

## The scientific status of the weak anthropic principle

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### I. Abstract

In this paper, I seek to determine whether or not the weak anthropic principle can be considered scientific by investigating various applications of the principle and evaluating each according to multiple criteria for what constitutes science. The applications I consider are William Paley's argument for the necessary form of the law of gravitation, Fred Hoyle's discovery of a resonance level necessary for carbon nucleosynthesis, Robert Dicke's explanation of some 'large number coincidences' in cosmology, and a debate between Leonard Susskind and Leo Smolin over the scientific status of the principle. The scientific criteria I develop and utilize are predictive power, explanatory power and heuristic power. I ultimately conclude that given the possibility that the universe is actually a 'multiverse,' the weak anthropic principle is scientific when the topics under consideration are physical constants and laws since 'anthropic selection' of these fundamental parameters provides a satisfactory explanation of their values and forms respectively.

### II. Introduction

What can we conclude given that we exist? Strict adherence to what is now often referred to as the Copernican principle—the idea that our place in the universe is of no importance whatsoever—would lead one to quickly dismiss this question. Before Copernicus made the first in a series of dislodgements of the supposedly privileged human position within the cosmos, most people believed this question to be of great importance. In pondering the apparent 'fine-tuning' of the universe for life, many humans came to believe that everything was made for them. Of course we now know that everything does not pivot on our existence, but is there any sense in which our position within the cosmos is special?

After some reflection, it is clear that the answer is yes: our position is privileged to the extent that our location must be suitable to the emergence of intelligent life, otherwise we would not exist. Although this is a simple and indisputably true fact, the idea behind this reasoning was not given a specific formulation until Brandon Carter (1973) coined the term "anthropic principle" to describe the concept in context to cosmology. He defined this term to represent the idea that "what we can expect to observe must be restricted by the conditions necessary for our presence as observers" (p. 291). He later called this the weak anthropic principle (WAP) to distinguish it from other possible formulation of the principle, the strong anthropic principle (SAP), which he defined as the idea that "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" (Ibid., p. 293). Referring to these principles as "anthropic" is somewhat misleading because they are intended to be valid for any form of life, but nevertheless the term has taken hold.

Much of the criticism of SAP stems from its frequent employment as an intelligent design argument. At this time, the general consensus among scientists is that SAP belongs to the realm of theology or philosophy, although some cautiously posit that the principle may be defensible (Davies, 2006, p. 251–293). On the other hand, although WAP itself is not contested by

scientists, there is currently a fierce debate over whether the principle can be considered scientific, and there are many prominent scientists in each camp. It is the intensity of this debate that lead me to focus on the scientific status of WAP for this paper. The main goal of my investigation was to clarify the opposing positions in the debate and to discern which side has the superior arguments. In the interest of having a more focused discussion, I only dealt with WAP as used in the field of cosmology. Also, instead of dealing with generalities, I felt it was better to investigate specific applications of the principle then analyze each according to multiple criteria for what constitutes science. This case study/multiple criteria approach has flexibility and broader scope in not adhering to any particular criterion while at the same time permitting in-depth discussion of a variety of applications of WAP.

In selecting the case studies, I sought to pick some of the frequently discussed applications while also making the set representative of different ways in which WAP is used. The applications I chose to consider are William Paley's argument for the necessary form of the law of gravitation, Fred Hoyle's discovery of a resonance level necessary for carbon nucleosynthesis, Robert Dicke's explanation of some 'large number coincidences' in cosmology, and a debate between Leonard Susskind and Leo Smolin over the scientific status of the principle. This follows the case study approach taken in the book *The Anthropic Cosmological Principle* by John Barrow and Frank Tipler (1986). With the exception of the debate between Susskind and Smolin, Barrow and Tipler discuss each of the case studies I chose, however they do not consider the implications of each for the scientific status of WAP. To my knowledge, a case study approach coupled with consideration of multiple science criteria has not been taken before, so this paper provides a novel approach to the subject.

Before beginning the case studies, I first summarize the current state of the debate and discuss the criteria of science that will be used. The ideas sketched in these sections are then developed throughout the paper. After considering all the case studies, the explanatory power criterion emerges as the most important in determining scientific status. I ultimately conclude that given the possibility that the universe is actually a 'multiverse,' the weak anthropic principle is scientific when the topics under consideration are physical constants and laws since 'anthropic selection' of these fundamental parameters provides a satisfactory explanation of their values and forms respectively.

### III. The State of the Debate

One of the first strong critiques of WAP was given by M. J. Carr and B. J. Rees (1979) in a paper reviewing various uses of the principle. They end this paper by noting four primary weaknesses with the principle. They contend that WAP (1) is an entirely post hoc form of reasoning, (2) is overly anthropocentric in its approach as it can only consider carbon-based life, (3) can only provide order of magnitude bounds on physical parameters and (4) lacks a mechanism that could produce variations in physical parameters. Given these weaknesses, they conclude that WAP "may never aspire to being much more than a philosophical curiosity" (Ibid., p. 612). I mention this paper because (1), (2) and (3) are still used as criticisms of the principle today and because possible responses to (4) that have emerged in recent years have greatly increased interest in the principle.

As for (1), although it is true that the vast majority of uses of WAP are after-the-fact analyses, WAP is not inherently unable to make predictions. Nevertheless, most uses of WAP are undeniably post hoc. Although there is nothing technically wrong with post hoc reasoning, confidence in the principle would be increased if it were to make more numerous predictions

rather than simply conforming to observed facts. Point (2) tries to establish that the scope of WAP is restricted by our lack of knowledge of other forms of life. This weakness does not come directly from the principle itself, but stems from the limitations of our imagination. Since we only have knowledge of carbon-based life, we are not in a position to declare which features of the universe are necessary for the emergence of intelligent life. One could object to (2) by noting that although the WAP is restricted in this sense, it does not endeavor to make claims about anything other than carbon-based life so (2) is irrelevant. Finally, (3) seeks to expose another inherent weakness of WAP in that bounds on physical parameters can generally only be set to within an order of magnitude. The imprecision of such bounding could lead one to question its usefulness.

If it were not for recent advances in cosmology, (4) would have remained a strong objection to WAP and interest in the principle would likely have diminished. Instead, since various mechanisms for creating variation in physical parameters have been advanced in the past few decades, interest in WAP has greatly increased. To name a few, eternal inflation, symmetry breaking, and string theories all permit such variation. If any of these theories proves correct, what were previously thought to be unchanging features of the universe become ‘environmental’ parameters in that they are allowed to assume different values in different regions of the universe. Such a universe that is actually a patchwork of distinct regions is now often referred to as a “multiverse.” Confusingly, this term is used to represent other ideas as well, such as the creation of parallel universes with every measurement in accordance to the many-worlds interpretation of quantum mechanics. This and other possible types of multiverses will not be considered in this paper.

Physicists currently have mixed opinions toward the multiverse hypothesis. Some reject it on the basis that a Theory of Everything (TOE) would show that physical parameters are fixed by mathematical necessity. Others reject it based on the belief that it would be impossible to prove the universe is actually a multiverse. To give an example, David Gross is one prominent physicist that strongly believes the scientific community should continue striving for a TOE and that WAP explanation of physical parameters is a dangerous distraction. In a 2003 debate on anthropic reasoning, Gross vividly expressed his sentiment toward WAP by saying the following: “My feeling is that anthropic reasoning is a kind of virus that people get infected with, and once infected are lost forever” (Hawking et. al., 2003, 55:00). After making similar points as Carr and Rees, Gross adds that WAP is defeatist, dangerous, ahistorical and unfalsifiable. He contends that anthropic explanations only serve to distract from searching for deeper explanations. On the other hand, Steven Weinberg, who also attended the debate, disagreed with Gross’s analysis of WAP by arguing that—however seemingly unsatisfying or disappointing an explanation it may be—WAP cannot be ruled out as a possible explanation of the values of physical parameters (Ibid., 1:04:00). These opposing viewpoints can be seen as a product of two different reactions to the suggestion that cosmology may be reducible to a kind of environmental science in which ‘anthropic selection’ (a phrase meant to draw parallels with natural selection) determines what constants and laws we observe in this region of the multiverse. Overall, the disagreement between Gross and Weinberg suggests that one’s attitude toward WAP is likely influenced by which cosmological model one is ultimately willing to accept.

The views expressed by Gross and Weinberg are characteristic of some the main arguments advanced today for and against the use of WAP, but this is only meant to be a sketch of the debate at a general level—more specific arguments will be presented in the following sections. Furthermore, for the purposes of this paper I will be analyzing these arguments in

context to their relevance to the scientific status of WAP. It must be admitted that the debate is not split entirely on the issue of scientific status. For instance, Weinberg is a supporter of the principle and yet admits that he does not think it is scientific, instead calling it a “guess at the shape of a future science” (Ibid., 1:04:45). Nevertheless, only considering the debate as a disagreement over scientific status is justified because the majority of opponents of WAP make scientific status the foundation of their critiques.

#### IV. What Counts as Science?

What counts as science? A quick survey of the philosophy of science literature on the topic leaves one with the impression that there is little hope of ever finding a definite answer to the question. In the absence of any well established criterion for determining what constitutes science, the possibility of determining the scientific status of WAP may seem dubious. However, much about the strengths and limitations of the principle can be discovered by developing various plausible criteria for what constitutes science and then referencing each criterion when relevant. There are many different candidates, but the ones I will discuss here are predictive power, explanatory power and heuristic power. It is of course possible for these criteria to overlap, but they each add something distinct to the picture. The predictive power criterion represents the ‘traditional’ stance whereas the other two offer alternate conceptions of science. There are no accepted definitions for these criteria and there are different formulations that are defensible, but I believe my formulations are all intuitively plausible.

The predictive power criterion will dictate that for any principle to be accepted as scientific it must be able to produce multiple testable predictions. This criterion is probably the most frequently cited in any discussion on the nature of science. It also seems to be the most clear-cut of the three, but some difficulty arises in deciding whether to allow what I will call postdictions. A postdiction can be loosely defined as any instance in which the use of a principle produces conclusions that prove to be consistent with things already known to be true. There is arguably nothing wrong with a principle whose use produces many more postdictions than predictions, but we certainly would be more confident in a principle from which the number of predictions are at least as numerous as the number of postdictions. We sense something fishy in a principle that can tell us little more than what we already know. It is on this issue that this criterion has the potential to take a different stance than one of the most commonly cited criteria of science: falsifiability. I have chosen not to make falsifiability a separate criterion because a predictive power criterion that only permits testable predictions is essentially the same. However, a predictive power criterion that allows postdictions is not in agreement with the falsifiability criterion. Rather than deciding now whether or not to allow postdictions to count, I consider this issue in one of the case studies.

The explanatory power criterion will dictate that any proposed hypothesis must provide a *satisfactory* explanation of why its prediction conforms to the observed facts in order to be considered scientific. It is difficult to define precisely what should be meant by ‘satisfactory’, and one may suspect that this criterion swaps the problem of defining science with an equally difficult problem of defining what constitutes a satisfactory explanation. However, I believe that one of the more accessible and intuitive ways of thinking of the idea of a satisfactory explanation is given by Bas van Fraassen (1980) in his book entitled *The Scientific Image*. Fraassen contends that explanation at its most fundamental level is an answer to a ‘why’ question, and he lays out a model of explanation based on this idea (Ibid., p. 134–157). With this in mind, one way of deeming an explanation satisfactory is if it provides a suitable answer as to *why* the phenomenon

in question takes place. This general requirement will prove adequate for my analysis. Overall, the explanatory power criterion is unique since it emphasizes science's need to provide cogent and cohesive explanations rather than just to produce results.

I will define the heuristic power criterion to dictate that for a principle to be considered scientific, it must offer unique insights that cannot be obtained through other methods, yet falls short of being able to make testable predictions by itself. One example of a tool that fulfills this criterion is dimensional analysis. A full justification of why dimensional analysis is of great heuristic power will be given in a case study. This criterion is unique in that it places emphasis on the process of discovery rather than just on the production of results when determining scientific status. The heuristic power criterion has the ability to be the most general of the three as there are many different features of any given principle that could be considered to be of heuristic utility. As this generality would make the criterion overlap significantly with the others, I take a narrow interpretation of heuristic power that will allow it to capture a possible interpretation of science yet to still remain distinct from the other interpretations.

So what are the possible outcomes of this multiple criterion analysis? If WAP fails to fulfill the conditions of any of these criteria, then we have very good reason to doubt that it can be considered a part of science. On the other hand, if various applications of the principle can fulfill all these criteria, then we can conclude the opposite. What will happen, however, is that any particular instance of the principle's use will only fulfill one of the three criteria and the extent to which it fulfills the criterion will be debatable. It ultimately will take a careful analysis to decide which conclusion the weight of evidence suggests.

## V. Case Study 1: Paley and the Law of Gravitation

For my first case study, I will discuss William Paley's argument involving the form of the law of gravitation laid out in his book *Natural Theology, or Evidences of the Existence and Attributes of the Deity* (Paley, 1802). This work seeks to demonstrate the existence of a creator by arguing that the complexity of the natural world can only be the product of intelligent design, and thus is essentially an application of the SAP. Most of the book restricts its focus to biological examples, but Paley does devote one chapter to consideration of coincidences in astronomy that call out for explanation (Ibid., p. 409–438). The section of interest for this paper is Paley's argument that if the form of the law of gravitation were slightly different, we could not exist. Although Paley's approach is teleological in that his ultimate goal is to establish God as the cause of all life, his argument is relevant for this paper because it can be moderated to make it consistent with WAP and because it will provide much insight into issues relevant to the scientific status of WAP.

Paley's argument consists of three claims: (1) there could have been other forms of the gravitational law, (2) only a small number of forms of the law allow for a stable, life supporting solar system and (3) the law we observe is the most beneficial of all possible laws. Paley takes (1) to be self-evident. In support of (2), Paley performs counterfactual analysis by considering what the solar system would be like if the law of gravitation were different. He concludes that the gravitation force between two objects must be approximately proportional to the inverse square of the distance between them in order to maintain stable orbits:

I must underrate the restriction, when I say, that in the scale of a mile they are confined to an inch. All direct ratios of distance are excluded, on account of danger from perturbing forces: all reciprocal ratios, except what lie beneath the cube of the distance, by the demonstrable consequence, that even the least change of distance, would, under the operation of such laws, have been fatal to the repose and order of the system (Ibid., p. 426–427)

In support of (3), Paley argues that an inverse square law is best suited to preventing perturbations in orbits to compound over time. In light of these three observations, Paley concludes that the only explanation given the sheer improbability of the law of gravitation being of a form suitable for life by chance is that the law was deliberately picked by a creator.

The view that the universe is fine-tuned for life is certainly appealing to those looking for evidence of design, and it is an idea that still carries much force in the present day. However, the religious implications of anthropic arguments are not meant to be the focus of this paper. Rather, the question of interest is whether Paley's argument can be considered scientific. To answer this, I will only consider the portion of his argument that is consistent with WAP, thus removing any mention of a designer from consideration. I am stripping down the argument in this way for a few reasons. First, it is only Paley's conclusion that is teleological; the anthropic observations he makes are very much in the spirit of WAP. Secondly, the general form of his argument is similar to current arguments using WAP. Lastly, his argument will be very useful in illustrating important aspects of the debate concerning the scientific status of WAP. For this modified argument, I take its purpose to be to explain why the law of gravitation has the form we observe it to have. This is not all that different from Paley's argument as he spends most of his time establishing the necessary bounds on the law. Only his interpretation of these constraints is teleological.

Paley's approach is an instance of what I will call anthropic bounding, a placement of limits on the possible form of laws or constants required by our existence as observers. It is for this reason that WAP is often identified as an observer selection effect. If we take the results of Paley's counterfactual analysis to be correct, we can conclude that the gravitational force between two objects must be approximately proportional to the inverse square of the distance between them. Now, one could object to this by claiming that Paley was simply not ingenious enough in his analysis. Perhaps there is a stable configuration of orbits that is possible with an inverse cube relationship. Likewise, there could be a law of gravitation having, say, ten terms which also allows stable orbits. This 'lack of ingenuity' objection is commonly used against anthropic arguments and is an issue that must be addressed at some point, but for now let us assume that Paley's counterfactual analysis was completely exhaustive and the bounds on the law are correct.

Now does the fact that counterfactual analysis showed that the law of gravitation could not have been otherwise provide a satisfactory *explanation* as to why the law has the form it does? To investigate this point, I wish to make a lengthy but instructive analogy. Consider the following two statements:

A: The sun radiates light primarily in a particular frequency range in the electromagnetic spectrum.

B: Most organisms have eyes that are sensitive to the same frequency range.

Both statements *A* and *B* are true, but does *A* explain *B* or does *B* explain *A*? Here I take arrows to indicate an explanatory relationship between the statements (i.e.  $A \rightarrow B$  means that *A* is the reason why *B* is the case).

$$A \rightarrow B$$

That the sun radiates light in a particular frequency range explains why organisms that emerge near the sun are more likely to develop eyes that are sensitive to that portion of the spectrum.

$$B \rightarrow A$$

That most organisms have eyes that are sensitive to a particular frequency range explains why the sun radiates light primarily in that frequency range.

It is accepted that  $A$  explains  $B$ . One might think that our eyes' sensitivity to particular frequencies of light must be explained by describing the physiology of the eye, but that sort of explanation merely describes how the eye works, not why it is the way it is. The eye itself is a product of evolution, and it is easy to imagine how natural selection over many generations would lead organisms' eyes to become sensitive to the most abundant type of light. But can  $B$  explain  $A$ ?  $B$  is consistent with  $A$ . In fact, if  $B$  is true then  $A$  is likely to be true as well. Nevertheless, the reason why the sun radiates light in a particular frequency range has nothing to do with the properties of life that happens to emerge near it. The only way to provide a real explanation of  $A$  is to understand the physics of thermal radiation.

This point is summarized well in the following quotation by Roger White (2005): "Human observational limits no more explain why any observed conditions took hold than the use of a fishing net with large holes explains the length of any fish. In each case it is only one's failure to make contrary observations that is explained" (p. 220). In other words, our presence must be consistent with our surroundings and the surroundings must be consistent with our presence, but our presence cannot explain why the surroundings are the way they are. With this analogy in mind, it is now clear that Paley's counterfactual analysis cannot be seen as an explanation of why the law of gravitation has the form that it does. That the law must be constrained within certain limits in order for us to exist no more explains its form than organisms' possession of eyes sensitive to a particular frequency range explains why the sun's peak radiated frequency is in that same range.

Compare this attempt at explanation with a currently accepted explanation of the law of gravitation which argues that the form of the law is dictated by the number of spatial dimensions. The geometry of three dimensions requires that the density of the gravitational field lines diminish as the inverse square of the distance from an object. This explanation does not possess the weaknesses of the WAP explanation. Interestingly, Paley actually considers and rejects this explanation:

There is, I know, an account given of attraction, which would seem, in its very cause, to assign to it the law, which we find it to observe, and which, therefore, makes that law, a law, not of choice, but of necessity: and it is the account, which ascribes attraction to an *emanation* from the attracting body. It is probable, that the influence of such an emanation will be proportioned to the spissitude [density] of the rays, of which it is composed: which spissitude, supposing the rays to issue in right lines on all sides from a point, will be reciprocally as the square of the distance. The mathematics of this solution we do not call in question: the question with us is, whether there be any sufficient reason to believe, that attraction is produced by an emanation (Paley, 1802, p. 423)

Paley accepts the mathematical grounding of this argument, but his objection rests on his doubt in the existence of a gravitational "emanation". It would have been interesting to know his response had he been convinced of its existence.

I have demonstrated that this application of WAP fails to provide a satisfactory explanation of the phenomena in question. If the criteria for what constitutes science consisted solely of explanatory power, we could deem this application of WAP as unscientific. But what about the other potential criteria? The one I wish to consider for this case study is heuristic power. More specifically, does the heuristic power of anthropic bounding make WAP scientific?

I first wish to make an analogy between WAP and dimensional analysis that I believe will aid in answering this question.

Dimensional analysis (DA) is undoubtedly useful as seen by the fact that it is a tool taught to all physics students as a way of both checking and discovering answers. No one would base a hypothesis solely on DA, but does DA deserve special recognition because of its ability to provide bounds on possible solutions?

Consider the following statements:

- A. If an equation is correct, then it must be dimensionally sound.
- B. If an equation is dimensionally sound, then it must be correct.
- C. If an equation is dimensionally sound, it is more likely to be correct.

It is clear that statement *A* is true and statement *B* is false. But what about statement *C*? After some reflection, we must invoke a principle of simplicity for *C* to be true. Since there are an infinite number of dimensionally sound possibilities, DA would be useless unless we expect the result to be relatively simple. To give an idea of what is meant by simplicity, an example of an unnecessarily complex equation would be one which has many superfluous terms that have no physical significance or have no grounds in previous theories. Statement *D* below adds the needed clause:

- D. If an equation is dimensionally sound and if the universe is such that the result must be relatively simple, then the equation is more likely to be correct.

If statement *D* is true, then DA can be considered as more than just a way of checking answers or providing a shortcut to the correct answer. It is a tool that makes use of the intelligible nature of the universe to significantly narrow down the set of possible solutions. This is one way in which DA offers unique insights. As further evidence of its unique usefulness, one can find numerous examples from the history of science in which DA played a central role in the development of new theories. To name one, DA was used extensively during the development of quantum physics, particularly in determining the significance of Planck's constant (Barrow & Tipler, 1986, p. 222). In this case, DA was one of a limited number of tools available to physicists trying to work out the fundamentals of quantum physics. With these considerations in mind, DA has undeniable heuristic power.

If we consider anthropic bounding to be analogous to DA, then WAP has an equal potential to offer unique insights and thus fulfill the heuristic power criterion. It is reasonable to assert that before the law of gravitation was discovered, one could have used anthropic counterfactual analysis to narrow down the number of possibilities. Thus, using WAP could have helped discover the law more quickly by restricting attention to forms permitting stable planetary orbits. This falls short of predicting the law of gravitation and so the predictive power criterion does not apply, but the ability to speed up discovery of the law gives it the potential to fulfill the heuristic power criterion. Before we can decide this matter, we must deal with the 'lack of ingenuity' objection I set aside earlier.

Similar to the step that had to be taken in the case of DA, we must make an appeal to simplicity in order for us to place confidence in WAP. Such an appeal to simplicity allows us to dismiss possible forms of the law that have a seemingly arbitrary number of terms. This may seem to sufficiently narrow the set of possible solutions, but there is still a nagging concern.

Given the inherent imprecision of anthropic counterfactual analysis, we cannot predict a specific value, we can only impose bounds based on the conditions for our existence which cannot be known to arbitrary precision. In the case of the law of gravitation, the great sensitivity of orbits to the exponent of the radial distance only allows a small range of values, but a finite range nevertheless. It would seem that we would have to allow the possibility of the law varying inversely as the distance to the, say, 2.00000016 power.

I picked this particular number to make a point. This was the number used by Asaph Hall (1894) in trying to explain the anomalous precession of the perihelion of Mercury. Since the deviation of the precession from the calculated value was so small, Hall was led to entertain the idea that the law of gravitation could actually vary as  $1/r^{2+\delta}$ , where  $\delta$  is a small fractional number. Hall found that a delta of 0.00000016 made the calculated value of the precession agree with the observed value. Luckily, this is not a viable possibility. Even the addition of such a small amount proved to have significant consequences in other areas that permit us to reject it as a possible form for the law. This is desirable since it allows us to remove many more possibilities from the solution set without having to make a more extensive appeal to simplicity.

Interestingly, the case could be made that the only remaining solution in the set is an inverse square law—powers of one or less and three or more excluded out of stability considerations and fractional powers between one and three ruled out by their ‘butterfly effects’. However, it must be emphasized that the ability to rule out all but one possibility is atypical of anthropic bounding. We can only expect to do so in a very small number of cases, and probably only when we already know the answer. Indeed, one might object that this example is contrived seeing as the counterfactual analysis was done only after knowing the correct law. Nevertheless, it is possible to imagine a case where a law is unknown and explanation of the phenomena in question is either impossible or would require insight too far removed from the present understanding. In this situation, WAP offers a possible avenue for making progress toward understanding the necessary bounds in the hopes that this insight will facilitate further discovery. This is analogous to how DA helped physicists to find their footing when trying to develop quantum physics.

However, even if we declare that WAP has undeniable heuristic power, this may do little to convince many that it is wholly scientific. Although I have made a case for DA having the ability to make unique insights and contributing to the development of new theories, on an intuitive level, people will always have trouble considering DA to be scientific in a similar sense as experiential confirmation of mathematically derived predictions is scientific. If this is the case for DA, then the outlook will certainly be worse for WAP. I had to resort to describing what WAP could *in principle* do to advance our knowledge. In the absence of examples in which the anthropic bounding makes before-the-fact insights, it is on less secure footing than DA. In light of these considerations, fulfilling the heuristic power criterion cannot yet convince us that WAP is scientific.

## VI. Case Study 2: Fred Hoyle and the Stellar Nucleosynthesis of Carbon-12

Now we fast forward 150 years and arrive at 1952, a year in which one of the most cited predictions using WAP was made. Fred Hoyle was seeking to understand the processes that occur within stars to produce heavier elements, carbon in particular. At the time, the creation of a significant amount of carbon within stars seemed impossible since it first required two helium nuclei to collide to form an unstable beryllium atom, then a third helium nucleus to collide with

the beryllium atom before it decayed. At this point, WAP enters the picture. Hoyle knew that there had to be a way for this reaction to proceed because Hoyle himself and all the living things around him were primarily composed of carbon. This led him to entertain the possibility that the reaction could proceed resonantly if carbon were to have an excited state of a certain energy. This resonance would allow the unstable beryllium atom to exist long enough for there to be an appreciable chance of it being hit by a helium nucleus. Hoyle was then able to predict precisely the value which this previously unknown energy level must have. The existence of the energy level was then verified by an experiment within a year.

That WAP played a role in predicting a previously unknown property of the universe appears to be good news for its proponents. It would seem that this application of WAP fulfills the predictive power criterion. However, I will argue that it does not. The basis of Hoyle's prediction seems almost too simple. In this instance, invoking WAP is not much more than acknowledging a tautology, albeit an important one for the situation. It is akin to saying "since I'm made of carbon, then there had to be *some* way for carbon to be produced." Well of course it had to happen somehow, that we already knew. It is unclear how much this insight benefits the situation. On an individual level, this idea may have lead Hoyle to consider resonance as a possibility, but nothing about WAP itself suggests the answer lies with resonance. WAP only indicates that there has to be an answer. To illustrate this point further, we easily think of an alternate scenario in which the existence of life does not need to be acknowledged. Imagine life on Earth was actually based on silicon chemistry rather than carbon chemistry, yet carbon was still abundant on the planet. The now silicon-based Hoyle is still trying to explain the abundance of carbon on Earth. Now he cannot invoke WAP since carbon has no role in his existence. Trying to apply a similar idea will only allow him to say that "carbon exists so it must have gotten there somehow." This is clearly tautological and offers no help whatsoever. WAP is only a slightly more sophisticated statement of this point.

In light of its tautological character in this instance, this application of WAP cannot fulfill the predictive power criterion. WAP could not have suggested any particular solution; it only convinced us that there must be an answer. Taking into account selection effects is a well established part of science, but labeling WAP as scientific just because it acknowledges an obvious observer selection effect is unlikely to convince many. Hoyle's discovery of the energy level necessary for the production of carbon is a true prediction, but one which has no dependence on WAP.

This application of WAP fails the explanatory power criterion as well. The same argument by analogy given before about explaining why our eyes are sensitive to a particular portion of the electromagnetic spectrum applies here. It is unlikely that the heuristic power criterion can be fulfilled either. Paul Davies (2006) tries to defend the anthropic basis of Hoyle's discovery when he says the following: "In science, one tries to avoid appealing to flukes. Occam's razor entreats us to try the simple and obvious explanations first...but there is one topic where even extraordinary flukes can enter into legitimate scientific explanation—and that topic is life" (p. 154). This is intended to establish that since life is such an anomaly, we are allowed to entertain unconventional possibilities, however I do not see why one would be unwilling to entertain the resonance possibility unless receptive to flukes. WAP only serves to convince us to not be surprised if the answer is "fluky". In the end, the insight offered by WAP in this case was not needed to make progress toward the answer and it likely played only a limited role for Hoyle himself.

Although this analysis is disheartening to one seeking to defend the predictive power of the principle, it must be reiterated that WAP is not inherently unable to make predictions. A good way of illustrating this is to again consider the analogy concerning the sensitivity of many organisms' eyes to a particular frequency range. Imagine the following scenario in which spectral properties of the sun are not yet known: Scientists begin to become puzzled by the discovery that many organisms have eyes sensitive to a narrow portion of the spectrum. As more organisms are discovered with the same sensitivity, what was initially thought of as a coincidence comes under greater scrutiny and a search for a suitable explanation begins. Eventually, one scientist hypothesizes that organisms' eyes are all sensitive to a particular range of the electromagnetic spectrum because perhaps the sun emits the most light in that range. This prediction is then verified by analyzing the spectrum of the sun.

This prediction does not make use of WAP, but it does give us an idea of what a prediction using an observer selection effect would look like. One can imagine an analogous scenario in which various coincidences are noted that do pertain to life-relevant features of the universe and in which consideration of these coincidences leads to a testable prediction. However, we must be fairly restrictive in what we allow to count as a coincidence from which a prediction can be made. If we are too permissive, then the abundance of carbon can be considered such a coincidence, however I have just argued that such an observation could not have been the ultimate basis of Hoyle's prediction. To avoid predictions based on tautologies, only coincidences that are suggestive of a particular solution should be allowed to count. For example, the observation that many organisms have eyes sensitive to a particular frequency range is sufficiently suggestive of the ultimate solution. My inability to give an example using WAP indicates that this type of prediction is difficult, but this discussion establishes that such predictions are not inherently impossible.

Now is a good time to discuss whether postdictions should be allowed to count as evidence for fulfilling the predictive power criterion. We can view Hoyle's discovery as consisting of two components: (1) a genuine prediction of the previously unknown energy level made independently of WAP, and (2) a postdiction, based on WAP, that the answer must be consistent with the abundance of carbon. The postdiction in this case was essentially an expectation that the solution be consistent with what we observe to be true. However, the trouble with this kind of postdiction is that it is necessarily true since it is based on an observer selection effect. Compare this type of postdiction with general relativity's postdiction of the precession of the perihelion of Mercury. The precession was already known and general relativity was able to accommodate this observed fact, but it could have failed to do so. On the other hand, it is not possible for an observer selection effect to fail in making a postdiction. This does not mean that there is no utility in thinking in terms of selection effects, but this utility must fall under the explanatory or heuristic power criteria. For these reasons, I will no longer consider postdictions as possible evidence for or against the scientific status of WAP.

I have argued that this use of WAP cannot fulfill any of the three criteria, and thus I conclude that this instance of its application is not scientific. However, there is one critical development that occurred as a result of Hoyle's discovery that must be discussed. His discovery was one of the first in a series of modern findings in cosmology that drew attention to the apparent fine-tuning of properties relevant to the development of life. That the value of the necessary carbon energy level, which itself is determined by the strength of the strong force, has to be such a specific value for the overall reaction to occur is somewhat strange. The recognition of this need to explain apparent cosmological fine tuning is what has generated the interest in the

anthropic principles. Properties that were previously seen as needing no explanation now became much more mysterious. As time has gone on, only more and more seemingly coincidental features of the universe that have influence over whether or not life can exist compound to make the probability of them all occurring together very low.

It is in an attempt to explain this tower of coincidences that variants of WAP have been developed. Unsurprisingly, many of these alternative formulations are distinctly teleological. Furthermore, it could be argued that the recent development of multiverse theories was spurred in part by the need to explain away the improbability of so many life-friendly features occurring simultaneously. The remaining two case studies will deal with issues relevant to these ideas in greater detail.

### VII. Case Study 3: Dicke and the Large Number Coincidences

Why are the fundamental parameters of the universe as we observe them to be? Could they have been otherwise? What, if anything, determines them? Any physicists adhering to what is often referred to as the ‘shut-up and calculate’ approach would likely believe these questions to be unworthy of much consideration. Despite the tendency to brush such questions aside, the need to explain apparent cosmological fine-tuning and the recent emergence of multiverse theories have greatly increased interest in these questions.

The point at the heart of this issue is whether the fundamental physical parameters are arbitrarily set in stone after the big bang or if they are determined by some definite process. A good way of elucidating this distinction is to consider whether the sizes of the planetary orbits are purely coincidental or if they follow as a consequence from deeper principles. To provide an example, one of the most well-known efforts to explain the sizes of the orbits was Kepler’s attempt to demonstrate that the planets orbited the sun on a series of spheres determined by inscription of the five Platonic solids. Kepler was ultimately unable to fit his model with the experimental data and was forced to abandon it. Paul Davies provides a good discussion of what ultimately turned out to be the correct explanation:

We now know that the arrangement of the planets is largely a historical accident... what we have ended up with is the result of chaotic circumstance—the amount of material in the solar nebula, the complicated forces that caused the planets to congeal when they did, the disturbances of nearby stars and gas clouds. Clearly there is nothing *fundamental* about the planets and their distances: these features are purely *incidental*... So what was once thought to be a deep law of nature turned out to be just a frozen accident of history... Drawing on the lesson of the solar system, it makes sense to ask whether other features of the world which we currently regard as law-like might also turn out to be accidents of history (Davies, 2006, p. 175)

This quotation highlights the important distinction between ‘environmental’ parameters which are purely coincidental versus ‘necessary’ parameters which result from deeper principles. Although some environmental parameters ultimately result from the interaction of multiple laws and thus are in some sense still ‘determined’, the distinction is still warranted, especially when the parameters in question are components of the physical laws themselves.

I will begin discussion of this distinction by analyzing one of the earliest direct applications of WAP to question of what, if anything, determines the values of the physical constants: Robert Dicke’s use of WAP to explain certain apparently coincidental relationships between large dimensionless numbers. In the early 20<sup>th</sup> century, physicists began to notice order of magnitude relationships between some large dimensionless ratios of various physical constants. These relationships became known as the ‘large number coincidences.’ The first physicist to undertake an extensive investigation of these coincidences was Arthur Eddington

(Barrow & Tipler, 1986, p. 224). After calculating the number of particles in the universe ( $N$ ) to be on the order of  $10^{80}$ , he noted that the value for the following dimensionless number (the ratio of the electrical and gravitational forces between a proton and an electron) is on the order of  $N^{1/2}$ :

$$\frac{ke^2}{Gm_p m_e} \sim 10^{39} \sim \sqrt{N} \quad (1)$$

where  $k$  is Coulomb's constant,  $e$  is the electron charge,  $G$  is the gravitation constant,  $m_p$  is the proton mass and  $m_e$  is the electron mass. Dimensionless ratios such as the fine structure constant (1/137) and the ratio of the proton to electron mass (1,800) he took to be on the order of unity.

One would expect the value of  $N$  to be very large, but that the value of ratio (1) is so large is unexpected and that it also is roughly proportional to the square root of  $N$  makes its value somewhat mysterious. Because of the apparent connection between (1) and  $N$ , Eddington proposed that (1) is actually *determined* by the number of particles in the universe. Dimensionless ratios on the order of unity he interpreted to be independent of  $N$ . If his proposal were correct, then the value of ratio (1) is unsurprising since it is connected with a necessarily large number. Eddington's postulate represented the first attempt to provide an explanation of a dimensionless ratio of physical constants.

The second notable attempt was advanced by Paul Dirac (1937). In addition to (1), he also considered the following two dimensionless ratios:

$$\frac{Gm_p^2}{\hbar c} \sim 5 \times 10^{-39} \quad T \frac{m_p}{\hbar} \sim 10^{42} \quad (2) \text{ and } (3)$$

where  $\hbar$  is Planck's constant divided by  $2\pi$ ,  $c$  is the speed of light and  $T$  is the Hubble age of the universe. The appearance of the age of the universe in ratio (3) led Dirac to postulate that the enormity of the values of ratios (1) and (2) could be explained if one or more of the constants appearing in these ratios were proportional to the age of the universe. Dirac saw the most likely candidate for this variation to be  $G$ , with  $G$  varying as  $T^{-1}$ . If this is the case, then the value of ratio (1) is proportional to  $T$  and the value of ratio (2) is proportional to  $T^{-1}$ .

Here is where Dicke enters the picture. Dicke noted that although Dirac's hypothesis can explain why (2) and (3) vary as  $T^x$ , it does not explain why the magnitude of each ratio is so large. In an attempt to explain this, Dicke was the first to introduce an explanation of these large number coincidences using WAP:

It will be shown that, with the assumption of an evolutionary universe,  $T$  is not permitted to take on an enormous range of values, but is somewhat limited by the biological requirements to be met during the epoch of man. The first of these requirements is that the universe, hence galaxy, shall have aged sufficiently for there to exist elements other than hydrogen. It is well known that carbon is required to make physicists. An upper limit for the epoch of man is set by the requirement that he has a hospitable home in the form of a planet circling a luminous star. This time is set by the maximum age of a star capable of producing energy by nuclear reactions... Thus, contrary to our original supposition,  $T$  is not a 'random choice' from a wide range of possible choices, but is limited by the criteria for the existence of physicists (Dicke, 1961, p. 440)

Dicke was able to set an anthropic bound on the possible values of  $T$  that would reproduce the relationship between (2) and (3) without having to assume that the gravitational constant varies with time. He argued that  $T_{\min}$  is set by the minimum amount of time required for stars to produce elements heavier than hydrogen and  $T_{\max}$  is set by the maximum age of a star able to undergo nuclear fusion. With these limits set and a few other assumptions about the energy

emission of stars, Dicke demonstrated that (2) is necessarily of the same order of magnitude as the inverse of (3) after deriving an expression for the lifetime of a star which involves the constants present in (2) and (3) (Ibid., p. 440). This connection between (2) and (3) shows that the apparently coincidental relationship between the two ratios is actually a consequence of necessary anthropic bounds on the age of the universe.

The heuristic power and predictive power criteria are not easily applicable in this case as all the quantities in question were already known, but the explanatory power criterion is relevant since the main goal of Dicke's analysis was to explain the already known values. Here is where we first see what a satisfactory explanation based on WAP may look like. Positing that the values of the ratios (2) and (3) are related as a result of anthropic bounds on the age of the universe is a viable explanation. There may be more that determines (2) and (3), but since it is possible that anthropic bounding is the *only* reason why we observe the connection between the ratios, the WAP explanation becomes satisfactory. It is not satisfactory in the sense that physicists should stop looking for other explanations (e.g. explanations based on mathematical necessity), but it is satisfactory in the sense that there may be nothing more to it than anthropic selection of the time-scale during which we can exist to ponder the relationship between the two ratios. Note that this instance of anthropic selection does not presuppose the existence of a multiverse since time is a quantity that is obviously allowed to vary in a regular universe.

With this in mind, should the earlier decision that WAP cannot provide a satisfactory explanation of the form of the law of gravitation be reversed? The form of the law of gravitation is certainly a fundamental feature of the universe. Furthermore, it could be the case that the only reason why the law has the form it does is because it is consistent with the existence of life. However, to allow this, one would first have to posit a mechanism that varies laws to demonstrate that the universe is actually a multiverse. Just as anthropic bounding of  $T$  makes sense given that time is a quantity that by definition must vary, anthropic bounding of constants or forms of laws requires that these features be allowed to change as well. As mentioned earlier, there are currently multiple candidates for these mechanisms so the existence of a multiverse and thus the possibility of satisfactory WAP explanations are made possible. Overall, it is only on the topic of fundamental features of a multiverse such as the values of constants and laws that WAP explanations gain credibility. For anything at a lower level of generality, it should be possible to come up with explanations based upon other principles. For example, it is possible to show why carbon has the particular energy level involved in stellar nucleosynthesis based solely on knowledge of nuclear physics.

The issue is complicated, however, in that we already have an explanation of the form of the law in terms of mathematical necessity. The question now is should an argument based on mathematical necessity trump an argument based on anthropic selection? Most would answer yes, but an affirmative response to the question does not necessarily mean that the WAP explanation is unscientific, simply that there is a better explanation. Furthermore, it is a rare occurrence to have a mathematical argument for the form of a law and there are not yet any such arguments for the value of a constant. The dream is to have a TOE that provides a mathematical derivation of most of the physical laws and constants, but it is a dream that is not guaranteed to become a reality. In some ways, if the universe is actually a multiverse, explanations based on WAP are the default stance in the absence of any 'deeper' explanations based on mathematics. I will not attempt to judge whether this stance is defeatist or simply realistic. Overall, this appears to be strong evidence for taking WAP as scientific when it is employed to explain the most

general features of a multiverse, but there are other grounds on which to object to this type of explanation that will be brought up in the next case study.

My reason for discussing this use of WAP was to trace the origin of the distinction between ‘environmental’ and ‘necessary’ parameters relevant to WAP and to provide historical context to the more modern manifestations of these issues. Just as the enormity of the values of ratios (1), (2) and (3) led physicists to consider alternatives to the default stance of the physical constants being entirely coincidental features of the universe, the apparent fine tuning of the constants for life has led physicists to search for alternate explanations as well. In general, whenever something apparently improbable is observed, the usual course of action is to search for a reason why the improbable event in question is not so improbable after all. The next case study will focus on two competing theories that seek to explain away this improbability.

### VIII. Case Study 4: Smolin vs. Susskind

This case study will be of a different format than the others as it will consider one physicist’s objection to considering WAP as scientific and another physicist’s direct response to the critique. The two physicists in question are Lee Smolin, an outspoken proponent of loop quantum gravity, and Leonard Susskind, a prominent string theorist. This case study is made possible by a series of emails between the two debating the scientific status of the WAP that were subsequently posted online (Smolin & Susskind, 2004). The exchange began after Smolin (2004) published a paper entitled “Scientific alternatives to the anthropic principle” and asked Susskind to comment on it. This debate is particularly relevant to this paper as Smolin makes the failure of WAP to make testable predictions his central point of criticism.

Before beginning, it is important to mention that both Smolin and Susskind believe in what they have termed a “landscape of possibilities” for the features of universes. This phrase was born out of the need to provide a means of visualizing the vast number of possible universes allowed by certain theories. The phrase entreats us to envision a three dimensional terrain containing many peaks and valleys. The valleys are the ‘low energy’ solutions, and are consequently more likely to be realized. For Susskind, the landscape contains the  $10^{500}$  possible universes permitted by string theory, and the mechanism for populating the landscape is the eternal inflation of space. For Smolin, the landscape contains the possibilities generated in every black hole, and the landscape population mechanism is the formation of black holes.

In his paper on WAP, Smolin begins by laying out a conception of science based upon falsifiability, drawing on the ideas of Karl Popper. He contends that “to prevent the progress of science from grounding to a halt, which is to say to preserve what makes science generally successful, scientists have an ethical imperative to consider only falsifiable theories as possible explanations of natural phenomena” (Ibid., p. 3). He goes on to describe his theory of cosmic natural selection (CNS) which he claims is able to explain all that WAP is able to explain and yet is also falsifiable. Without going much into the details, CNS holds that inside every black hole is another universe in which its fundamental features (laws and constants) are allowed to vary by a small amount from the ‘parent’ universe. These other universes are, in a sense, offspring. If CNS is true, then basic probability considerations would lead us to conclude that we are most likely to be in a universe whose fundamental parameters favor black hole production. The key point is that it just so happens that many of the prerequisites for life are also prerequisites for black hole production. One simple example is that many massive stars must exist for the formation of a significant amount of carbon as well as for the formation of black holes. Smolin then goes on to describe multiple ways in which CNS could be falsifiable

Susskind, on the other hand, is an advocate of eternal inflation. Eternal inflation is the theory that space expands at a variable rate with multiple ‘pocket universes’ created with each expansion. Each of these pocket universes has different fundamental parameters and together they constitute the multiverse. If the theory of eternal inflation is true, then we should not be at all surprised that so many features of our universe seem fine-tuned for life. It is because they *are* fine tuned, although instead of an intelligent designer doing the fine-tuning, it is the random generation of pocket universes. Most of the pocket universes are actually ‘dead’ in that they never can support life. We happen to inhabit an atypical universe because it is only in an atypical universe that we could exist.

The physics based arguments for and against these theories are not relevant for this paper. It is only general features such as testability that I will discuss. Susskind agrees with Smolin that CNS is falsifiable and offers many arguments as to why he thinks it is incorrect. Smolin on the other hand does not believe eternal inflation—and by association, WAP—are falsifiable. His primary concerns are the inability to ever observe another pocket universe, as all pocket universes are causally disjoint from one other, and the presence of multiple distinct inflationary theories that are all consistent with observational evidence. If it is therefore impossible to verify any given inflationary theory, Smolin believes that it is in the best interest of science that they are abandoned for other theories, such as CNS, that are falsifiable.

Susskind is willing to concede that it may prove impossible to falsify inflationary theories, but he does not believe that will turn out to be the case. However, Susskind’s primary point of disagreement with Smolin is over what constitutes science. Susskind takes Smolin’s falsifiability criterion to exhibit a complete lack of understanding of the nature of science:

There are people who argue that the world was created 6000 years ago with all the geological formations, isotope abundances, dinosaur bones, in place. Almost all scientists will point the accusing finger and say "Not falsifiable!" I'm sure that Smolin would agree with them and so would I. But so is the opposite—that the universe was not created this way—un-falsifiable. In fact that is exactly what creationists do say. By the rigid criterion of falsifiability "creation-science" and science-science are equally unscientific. The absurdity of this position will, I hope not be lost on the reader. Good scientific methodology is not an abstract set of rules dictated by philosophers. It is conditioned by, and determined by, the science itself and the scientists who create the science. What may have constituted scientific proof for a particle physicist of the 1960’s—namely the detection of an isolated particle—is inappropriate for a modern quark physicist who can never hope to remove and isolate a quark. Let's not put the cart before the horse. Science is the horse that pulls the cart of philosophy (Smolin & Susskind, 2004)

This quotation argues that strict adherence to the falsifiability criterion leads to the counter-intuitive conclusion that any theory is as unscientific as creationism and argues that it is simply false to ever set out a single criterion which will forever serve as the hallmark of science. The nature of science is determined by the scientists themselves, and we should trust them to formulate their definitions intelligently without the guidance of philosophers.

Nevertheless, is Smolin justified in having concern that scientists have been lead astray in accepting the WAP explanation too quickly? Susskind thinks not. He goes on to say that what I find especially mystifying is Smolin's tendency to set himself up as an arbiter of good and bad science. Among the people who feel that the anthropic principle deserves to be taken seriously, are some very famous physicists and cosmologists with extraordinary histories of scientific accomplishment. They include Steven Weinberg, Joseph Polchinski, Andrei Linde, and Sir Martin Rees. These people are not fools, nor do they need to be told what constitutes good science (Ibid., 2004)

This argument is certainly ad hominem. Furthermore, I earlier quoted Weinberg admitting that WAP is not strictly speaking scientific. Susskind also fails to acknowledge that there are many prominent scientists in the other camp as well. Evidently something is leading scientists astray, but Smolin and Susskind disagree over which side is still in the dark. Putting this aside, the most

important thing to note from this case study is that if we take Susskind's words on falsifiability to heart, then a falsifiability criterion (similar to my predictive power criterion) does not need to be fulfilled. This taken with the conclusions of the third case study analysis provide good evidence for considering WAP as a valid explanation of the fundamental parameters of the universe.

### IX. Concluding remarks

Through these case studies we have seen WAP employed, with varying degrees of success, to provide explanations, make predictions and promote further discoveries. At first, I had to rely on analogies and somewhat contrived examples to demonstrate what WAP could, in principle, accomplish. Eventually, however, I reached more secure footing when the topic of investigation became the fundamental parameters of the universe. Here the explanatory power criterion proved to be decisive. At this level of generality, WAP, when taken in conjunction with a multiverse theory, is able to provide a satisfactory explanation as to why the fundamental constants and laws are as we observe them to be. If we are then able to dismiss nagging concerns about falsifiability, as Susskind argues we can, then WAP as applied to these issues can be deemed fully scientific. I agree with Susskind's argument, and thus I accept WAP as scientific. Care must be taken, however, in recognizing the significance of this conclusion. Declaring WAP as scientific does not mean that the search for what may be thought of as deeper explanations should be halted. If anything, such a search should be intensified to avoid the somewhat unpalatable WAP explanation. But ultimately, the WAP explanation may prove to be the only suitable non-teleological explanation of the apparent fine-tuning of the universe.

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