do. To explain that would require explaining why that sort of universe exists, how we developed in it, and how we got our eyes. The fact that we need isotropy no more explains why we observe a universe with isotropy than does the fact that we need oxygen explain why we observe green plants within some miles of us. There is a *conditional* fact that our need for isotropy and other niceties explains, namely, if we observe then the (mini-)universe we observe will be

isotropic. But this conditional is an immediate consequence of what explains it, and is anyway not what we set out wanting to explain.

We can see the legitimate force of Collins and Hawking's mention of human beings in their 'we are here' answer to the question why the universe is isotropic if we take the emphasis to be on the word 'here.' On this reading, they meant to highlight that though what we took to be the universe is isotropic, we were looking only at part of the universe—we were 'here,' a parochial place, rather than there, in any of those newly postulated other places. This reference to ourselves does not explain why the universe or any part thereof is as it is or is seen to be as it is, as I have just argued. However, it does explain, assuming their hypothesis, why *we thought* the universe was isotropic: we were looking at only a part of it.

This interpretation may seem to take the punch out of what the authors have written, but all the alternatives are unacceptable: our existence does not explain why the universe is isotropic because our existence did not bring it about that the universe (or our mini-universe) is isotropic or that we observe an isotropic universe, and this is so despite the fact that it follows more or less deductively from the fact that we exist that the universe that exists around us is isotropic. Our existence is an indication (if we know enough about ourselves and about physics) that the universe around us is isotropic, but so is the height of a flagpole's shadow an indication of the height of the flagpole. Neither explains what it indicates.

4. The weak anthropic principle

The WAP has in common with the SAP that both make reference to human beings, and make use of the claim that galaxies (for example), and hence certain values of the parameters or initial conditions, are necessary conditions for beings like us to exist. There the similarity ends. According to the WAP:

> Our evidence about the universe (what we observe) may be restricted by the conditions necessary for our presence as observers.13

The purpose of the WAP is not to provide, or point to, explanations, but to identify a way in which we must take care in evaluating the evidence we have for cosmological hypotheses. Whereas the SAP encourages us to speculate boldly and adopt grand hypotheses to explain the fine-tuning, the WAP counsels prudence in considering any cosmological hypothesis for adoption because of the humbling thoughts that we cannot observe in an environment that does not support our existence, and that the physical conditions for our existence are not trivial. The WAP has an epistemic whereas the SAP has an ontological significance. This difference is reflected in the reception the two principles have received. SAP God-hypotheses and SAP many-world hypotheses are not regarded as part of physics by mainstream

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13 This is a reformulation, that I will defend in what follows, of the WAP as it appears in Carter (1974, p. 291). The WAP is often confused with, but is not the same as, what I call the Trivial Anthropic Principle (TAP): Since human beings are actual, they must be possible. Unlike WAP, that is a tautology.

philosophers or physicists, non-SAP many-world hypotheses are considered to be playing the right game though highly speculatively, and the WAP is unanimously regarded as valid by physicists and philosophers alike. According to Steven Weinberg, the WAP is common sense, while the SAP is nonsense.14

The strategy encouraged by the WAP is best understood through consideration of its most discussed example, the 1961 argument that the physicist R. H. Dicke made against a speculative cosmological hypothesis proposed by P. A. M. Dirac in 1937. Dicke's argument, and examples modeled closely on it, are the only anthropic arguments universally regarded as legitimate. Carter (1974, 1983), Barrow and Tipler (1986), Earman (1987), and Weinberg (1989) all cite, summarize, and endorse Dicke's reasoning as the paradigm case of legitimate use of the WAP. It is thus this case, and the claims that have been made about it, that I will discuss in some detail, in order to show how the reasoning associated with the WAP is supposed to work, and on what grounds it is justified. In the process, I will defend some refinements of the original formulation of the WAP.

It is well-known that fromthe constants of physics, such as c; the velocity of light, h; Planck's constant, G; the gravitational constant, and so on, dimensionless numbers can be constructed as ratios. Dirac (1937) noticed that certain large numbers of this sort turn out to be roughly powers of 10^{40}. The Hubble age of the universe, T; usually of the same order of magnitude as the actual age of the universe,15 in combination with other atomic constants, can also be made into a dimensionless number, which turned out, according to the state of knowledge when Dirac was writing, also to be in the neighborhood of 10^{40}. Dirac judged these numerical coincidences to be highly unlikely, other things being equal, and to explain this ‘improbable’ finding he proposed that these and all other large dimensionless numbers of physics were ‘simple functions of our present epoch’. That is, he proposed that all the large numbers of physics are related to each other by a universal law, each of them changing over time to remain in a fixed relation to T (which of course itself changes over time). In particular, these numbers were to be understood as T^n, with n = 1, 2, … , and a different value of n associated with each constant. Those large dimensionless numbers were regarded by other physicists as constant over time, because they were composed of numbers like the gravitational constant, so the novelty—some would say preposterousness—of Dirac’s hypothesis was the proposal that those ‘constants’ should change over time. Schematically, Dirac proposed that certain parameters that had been given no physical or law-like explanation—whose values were regarded by most as brute facts—have a law-like connection *to each other* of the sort described.

In sum, because he regarded the numerical coincidence he found as a priori unlikely, Dirac proposed that the relation of the numbers to each other indicates an

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14 Personal correspondence. Indeed, Weinberg (1989) employed a WAP strategy to articulate one of many possible types of solution to the cosmological constant problem in a survey paper on that topic. He expresses the same sentiments in Weinberg (1992).

15 The Hubble Age is related to the actual age of the universe differently in different cosmological models. They are interchangeable for our purposes.

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unknown causal connection and holds at all times. Dirac’s proposal, that the numerical relation that holds now should hold at all times, was in disagreement with existing cosmological models, because since the parameters involved were regarded as unchanging, their relation to the (changing) Hubble Age could not remain constant. Accordingly, Dirac constructed a new cosmological model based on his idea (Dirac, 1938), which P. Jordan then took up and made relativistic (Jordan, 1952).

At its announcement, ‘most astronomers and physicists received Dirac’s unorthodox theory with silence, if not embarrassment’ (Kragh, 1996, p. 69). Though it could not be denied that Dirac had produced a physical theory, it was widely regarded as a peculiar one because its motivation appeared to be not physical argument but pure numerology. Dirac shared with physicist Sir Arthur Stanley Eddington a conviction that the pure numbers of physics hide some deep significance, but the majority of the physics community was not in sympathy with such ideas. Few physicists even bothered to respond to Dirac’s proposal.16 With or without Dicke’s argument, few physicists took the merely numerical relation between these parameters to be significant enough to require explanation, or even attention. However, even if Dirac's hypothesis is hare-brained, and even if it is false, these do not imply that Dicke's argument against Dirac is any good. In fact, they might make us suspect that we have assented to Dicke's argument too easily, because we agreed with its conclusion.17

Against Dirac, Dicke argued that in order for the numerical relation between three particular numbers to be likely to be a regularity holding at all times rather than an accidental feature of the present epoch, the present value of T would have to be 'regarded conceptually as a random choice from a wide range of possible values of T' (Dicke, 1961, p. 440). Only then could its present coincidence with the other numbers be evidence for a law holding between those numbers at all values of T; that is, at all times. But the present value of T could not, Dicke argued, be regarded as a random choice from a wide range of possible values. This was because the age of the universe (roughly, the value of T) at which human beings could exist to be observing was restricted, so he thought, to the ages when there would already have been stars that distributed heavy elements at their death, and when there would still be stars in the

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16 Dicke is one of only two physicists that I know of who troubled to respond to Dirac in print. In the 1950s, Dirac's cosmology with G varying as 1/t was widely regarded as falsified by an argument of EdwardTeller's which claimed that if G ~ 1/t, then the Earth was 110°C in the Cambrian era, which it could not have been, since we know there was life then. Teller's assumptions were later found questionable. Dicke, for his part, cannot have been offended by the mere idea that the gravitational constant might change over time, since in the same year he criticized Dirac's proposal, he published with Carl Brans a theory of gravitation in which the gravitational 'constant' depended on the structure of the universe through a scalar field which could vary not only in space but also in time. This, they thought, was more satisfactory than ordinary general relativity from the point of view of Mach's principle (see Kragh, 1996, pp. 68–69, 348).

17 Kragh (1996, p. 269) claims, without citation, that Dirac's hypothesis was falsified by measurements From the late 1970s Viking landers on Mars. As I understand the results of the Viking experiment testing General Relativity, they do not rule out Dirac's cosmology (Shapiro et al., 1977). In any case, for reasons that will shortly become clear, the truth or falsity of Dirac's hypothesis does not make a difference to the legitimacy of Dicke's argument against the evidence Dirac presented for it.

main sequence phase of their life cycles when they stably generate energy. For us to be observing anything, including these numerical values, he claims, some stars must already have died, and some must still be alive. 'It is well-known that carbon is required to make physicists,' Dicke (1961, p. 440) wrote, and (he might have added) that warmth is required to maintain them.

By a physical argument, Dicke expressed the maximum age of a still-burning star in terms of other parameters Dirac was concerned with, and this order of magnitude relation was the same as the order of magnitude relation between the Hubble age and the gravitational parameter that Dirac proposed holds at all times. In other words, Dicke argued that any time there are stars in main sequence (and some stars have already burned out), Dirac's coincidence must hold. Thus, he argued, the relation of these numbers to the present value of T is not an arbitrary data point to be generalized over. The physical requirements for the existence of human observers to draw out that relation tell us we do not have a right to think this is an unbiased sample (Dicke, 1961).

Notice that Dicke does not complain of Dirac's generalizing over a single instance, though he might well have. Dirac hypothesized that a relation holds at all times that he observed to hold at only one time, the present value of T. Dicke's complaint is not that Dirac had too few data points, but rather that the one he had cannot be regarded as a random sample. To express Dicke's conclusion in the language of the confirmation theorist, Dirac's instance does not confirm—is not evidence for—its generalization.18 Having more instances of the same sort would not change this. If Dicke is right, this does not imply that the generalization is not true. However, this instance was Dirac's only evidence for his generalization, so if Dicke is right there is no empirical reason to switch our allegiance to Dirac's hypothesis.

Dicke's argument is often compared to an argument we could make about the selectivity of a coarse-grained fishnet (Carter, 1983, pp. 138–139; Barrow & Tipler, 1986, p. 17, Earman, 1987, pp. 308–309). We notice what gets called a 'selection effect' in our evidence, when we recognize that catching, say, fish all longer than six inches does not give good grounds for concluding that all the fish in the sea are at least so long if the nets we used in the catching were not fine enough to hold anything shorter.19 Our evidence in such a case is selective, a biased sample, and therefore inconclusive. The gross structure of Dicke's argument corresponds well with how we reason about what we learn about our evidence from inspection of the size of the fishnet's holes. Finding that our net is too coarse to hold fish shorter than six inches does not allow us to conclude that not all fish in the sea are longer than six inches, but only that our catch is not evidence that all are longer than six inches. With respect to that hypothesis, our evidence is inconclusive. Likewise, Dicke's argument

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18 'Confirmation theory' is an umbrella term for efforts to define the confirmation relation, the relation thought to obtain between evidence and hypothesis when the first makes the second more probable.

19 For simplicity, I assume that fish are never wider than they are long. In addition, I ignore the possibility that small fish may be caught by a net with large holes if they get trapped behind big fish.

does not show that Dirac's hypothesis is false, but only that the evidence put forward for the hypothesis does not support it.

The selectivity of a coarse-grained fishnet is easy to picture; little fish are likely to be able to swim through big holes. In what is the selectiveness of Dirac's evidence supposed to consist? According to Dicke's assumptions, a casual human observer is likely to observe a universe with values in the relation Dirac notices if he observes anything about a universe at all, just as the coarse-grained net is likely to catch large fish if it catches any fish at all. And just as small fish, if there are any, are likely to escape a coarse-grained net, other relations of the gravitational parameter to the Hubble Age, if there are times when they exist, are likely to be unavailable to the human observer who observes those values only for the epoch during which she exists. (This, to repeat, is because Dirac's coincidence must hold any time she exists, since the physical requirements for her life include stars, some long dead, some still alive).

This is the upshot of Dicke's derivation of one of Dirac's coincidences from the maximum age of a still-burning star. Any time a human physicist exists to observe the relation of the numbers in question (or anything else), Dirac's order of magnitude coincidence will hold, regardless of whether it holds at all times, that is, regardless of whether Dirac's hypothesis is true. In particular, any time a human physicist exists to observe, Dirac's order of magnitude relation will hold even if Dirac's hypothesis is false.20 Dirac's coincidence is the only one of the possible relations of the gravitational parameter to the Hubble Age that human observers could have noticed at all using the methods that were employed.

It is important to keep firmly in mind what Dicke is arguing: the method through which Dirac's evidence was gathered makes it unsuitable for confirming Dirac's hypothesis. Dicke is not, in this argument, proposing a new cosmological hypothesis of his own. It is sometimes said that Dicke offered an alternative explanation of Dirac's coincidence (Barrow & Tipler, 1986, p. 219, 247), but this is a misleading way to reconstruct his argument. The only explanation Dicke offered was of the fact that if one used Dirac's method of gathering data one would be likely to get Dirac's outcome (regardless of whether his hypothesis was true). There is a loose sense of 'explanation' according to which this is an explanation of why Dirac got the outcomes he did, but we cannot afford to be loose here. It could not be an explanation of why these parameters had the values they did at a certain time, or why Dirac observed them at a certain time, and so is not an explanation that competes with, or in that sense provides an alternative to, Dirac's hypothesis. We are not

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20 The intuitions I appeal to here, about what makes evidence good or bad, are the same as those behind error statistical analyses of hypothesis-testing. A test is *severe* if and only if had the hypothesis been false the test was likely to have shown that. The same intuitions have been developed in general epistemology in the form of a counterfactual view of knowledge: what makes a belief knowledge beyond its being true is that the method you used to come to the belief would have made you believe that if it were true and would not have made you believe that if it were false. In such cases, our beliefs are said to be 'tracking' the world. See Nozick (1981, pp. 172–196).

dealing here with an alternative explanation but a criticism that purports to block a positive inference.21

To follow Dicke's reasoning is to recognize an instance of what Carter calls attention to with his WAP: 'What we can expect to observe must be restricted by the conditions necessary for our presence as observers' (Carter, 1974, p. 291). There is something right in Carter's idea, but far from being the tautology Earman (1987, p. 308) suggests it is, his principle is not even true. What we observe is not *necessarily* restricted by the conditions required for our existence. For consider the fact that due to the finite speed of light we can and do observe parts of the universe that existed billions of years before we could have existed. Light is a medium for this observation, to be sure, but light is a medium for most any observation we make in our local spatio-temporal neighborhood as well. Recognizing that our intellectual activities have physical requirements does not give us any grounds for claiming that what we observe must in every case be restricted by the conditions necessary for our existence in any way that could be stated a priori. Granted, we need to be alive to observe; but if we are clever enough, we gather evidence in our own life-supporting epoch or region about times and places in which we could not live or have evolved. It is crucial to the cogency of Dicke's argument for the claim that Dirac's evidence is selective that the only method through which Dirac had inspected instances of his hypothesis was observation of the epoch in which human beings happen to live.22

It is also inappropriate to claim, as Carter's principle does, that what is restricted is 'what we can *expect* to observe'. Given human beings' poor track record of imagining the possibility of observations their descendants actually made, we have no business declaring any restriction on what we can expect. What we can expect ever to observe is not known to us, and is fortunately irrelevant to the reasoning Dicke employed. The topic of the application of WAP is observations we have actually made, and their potential selectiveness. An improvement in formulation of the WAP would thus be: What we observe *may* be restricted by the conditions necessary for our presence as observers, as submitted above. In other words, for any observations made by human observers, it is possible that they are selective due to the conditions required for the existence of human observers. In normative terms, among the many things that threaten to make our evidence selective, we must include the conditions required for human existence. This correction of Carter's formulation is important to what I take to be significant about the WAP, namely that it exposes potentially deep biases of the human observer which nevertheless we do not have grounds for regarding as uncorrectable.

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21 These points should be kept in mind when evaluating a quite common sort of claim, e.g. when Garriga, Livio, and Vilenkin (1999) claimto have offered a possible *explanation* of the coincidence of three cosmological time scales on the basis of the conditions required for observers. Their considerations are strictly analogous to those of Dicke, and do not explain why the universe or our observations are as they are.

22 It is often possible for human observers to measure, and calculate, what things were (or will be) like in the universe at times when we do not and cannot exist. Measurements to test predictions of that sort had not been done with Dirac's numerical relation at the time when either he or Dicke was writing. In his response to Dicke, Dirac (1961, p. 441) proposes one way to do such measurements for this case.

Dicke's argument stands in striking contrast to strong anthropic approaches, and shows that the WAP is not a weak form of the SAP but a principle that works in the opposite direction. Dicke argued against, rather than in favor of, the significance of coincidences between the observed values of parameters, that is, against inferring a grand cosmological hypothesis from them. Advocates of strong anthropic approaches today are more analogous to Dicke's opponent Dirac than they are to Dicke. Typically, they observe fine-tuning, argue that it was a priori improbable, and conclude that this evidence makes it more probable that either God exists or there are many universes. Similarly, from the presumed improbability of the relation of values of parameters, Dirac inferred that a highly speculative general hypothesis was more probable. There is of course still a difference, in that Dirac's idea that all of the large numbers of physics were connected by physical law inspired formulation of a physical theory. We cannot say the same for SAP-God hypotheses or SAP many-world hypotheses that simply postulate the existence of a great many universes.

5. Copernicanism, Copernicus, and Kant

The WAP bears a different relationship to Copernicanism than does any of its strong cousins. It has been claimed by promoters of anthropic principles that all of these principles represent a limitation on the so-called Copernican Principle that human beings have no privileged status or position in the physical universe (Barrow & Tipler, 1986, p. 1; Carter, 1974, p. 291). Human beings are special, according to strong anthropic principles, since the universe was obliged to call us, or something intelligent like us, into existence. Human beings are special, according to the WAP, since our physical requirements for existence bring it about that we observe a privileged subset of the universe (Carter, 1974, p. 291). However, while the first claim makes sense, and shows that the SAP violates at least what we take to be the spirit of Copernicus's theorizing, I will argue that the second claim is confused and misleading. The subset of the universe human beings are restricted to observing, according to the WAP, is more accurately described as unrepresentative or biased, than as special or privileged. Moreover, as I will argue, if we understand the lesson of Copernicus on the basis of his reasoning to the claim that the earth might be moving rather than on the basis of his having denied the earth a central position in the universe, then we will see that the reasoning associated with the WAP is a case of reasoning like Copernicus, rather than a limitation on Copernicanism. Finally I will discuss the ways in which that reasoning was also the part of Copernicus's steps that Kant took himself to be imitating in the Critique of Pure Reason.

In his first piece of writing about the WAP, Brandon Carter framed the line of thought he was pursuing as ''basically … a reaction against exaggerated subservience to the 'Copernican principle''':

> Copernicus taught us the very valuable lesson that we must not assume gratuitously that we occupy a privileged *central* position in the Universe. Unfortunately there has been a strong (not always subconscious) tendency to

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> extend this to a most questionable dogma to the effect that our situation cannot be privileged in any sense. This dogma (which in its most extreme formulation led to the 'perfect cosmological principle' on which the steady state theory was based) is clearly untenable, as was pointed out by Dicke (Nature 192, 440, 1961), if one accepts (a) that specially favourable conditions (of temperature, chemical environment, etc.) are prerequisite for our existence, and (b) that the Universe evolves and is by no means spatially homogeneous on a local scale. (Carter, 1974, p. 291)

One might have thought that the perfect cosmological principle—the universe is Uniform in key respects in space and time—was motivated, not by thoughts of our Copernican heritage, so much as by a penchant to see the universe as maximally uniform. However, there is some relation between a tendency to see the universe as uniform and adherence to 'Copernican' tradition. The Cosmological Principle—the universe is uniform (homogeneous) at a large scale in space—that dominated cosmology from the 1960s to the 1980s, was often argued for as follows: we observe the universe to be isotropic at a large scale from here, and the only way the universe could be isotropic from here and yet not homogeneous would be if we occupied the center, an assumption that would be gratuitous.

This appears to be a good argument for the homogeneity of the observed and perhaps even the observable universe, given the evidence cited, but is much more speculative if the conclusion is meant to apply to the entire universe, observable and unobservable. The more general conclusion tended to be defended by statements such as 'we would not know how to do cosmology without assuming this.' (We have, in the meantime, learned how to do just that, for example with inflation.) This table-thumping sort of defense seems a sure sign that reasons ran out. When in doubt, though, why not extrapolate the 'Copernican' point? Thus, Carter is right that adherence to 'Copernicanism' had something to do with the dominance in cosmology of what we might call uniformitarianism.23

Carter is also right that application of the WAP can act as a check on this tendency, in the following sense: notice that an argument like Dicke's uses the fact that our evidence gathering activities have non-trivial physical conditions to convince us that putative evidence for a generalization claiming uniformity in the universe (in Dirac's case, that the current relation between parameters held at all times) does not count as evidence at all. There could be situations in which thus removing a putative evidential advantage the uniformity hypothesis has over its non-uniformity rivals levels the playing field and gives a hypothesis of non-uniformity a chance it would not otherwise have had.

Carter was correctly perceiving an exaggerated subservience to 'Copernicanism' in cosmology, and possibly elsewhere in science, that is, to what we generally take Copernicus to have taught us. And he describes what scientists and others take

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23 For discussion of indifferentism and uniformitarianism in the history of cosmology, consult McMullin

(1993) and Balashov (1994).

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Copernicus to have taught us more or less correctly: do not assume that our position is special, or that we are special. Barrow and Tipler put this sentiment in a vivid and recognizable form when they say:

> The expulsion of Man from his self-assumed position at the centre of Nature owes much to the Copernican principle that we do not occupy a privileged position in the Universe. (Barrow & Tipler, 1986, p. 1)

Their formulation highlights as well the fact that we congratulate ourselves for our humility in following this Copernican way. The image of expulsion potently evokes the conception of modern science as having denied and replaced a self-serving Christian theology in which God created nature specially for his creatures, with Man among them at the focus of His attention.24

However, after several centuries of anxiously avoiding naive self-love, we need to formulate what Copernicus has taught us epistemologically, in a more subtle way than talk of privilege, specialness, and self-centeredness has achieved, for there is a way in which this talk can become misleading. Suppose we are not special. From this we might infer that we are average, and from this that we are representative. From a representative sample one may infer that the whole population in question is the same. That is, we will have generalized to conclude to a uniformity. Indeed, to assume we are not special in any way should thus allow us to conclude that every thing, everywhere, is like us and our surroundings in all respects. But this is surely not what Copernicus has taught us.

Carter is right to think that the WAP represents a limitation on this crude idea of Copernicanism, though the language of privilege is not a sound way of formulating why, and I have rejected above his claim that our position is *necessarily* privileged. There is a more interesting way in which the WAP opposes the crude idea of what Copernicus taught us, and in opposing the crude idea carries on another aspect of Copernicus's insight. The idea that we must avoid thinking of ourselves as special encourages us to think that the best epistemic policy for arriving at objective knowledge is to ignore the subject, the one who observes, even to the extent of never considering that subject except as an object, an extended body, or a thing. The general notion of a selection effect, and the WAP, encourage in contrast the valuable recognition that we do not arrive at objective knowledge except by correcting for the biases of the observing subject, and, further, that one does not achieve this correction except through a great deal of *attention* to the observing subject. It is not only naive self-love, but also naive self-loathing or self-avoidance, that must be rejected to come to an objective view.

A more reasonable approach is to extend even further the range of application of the kinds of reasoning about selection effects and error induced by methods and

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24 This is not an accurate but a somewhat self-serving conception of the Christian-Aristotelian worldview that modern science shook. Note, for example, that the center of that universe was the location of hell, the firmament that of heaven. Being on earth was then almost as far from 'privileged' as a being could get.

instruments that observational and experimental scientists accomplish with facility every day. We extend it in this case to ourselves, the investigators. However, it is not because we are self-centered, or 'woolly humanists', that we conclude that paying attention to ourselves is crucial in this case. We observers are crucial rather because we happen to have been involved in the gathering of evidence whose quality we must judge. A common quipping response to anthropic principles points out that the same special physical conditions that were necessary for giving rise to human beings were also necessary for cockroaches, and asks why we are not talking about cockroaches. This may be a show stopping objection for the SAP, but the answer for the WAP is clear and easy: cockroaches do not do physics. If cockroaches start gathering evidence, and using it to argue for hypotheses, then we will talk about them.

Copernicus himself was far more sophisticated on this point than some of his latter-day followers are. To see this, we need to recall that Copernicus proposed not only that the earth is not at the center of the universe, but also that it moves while the stars remain stationary, and the latter is the more intriguing part epistemologically. When we consider one of the steps in his reasoning to the second conclusion, we will find that one of Copernicus' important steps on the way to heliocentrism was to notice an anthropic selection effect.

Copernicus could not deny that it is the heavens that appear to us to be moving, and we stationary. What he noticed, by paying careful attention to the fact that we observers are situated on the earth, is that this is how things might appear to us regardless of whether it was in fact the earth or the heavens in motion. If we are stationary, and the heavens move, then they will appear to us to move. If the earth is moving while the heavens are at rest, then from a point of view that is glued to the earth's surface the heavens will also appear to be moving. This is so as long as the observer on Earth could not feel her own motion, a point that Copernicus had difficulty convincing his opponents of because the physics in use was Aristotelian. Copernicus did, however, present an argument by analogy that we would not feel the motion:

> As a matter of fact, when a ship floats over a tranquil sea, all the things outside seem to the voyagers to be moving in a movement which is the image of their own, and they think on the contrary that they themselves and all the things

> with them are at rest. So it can easily happen in the case of the movement of the earth that the whole world should be believed to be moving in a circle. (Copernicus, 1952, I, 8)

If this point be granted him, then Copernicus has shown a selection effect in the evidence that says that the heavens appear to be moving.
Copernicus has drawn attention to an aspect of the (16th century) method of gathering evidence—the fact that we observed from the earth—that he suspects makes the primary evidence very likely to be our evidence regardless of whether the hypothesis that the heavens move is true or false. He has noticed that it could well be that even if the hypothesis that the heavens are moving is false, our method would not have detected that. Copernicus is quite conscious that what he has claimed is that

the evidence of the heavens appearing to move does not decide the question of whether they do. He says:[25]

> Although there are so many authorities for saying that the Earth rests in the centre of the world that people think the contrary supposition inopinable and even ridiculous; if however we consider the thing attentively, we will see that the question has not yet been decided and accordingly is by no means to be scorned. For every apparent change in place occurs on account of the movement either of the thing seen or of the spectator, or on account of the necessarily unequal movement of both. For no movement is perceptible relatively to things moved equally in the same directions—I mean relatively to the thing seen and the spectator. (Copernicus, 1952, I, 5)

He next cites the evidence crucial for showing the selection effect:

> Now it is fromthe Earth that the celestial circuit is beheld and presented to our sight. Therefore, if some movement should belong to the Earth it will appear, in the parts of the universe which are outside, as the same movement but in the opposite direction, as though the things outside were passing over. And the daily revolution in especial is such a movement. For the daily revolution appears to carry the whole universe along, with the exception of the Earth and the things around it. And if you admit that the heavens possess none of this movement, but that the Earth turns fromwe st to east, you will find—if you make a serious examination—that as regards the apparent rising and setting of the sun, moon, and stars the case is so. And since it is the heavens which contain and embrace all things as the place common to the universe, it will not be clear at once why movement should not be assigned to the contained rather than to the container, to the thing placed rather than to the thing providing the place. (Copernicus, 1952, I, 5)

Copernicus has argued that the evidence (of the time) did not represent a severe test for deciding whether it was the earth or the heavens that move.

We could consider this an ordinary selection effect if we regard the earth we stand on as a kind of instrument for observing. Yet we could also regard it as an anthropic selection effect, because the environment we happen to need (or rather, used to need) to observe from is what induces it. The second is preferable, I think, because as in a weak anthropic argument, and as is not so clearly the case with the selection effects induced by instruments, Copernicus in a single argument considers the observer both first-personally—by considering 'what we would see if … .'—and third-personally, as an object in the world that happens to be resting on another object, the earth. It is in combining these two ways of looking at an observer, privileging neither to the exclusion of the other, and discovering how each might constrain the other, that the distinctiveness of a weak anthropic argument lies. From this I conclude that the talk of Copernicus that often accompanies discussion of the anthropic principles is more

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25 Note that the question of whether the earth is in the center is linked with that of whether it moves since the appearances determine that either the earth or the firmament is moving in a circle. Since the movement is circular, only something at the center could be at rest.

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appropriate than the deflationary criticism of Earman (1987) admits. Yet, far from being a limitation on Copernicanism, the WAP exemplifies a certain key part of it.

A similar point can be made about the work of Kant, namely, that in an important sense it exemplifies Copernicanism while appearing to flout it. Examining this will also allow us to see a close relationship between Kant's critical philosophy and the WAP. Kant famously declared in the 1787 preface to his *Critique of Pure Reason* that the 'new method of thought' he was following in this work proceeded precisely along the lines of the 'primary thoughts of Copernicus' (Kant, 1929, p. 22). Kant's brief invocation of the astronomer has caused a good deal of confusion, and naturally so. Copernicus was the one who supposedly taught us that human beings are not at the center of the universe, geometrically or otherwise. Yet Kant, the transcendental idealist, came to a view in which the only world we ever have anything to do with or meaningfully talk about is the one that appears to us in experience. On Kant's view, there is an important sense in which the transcendental subject is even responsible for there being a world, and to that extent this subject is squarely in the center of everything there is. From these quick impressions, it seems something of a travesty for Kant to have associated such a subject-centered view with the good name of Copernicus.

The analogy Kant draws makes a great deal more sense when we recognize, as we have just above, that Copernicus did more than question the view that the earth was in the center of the universe. His question was not only about the earth's relative location, but also about whether it moved. It is Copernicus's thoughts about motion rather than centrality that Kant clearly has in mind when he describes his own project as analogous. He writes of Copernicus:

> Failing of satisfactory progress in explaining the movements of the heavenly bodies on the supposition that they all revolved round the spectator, he tried whether he might not have better success if he made the spectator to revolve and the stars to remain at rest. (Kant, 1929, p. 22)26

This 'experiment' (his word) that Copernicus tried is supposed to be analogous to the 'experiment' Kant would perform on metaphysics in his *Critique*. Metaphysics, the discipline which purported to arrive at substantive knowledge of the world without consulting empirical data but merely by taking thought (thus aiming for *synthetic* a priori knowledge), was in Kant's opinion a failure, in that it remained a continuous strife of systems, each side producing arguments for its own view and against its opponents', with no resolution.

Kant's experiment would show how to draw a line between the kind of metaphysical knowledge we could have and the kind we might as well give up on having by trying out, like Copernicus, the supposition that the spectator moves and that the world that appears to us is, in part, a consequence of the spectator's own

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26 The move Kant associates with Copernicus and himself is even clearer in Kant (1929, p. 25n.) where he writes that Newton's gravity would never have been discovered 'if Copernicus had not dared, in a manner contradictory of the senses, but yet true, to seek the observed movements, not in the heavenly bodies, but in the spectator'.

motion. As Copernicus argued that the stars' appearance of motion could equally well be due to the motion of the spectator's platform Earth, so Kant argued that many aspects of the organization of our experience—that it is spatial and temporal and involves causality, for example—are due to the 'motions' of the faculties of the mind, the Sensibility and the Understanding, as they work up the raw material they receive into objects. A priori knowledge of experience is possible on this view—i.e., we can know things like that every event has a cause—because we ourselves put these things *into* the objects of experience (Kant, 1929, p. 23). We do not have to consult experiences, but only our own minds, to know certain things about what all of our experiences will be like.

Of course, the claim that gets us assurance about what we think we know of objects of experience—that these features of the objects of experience are contributed by the mind's organizing activities—has an important price. For it follows from these things' being our contribution that we have no grounds for believing that they indicate the way things are in themselves, apart from human experience. When Copernicus considers that the Earth may be moving, he realizes that we have no right to read the appearances literally as an indication of how the world is—the apparent movement of the stars may be an artifact of our method of experiencing. Analogously, on Kant's view of how experience is produced, we have no right to take that experience literally as a guide to reality. This is the way experience would be for us *regardless* of how things may be in themselves.

Similarly, the parameters standing in the relation Dirac noticed is how we would experience the universe, if we did so casually, *regardless* of whether the universe is always so. Dirac's evidence was not good enough to speculate as far as he did, just as, according to Kant, the traditional metaphysician's evidence did not warrant his speculation. The WAP thus shares with Kant's philosophy the aspect of it that made him call it 'critical' rather than 'dogmatic.' It also shares with the philosophy of Kant the fact that the limitations that lead the WAP to critical caution follow from our nature as human beings; in both cases, it is not by ignoring human beings, but by paying careful attention to the human subject, that we become more objective. For Kant, it was the nature of our minds that led to limitations, for the WAP the nature of our mental capacities' embodiment. Finally, as with Kant's conclusions, the scope of the things that give us limitations is dramatic; just as the actions of Sensibility and Understanding are necessary not just for this or that experience but for all possible experience, so the existence of stable nuclei (for example) is necessary not just for this or that experience but for all possible experience of human beings, because it is necessary for life as we know it, and without life no one has any experiences.

There remains an important sense in which the WAP is different from Kant's critical philosophy. When Kant gave an account of the workings of the mind in building up experience and otherwise, he took himself to be canvassing all of the 'tools' (Sensibility, Understanding, Reason) the mind would ever have, and to be giving an exhaustive account of the 'methods' these tools could employ. Most also think that Kant regarded his account of these things as immune to revision. As a consequence, the limitations on our knowledge of reality that he derived were not understood as temporary setbacks, to be overcome through ingenuity, but as final

pronouncements on our capacity for knowledge. The physical conditions of human existence that the WAP attends to are not likely to change any time soon. However, nothing follows from those physical conditions about what cognitive methods we can employ to secure observations. When we are clever, we gain evidence about times and places we probably could never live to observe in.

We cannot change the conditions we require to live, but we can either gain evidence cleverly or build spaceships to take our requirements with us to more hostile terrain. Nothing about our having physical requirements tells us a priori that the methods we use today could not be outdone in either of the ways I have mentioned (even if they cannot be outdone as a matter of fact), so the caution that the WAP counsels pronounces no final verdict of doom on our attempts at greater knowledge of the universe. In this, the WAP avoids repeating the aspect of Kant's system which has caused his admirers the greatest embarrassment in the face of later advances in science, such as non-Euclidean geometry (which some think Kant's account of the mind declared impossible) and quantum mechanics (which does without a universal version of Kant's principle of causality). The WAP avoids commitments about the limits of possible knowledge.

Many philosophers today, even many of Kant's admirers, admit that Kant's view was itself a dogmatic metaphysics—because of his claim to know how the mind is and what its limitations are—despite the fact that his overriding aim was to avoid this particular foible of his predecessors. The reasoning associated with the WAP has some claim to be the inheritor of all that is best in Kant, since it continues the questioning Kant began about the conditions of all possible human experience, without declaring—as if we knew—the limits of all possible knowledge. The WAP also appears to be the only thing worth preserving, for physics, of the colorful carnival of anthropic suggestions.

References

Aguirre, A. (2001). Cold big-bang cosmology as a counterexample to several anthropic arguments. Physical Review D, 64 (083508) 1–12.

Balashov, Y. V. (1994). Uniformitarianism in cosmology: Background and philosophical implications of the steady-state theory. Studies in the History and Philosophy of Science, 25, 933–958.

Barrow, J. D., & Tipler, F. J. (1986). The anthropic cosmological principle. New York: Oxford University Press.

Carter, B. (1974). Large number coincidences and the anthropic principle in cosmology. In M. S. Longair (Ed.), Confrontation of cosmological theories with observational data (pp. 291–298). Boston: Reidel.

Carter, B. (1983). The anthropic principle and its implications for biological evolution. Philosophical Transactions of the Royal Society of London A, 310, 347–363.

Collins, C. B., & Hawking, S. W. (1973). Why is the universe isotropic? The Astrophysical Journal, 180, 317–334.

Copernicus, N. (1952). On the revolutions of the heavenly spheres. Chicago: Encyclopaedia Brittanica, Inc..

Dicke, R. H. (1961). Dirac's cosmology and Mach's principle. Nature, 192, 440–441.

Dirac, P. A. M. (1937). The cosmological constants. Nature, 139, 323.

Dirac, P. A. M. (1938). A new basis for cosmology. Proceedings of the Royal Society of London, Series A, 165, 199–208.

Dirac, P. A. M. (1961). Response to Dirac's cosmology and Mach's principle. Nature, 192, 441.

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Dowe, P. (2000). The inverse gambler's fallacy revisited: Multiple universe explanations of fine-tuning. Manuscript.

Earman, J. (1987). The SAP also rises: A critical examination of the anthropic principle. American Philosophical Quarterly, 24, 307–317.

Garriga, J., Livio, M., Vilenkin, A. (1999). Cosmological constant and the time of its dominance. Physical Review D, 61 (023503) 1–9.

Hacking, I. (1987). The inverse gambler's fallacy: The argument from design. The anthropic principle applied to wheeler universes. Mind, 96, 331–340.

Hogan, C. J. (2000). Why the universe is just so. Reviews of Modern Physics, 72, 1149–1161.

Jordan, P. (1952). Schwerkraft und weltall: Grundlagen der Theoretischen Kosmologie. Braunshweig: F. Vieweg.

Kant, I. (1929). Critique of pure reason (Norman Kemp Smith, Trans). New York: St. Martin's Press.

Kragh, H. (1996). Cosmology and controversy: The historical development of two theories of the universe. Princeton: Princeton University Press.

Leslie, J. (1988). No inverse gambler's fallacy in cosmology. Mind, 97, 269–272.

Leslie, J. (1989). Universes. London: Routledge.

Linde, A. (1994). The self-reproducing inflationary universe. Scientific American, 271, 32–39.

Mayo, D. (1996). Error and the growth of experimental knowledge. Chicago: University of Chicago Press.

McGrath, P. J. (1988). The inverse gambler's fallacy and cosmology—A reply to Hacking. Mind, 97, 265–268.

McMullin, E. (1993). Indifference principle and anthropic principle in cosmology. Studies in the History and Philosophy of Science, 24, 359–389.

Nozick, R. (1981). Philosophical explanations. Cambridge, MA: Belknap Harvard University Press.

Parfit, D. (1998). Why anything? Why this? London Review of Books 20 (22 January) 24–27.

Shapiro, I. I., et al. (1977). The Viking relativity experiment. Journal of Geophysical Research, 82, 4329–4334.

Smolin, L. (1997). The life of the cosmos. New York: Oxford University Press.

Tipler, F.J. (1982). Anthropic-principle arguments against steady-state cosmological theories. The Observatory: A Review of Astronomy, 102, 36–39.

Weinberg, S. (1989). The cosmological constant problem. Reviews of Modern Physics, 61, 1–23.

Weinberg, S. (1992). Dreams of a final theory. New York: Pantheon Books.

White, R. (2000). Fine-tuning and multiple universes. Nous, 34, 260–276