# The Fine-Tuning for Discoverability



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## I. Introduction

One of the most persuasive evidences for the existence of God from the cosmos is the argument from the fine-tuning of the cosmos for the existence of life, the so-called anthropic fine-tuning. This refers to the fact that laws, initial conditions, and the fundamental parameters of physics must be precisely set for life to exist. The relevant kind of life depends on the hypotheses that the evidence is supposed to support, which in the case of theism is embodied conscious agents who can interact with each other based on what they perceive as moral criteria. For convenience, I will simply refer to such agents as "observers." The most commonly cited case of anthropic fine-tuning is that of the cosmological constant.[i] If it were not within one part in $10^{120}$ of its theoretical possible range of values, either the universe would expand, or collapse, too quickly for galaxies and stars to form. There have been a variety of challenges to the fine-tuning evidence itself, and whether it supports the existence of God or a multiverse. I have developed a detailed argument elsewhere (Collins, 2009) that the fine-tuning evidence does provide strong confirmatory evidence for theism over naturalism. Here I primarily want to explore another kind of fine-tuning and its implications for this debate: the fine-tuning of the universe for being discovered. By this fine-tuning, I mean that the laws, fundamental parameters, and initial conditions of the universe must be just right for the universe to be as discoverable as ours. After presenting examples to illustrate this kind of this fine-tuning, I will argue that if this kind of fine-tuning exists, in general it cannot be explained by a multiverse hypothesis – by far the leading non-theistic explanation for anthropic fine-tuning. Further, I will show how the idea that the universe is fine-tuned for discovery answers some other commonly raised objections against the fine-tuning argument, and finally I will look at its potential predictive and explanatory power.

Finally, to be absolutely clear, my project in this paper is not so much to argue for the existence of God, but to explicate where one might look for new evidence one way or another. This is in keeping with the spirit of scientific inquiry.

## Background

Many scientists and others have commented on the seemingly "miraculous" intelligibility and discoverability of physical reality, most famously Albert Einstein and Eugene Wigner. Recently this idea has been developed more carefully by Mark Steiner in his 1998 book *Mathematics as a Philosophical Problem* (Harvard University Press). Steiner presents an array of examples where, in their attempts to discover the underlying laws of nature, physicists successively used lines of reasoning that only make sense if they were implicitly assuming that the world was structured for discoverability. He concludes that the world "looks 'user friendly.' This is challenge to naturalism." (p. 176.)[ii] In a project I am near completing, I have attempted to quantitatively test this idea that the universe is in some sense "fine-tuned" for discoverability by calculating the effects on our ability to discover the major and/or important domains of reality – such as cosmology, microbiology, and the past history of the earth – by varying the some of the fundamental parameters of physics. The cases I will cite involve original calculations; they all have been verified by at least two physicists. The calculations can be found on my website: just google my name, Robin Collins. Nonetheless, because they are not yet part of the peer-reviewed literature, I do not expect everyone to accept their legitimacy. For those who do not, they should take this paper conditionally, as spelling out the implications this sort of fine-tuning would have if it is legitimate.

I have found around a dozen cases of this kind of fine-tuning. Below are three illustrative examples involving the fine-structure constant. Except for the first example, a basic explanation of the physical lines of reasoning behind them is left for the appendix. Later, in the course of articulating the significance and predictive and explanatory power of this sort of fine-tuning, I will look at two other examples in the cosmological context.

## Examples of fine-tuning for discoverability.

The first two examples involve the fine-structure constant, commonly designated by the Greek letter α. This is a physical constant that governs the strength of the electromagnetic force. If it were larger, the electromagnetic force would be stronger; if smaller, it would be weaker. A small increase in α would have resulted in all open wood fires going out; yet harnessing fire was essential to the development of civilization, technology, and science – e.g., the forging of metals. Why would an increase in α have this result? The reason is that in atomic units, everyday chemistry and the size of everyday atoms are not affected by up to a nine-fold increase or any decrease in α. Hence, the combustion rate of wood would remain the same with such a change. In these units, however, the rate of radiant output of a fire is proportional to $\alpha^2$ -- for example, a two-fold increase in α would cause the radiant output of an open fire to be four times as great. A small increase in α – around 10% to 40% -- causes the radiant energy loss of an open wood fire to become so great that the energy released by combustion cannot keep up, and hence the temperature of the fire would decrease to below the combustion point. The above argument applies to all forms of biomass, not just wood: since in atomic units, chemistry does not change with the changes in α considered above, their combustion rate would also remain the same. Although some biomass is much more combustible than wood – such as oil – these types of biomass are either not be readily available to primate carbon-based observers or would be less suitable for the size of fires needed for smelting metals; and hence it would be far less likely that primitive carbon-based observers would have regularly used them and thus discovered the smelting of metals.

Going in the other direction, if α were decreased, light microscopes would have proportionality less resolving power without the size of living cells or other microscopic objects changing (when measured in atomic units). As is the maximum resolving power of light microscopes is about 0.2 microns, which happens to be the size of the smallest living cell. The only alternative to light microscopes for seeing the microscopic world is electron microscopes. Besides being very expensive and requiring careful preparation of the specimen, electron microscopes cannot be used to see living things. Thus, it is quite amazing that the resolving power of light microscopes goes down to that of the smallest cell (0.2 microns), but no further. If it had less resolving power, some cells could not be observed alive. The fine-structure constant, therefore, is just small enough to allow for open wood fires and just large enough for the light microscope to be able to see all living cells.

Other constants also must be just right for other major domains to be discovered. For example, the ability to use radioactive dating – which plays a crucial role in geology, archeology, and paleontology -- depends on the density of radioactive elements in the crust of the planet on which observers evolve. As the strength of gravity is decreased (e.g., as measured by the force between two protons a unit distance apart), the density of radioactive elements must decrease to keep the number of volcanoes per unit area from increasing, which would decrease livability.

## Theses of Discoverability

If the cases of discoverability are indeed coincidental under naturalism, the thesis they directly support is what I will call the discoverability thesis:

*Discoverability Thesis*: This thesis is that the universe is non-accidentally structured in such a way as to be highly discoverable.[iii]

If we define naturalism to include the thesis that any apparent teleology in the universe is accidental, then the discoverability thesis is in conflict with naturalism. In arguing for the discoverability thesis, I ultimately argue that the level of discoverability in our universe is much more coincidental than one would expect under naturalism. Specifically, I argue that among the alternative universes generated by varying the parameters of physics, a very small proportion are as discoverable as ours when the parameter itself is used as a natural measure of proportion. I call this *the discoverability coincidence thesis*. Finally, the data suggest a particularly strong version of the discoverability thesis, what I call the *discoverability/livability optimality thesis* (DLO):

*DLO*: Within the range of values of a given parameter p that yield near-optimal livability, p will fall into that subrange of values that maximize discoverability (given constraints of elegance are not violated).

In every case that I was able to make calculations regarding whether the fundamental parameters of physics are optimized in this way, they appear to pass the test.[iv] This alone is significant since this hypothesis is falsifiable in the sense that one could find data that potentially disconfirms it – namely, cases in which as best as we can determining, such as a case in which changing the value of a fundamental parameter – such as the fine-structure constant – increases discoverability while not negatively affecting livability.[v] Below, I will look at a case from cosmology where this thesis could have been disconfirmed but was not.

New ideas are very subject to misinterpretation. So, before moving on, it is important to clear up a misunderstanding of what I am claiming, namely that I am arguing that this is the most discoverable possible universe. We can certainly imagine what initially might seem to be more discoverable universes and much less discoverable universes. We cannot draw any conclusions from this, however, unless we know the underlying laws of those universes – for example, an imagined more discoverable universe might require laws that are far more complex or inelegant, thereby taking away from their seeming discoverability. Rather, if we are going to test the thesis that the level of discoverability is coincidental, we must restrict ourselves to alternative universes chosen by a method that (1) is not *a prior* biased for or against the discoverability coincidence thesis and (2) such that we can make reasonable determinations of the level of discoverability of each universe. That is why the possible universes being considered are those with different values of the fundamental parameters, and why I restricted the DLO to those universes with different values for a given parameter – such as the fine-structure constant -- but the same underlying laws. Further, as noted below, it is unsurprising under theism that the world has an elegant mathematical structure; in fact, physicists have often used elegance as a guide to new theories. This is why elegance was included in the discoverability/livability optimality thesis.

So far, I have talked about the discoverability thesis. What is theism's relation to this?

## God and Discoverability

God is often defined as an omnipotent, omniscient, perfectly good being that created all contingent reality. Because God's goodness is the only attribute that tells us anything about what God would do, theism leads us to expect that God would create a reality structured to realize a positive, and if possible an optimal, balance of good over evil. [vi] . Thus, theism renders unsurprising any feature of the world for which we can glimpse how it could be of moral or aesthetic value, such as the existence of embodied conscious agents or the elegance and harmony of the underlying laws of nature. If we can glimpse how discoverability might be of value, then theism would also render it unsurprising that the universe is highly discoverable.

Why might discoverability be of value? First, it allows us to develop technology, which in turn allows us to greatly expand our ability to improve our conditions. Second, being able to understand the universe is widely perceived (at least on an implicit level) as being intrinsically valuable. If it were not, it is difficult to explain why many have sacrificed financial and other sorts of rewards to pursue fields such as cosmology, advanced physics, and the like. If one merely enjoyed solving puzzles, it would make much more sense to pursue a career that involved puzzle solving but in which the likelihood of employment was far higher. Further, the fact that governments spend billions of dollars on research into the fundamental structure of the cosmos, and that the public generally supports this, shows that collectively we find such knowledge of value. So, although theism does not require that the universe being highly discoverable, it renders it unsurprising and hence fits with it much better than naturalism.

## II. Significance

Now, we are ready to see the significance of the above discoverability theses for the debate over God and cosmology. I begin with the multiverse hypothesis.

### Multiverse Hypothesis

A significant number of philosophers and scientists respond to the anthropic fine-tuning evidence by claiming that it is brute fact that does not need any explanation. I find such a response incredible when one looks at the degree of fine-tuning: one part in $10^{120}$ – that is, one followed by 120 zeroes -- in the case of the effective dark energy density and a ridiculous 1 part in 10 to the $10^{123}$ ($10^{10^{123}}$) for the probability of the universe having an entropy as low as ours. Speaking for myself, almost anything is more believable than that.[vii] Thus, in order to believe that, I would have to be given an exceedingly strong argument that there was no other alternative, not the kind of arguments typically offered against the theistic alternative. At the very least, such evidence puts a burden on naturalists to provide powerful reasons for rejecting the theistic explanation.

A more common response among cosmologists is to invoke a multiverse to explain the fine-tuning. According to this hypothesis, there is a very large, if not infinite, number of regions of space-time with different values of the fundamental parameters of physics, different initial conditions, and perhaps even different laws of nature. It then claims that in a sufficiently varied multiverse, it is no surprise that some universe is structured so that observers will arise in it. Finally, it invokes the so-called *observer-selection principle*, which is the tautological claim that embodied observers can only exist in a region of space- time that allows for them to exist. This renders it unsurprising that as observers we find ourselves in an observer-structured region of space-time since it is impossible for us to exist in any other type of region.

The observer-selection principle is essential to the multiverse explanation because it prevents it from undercutting the need to explain other seemingly surprising events and features of the universe. For example, normally one would think that it is too coincidental for a six-sided die to land 50 times in a row on four just by chance. Yet, in a large enough multiverse, someone will observe this to happen. Nonetheless, it is still improbable that a generic observer in a generic multiverse will see such an occurrence. Hence, purportedly, via the observer selection principle the multiverse hypothesis combined with the observer-selection principle can render it unsurprising both that we exist and that we find ourselves in an observer-structured universe while at the same time not undercutting ordinary claims of improbability.

Because of its reliance on the observer selection principle, the multiverse can only directly render unsurprising that we find ourselves in an observer-structured universe. Because of this limitation, it cannot, without additional hypotheses, explain the fine-tuning of the constants or the fine-tuning for discoverability. With regard to the former, all those universes that do not have life-permitting values for the fundamental parameters of physics – such as the cosmological constant -- and are sufficiently large (e.g., infinite) will be dominated by isolated observers arising from thermal fluctuations.  Thus, the parameters of physics are not fine-tuned for observers. Rather, they are fine-tuned so that embodied conscious agents can arise that can significantly interact with one another. But, because of its reliance on the observer-selection effect, without additional postulates the multiverse only implies that we will find ourselves in an observer-structured universe.  Thus, it cannot of itself directly explain the actual anthropic fine-tuning – that is, why as generic observers, we find ourselves in a universe whose fundamental parameters allow for embodied conscious agents.  The existence of these Boltzmann brain universes, therefore, poses a problem not just for a multiverse explanation of the low entropy of the universe, but more generally for explaining the fine-tuning of the constants.

According to the thesis I am proposing, the universe is not just fine-tuned so that ECAs can exist, but that they can develop technology and discover its nature.  The multiverse hypothesis also runs into a major problem explaining this.  The reason is that there seems to be no necessary connection between a universe being ECA-permitting and its being discoverable beyond that required for getting around in the everyday world. Thus if, because of the fine-tuning for discoverability, the proportion of observer-permitting universes that are as discoverable as ours is really small, it would be very improbable under a generic multiverse hypothesis that as generic observers we would find ourselves in such a universe.  So, the fine-tuning for discoverability, if legitimate, presents a further problem for the multiverse as a complete explanation of the fine-tuning; since this discoverability is not surprising under theism, it provides further data to test these two hypotheses and thus move the debate forward.

## Irrelevant to Life Objection

I will now consider how the discoverability theses help to answer a common objection, usually raised by physicists, against anthropic fine-tuning: namely, many features of the universe seem irrelevant for the existence of life. I will call this the *irrelevant to life* objection. This objection is nicely stated by Sean Carroll. After listing some reasons to be skeptical of fine-tuning claims, Carroll states that "But in fact there is a better reason to be skeptical of the fine-tuning claim: the indisputable fact that there are many features of the laws of nature which don't seem delicately adjusted at all, but seem completely irrelevant to the existence of life**."** [viii] One commonly used example – for example by Carroll, Steven Weinberg, and Mario Livio -- is the existence of extra generations of particles, such as the muon, a particle that is in all ways like the electron except being much more massive; such particles do not seem in any way needed for life.[ix] Along similar lines, Carroll takes issue with a theistic explanation of the low entropy of the universe, correctly noting that only a universe with a local region of low entropy is needed for life, Carroll rightly notes that in creating a universe with low entropy throughout, God would have had to fine-tune the universe far more than would have been necessary for life. This, he states, poses "a bigger problem for the God hypothesis than for the multiverse." [x]

Contrary to what Carroll assumes, it is not clear why under theism every feature of the universe would have to serve a purpose. But even if theism did, discoverability (and perhaps considerations of elegance) could offer a way of explaining them. The extra generations of particles could very well help with humans discovering the fundamental structure of matter. For instance, these extra generations fall into a highly symmetric pattern, three for each of the two types of quark and three for the two types of leptons. This symmetry suggests that they are clues to an even deeper, more elegant theory. Further, they could help in discoverability in other ways. For example, according to the June 2012 issue of *Symmetry Magazine* (a joint publication of Fermilab and Stanford Linear Accelerator Center), the muon – the particle perhaps most commonly cited as an added extra whose existence seems purposeless -- is playing an increasingly important role in particle physics. According to Chris Polly, one of the Fermilab physicists involved in muon research, one reason the muons are special is that "they are light enough to be produced copiously, yet heavy enough that we can use them experimentally to uniquely probe the accuracy of the Standard Model." Further, the article notes that "Today scientists can manipulate the muon and use it as a tool not only for particle physics research but also for cosmology, archeology and public safety.[xi]

With regard to the low entropy of the universe, having a low entropy throughout the entire universe makes it more discoverable for at least two reasons. First, a universe that has a low entropy over a vast region is necessary for us to observe other stars and galaxies, and thus to understand the big bang origin of our own universe. (The existence of stars and galaxies requires low entropy.) As Carroll notes, if the region of law entropy were not large enough, the universe would be devoid of other galaxies.[xii] Second, to solve the equations of general relativity in closed form for the entire cosmos – which is central to doing cosmology – one must assume that the distribution of matter is nearly uniform at large scales, a cosmological scenario known as Friedmann cosmology. This would not be true if the universe was not in a low entropy state throughout. Of course, one could respond that God could have created a universe with one galaxy, which would have been even more discoverable. The problem is that we have no clue what the underlying laws of such a universe would have to be, and thus whether they would be as discoverable as ours. As I noted above, to make any kind of judgments about overall discoverability, we must restrict ourselves to alternative universes in which the fundamental parameters of physics are changed – in this case, the spatial distribution of entropy; because of this restriction, the above example universe is irrelevant to my argument.

In light of the possibilities that discoverability offer for understanding why the universe is this way, let me suggest that objections like the above run the risk of being an ungodly appeal to gaps: just because we do not understand the reason God would have created the world with a particular fundamental feature does not mean there is not one.

Besides its ability to make sense of the items mentioned above, below I consider an examples of the discoverability/livability optimality thesis's (DLO) potential predictive power.

# III. Predictive and Explanatory Power of Discoverability

## Cosmic Microwave Background Radiation

The most dramatic confirmation of the DLO is the dependence of the Cosmic Microwave Background Radiation (CMB) on the baryon to photon ratio. The CMB is leftover radiation that permeates space from the big bang that has been redshifted into the microwave region of the electromagnetic spectrum. Because its source is in the big bang, the CMB tells us critical information about the large scale structure of the universe: for example, physicists John Barrow and Frank Tipler point out that "The background radiation has turned out to be the 'Rosetta stone' on which is inscribed the record of the Universe's past history in space and time."[xiii] Much of the information in the CMB is in very slight variations in its intensities of less than one part in 100,000 in different parts of the sky. Since the CMB is already fairly weak, this implies that within limits, the more intense it is, the smaller the fluctuations it can detect, and hence the better a tool it is for discovering the universe.

Now, the intensity of CMB depends on the photon to baryon ratio, $\eta_{\gamma b}$, which is the ratio of the average number of photons per unit volume of space to the average number of baryons (protons plus neutrons) per unit volume. At present this ratio is approximately a billion to one ($10^9$), but it could be anywhere from one to infinity; it traces back to the degree of asymmetry in matter and anti-matter right after the beginning of the universe – for approximately every billion particles of antimatter, there was a billion and one particles of matter. So far it is a mystery why this ratio is what it is. Even if physicists can give a further explanation for why this ratio has the value it does, the question would still arise as to why that deeper physics instead of some other.

The only livability effect this ratio has is on whether or not galaxies can form that have near-optimally livability zones. As long as this condition is met, the value of this ratio has no further effects on livability. Hence, the DLO predicts that within this range, the value of this ratio will be such as to maximize the intensity of the CMB as observed by typical observers. According to my calculations – which have been verified by three other physicists -- to within the margin of error of the experimentally determined parameters (~20%), the value of the photon to baryon ratio is such that it maximizes the CMB. This is shown in

**Figure 1** below.

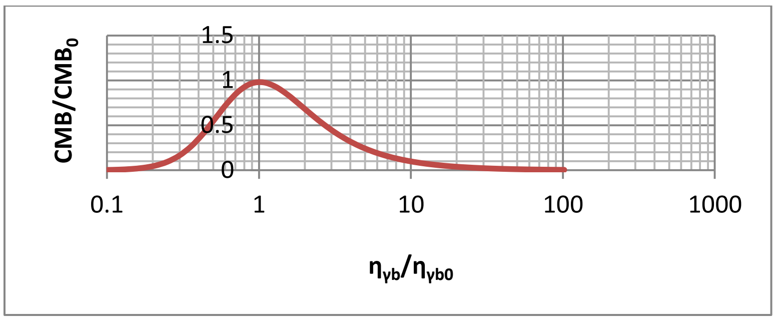


Figure 1: Variation of the intensity of the cosmic microwave background radiation (CMB) observed by a typical observers for various values of the photon to baryon ratio ($\eta_{\gamma b}$). $CMB_0$ and $\eta_{\gamma b0}$ are the values of the CMB and $\eta_{\gamma b}$ in our universe. Notice that the CMB is maximal at $\eta_{\gamma b}/\eta_{\gamma b0} = 1$ -- that is, for the value of the photon/baryon ratio in our universe.

It is easy to see that this prediction could have been disconfirmed. In fact, when I first made the calculations in the fall of 2011, I made a mistake and thought I had refuted this thesis since those calculations showed the intensity of the CMB maximizes at a value different than the photon-baryon ratio in our universe. So, not only does the DLO lead us to expect this ratio, but it provides an ultimate explanation for why it has this value, whatever other explanation we find based on some deeper physics. This is a case of a teleological thesis serving both a predictive and an ultimate explanatory role.

# IV. Objections

Now I turn to a couple of objections.

## Discoverability-Selection Objection

One objection to the above argument is that there is a discoverability selection effect. One form this objection takes is the claim that if a domain were not discoverable, we would not know what we are missing.  This objection is similar to the "weak anthropic principle" response to the anthropic fine-tuning: if the fundamental parameters of physics were not observer-permitting, there would be no one here to observe the fact.

The first, and simplest, answer to this objection is that this is not generally the case, as the following examples will demonstrate. As our first example, suppose that α were 50 times smaller. In that case, light microscopes could only resolve objects down to 10 microns. Yet, if observers could exist in such a universe, they could observe some cells and thus develop cell theory, and gain indirect knowledge that there were cells less than 10μm in size, and yet wish that they had an instrument that could see them. Or, consider radioactivity dating. Even without high enough levels of radioactive elements in the earth's crust to be of much use in geology, there could be enough radioactive elements for us to learn about radioactivity; we would then be able to determine that if only the earth had a higher density of radioactive elements, we could have a useable dating method. In fact, it should be noted here, the level of background radiation is as about as high as it could be without posing a significant threat to life, thus meeting the expectations of the DLO (since the higher the level, the more useful radioactive dating would be.) Finally, we could have lived in a universe in which the photon to baryon ratio was substantially different, but where a very weak CMB was still detectable. Then one could show that the photon to baryon ratio in our universe would maximize the intensity of the CMB and hence would make it more useful than any other value of this ratio. [xiv]

## Cherry Picking Objection

Another possible response to cases of discoverability is that they involve “cherry picking”: one looks for and finds the information that confirms one’s hypothesis, ignoring all the disconfirming evidence.  There are several types of “cherry picking.” First, one might pick features of the world that are helpful for discovery and ignore those features of the world that hurt discovery; since there are so many domains that could be discovered, it seems likely that one could always find some features of the world that are helpful for discovery with almost any kind of world that could give rise to observers. This objection can be avoided by restricting ourselves to only considering widely recognized major domains – cosmology, geology, cell biology, the fundamental microscopic structure of the world, and the like – and the major possible tools for those domains, such as the light microscope, radioactive dating, and the CMB.

Further, one might worry that since the tools used for discovery are often not obvious until they are developed, if the values of the parameters were different, there might be other possible tools that observers could develop that we are not presently aware of.  Thus, although the usefulness of our present tools of discovery depends on the parameters falling into a restricted range of values, this does not mean that an observer’s ability to discover the domains in question depends on a small range.  For the major domains of discovery, this is typically not the case.  For example, alternative values for $\alpha$ will not give rise to alternative forms of radiation that would be as good as light for observing cells; hence, for at least a very wide range of values of $\alpha$ there will not be any adequate replacement for the light microscope.  Or consider the CMB.  Different values for the photon to baryon ratio will not give rise to an alternative form of radiation that is a substitute for the CMB.  Similarly, a lower value of the strength of gravity is not going to give rise to a “clock” that is as good as radioactive dating.

## V. Conclusion

In conclusion, looking for cases of fine-tuning for discoverability has the potential of providing a new set of empirically-based evidence with regard to the debate whether the universe is teleologically structured or indifferent to our existence. It thus has the promise of substantially moving the debate forward.

## Appendix A: Dark Energy and Cosmic Coincidence Problem

Another explanatory potential of the DLO involves the so-called "cosmic coincidence problem." This problem has to do with the effective dark energy density being about the same as the energy density of matter at the present age of the universe. This is thought a coincidence because the matter density falls off very fast with the universe's expansion (specifically, with the inverse cube of the amount of expansion) whereas the effective dark energy density is nearly constant. As Sean Carroll notes, if these two densities are comparable today, "in the past the vacuum energy would be undetectably small, while in the future the matter density will be negligible. This 'coincidence problem' has thus far proven a complete mystery." (2004, P. 359).

Initially, the existence of this effective dark energy might seem to disconfirm the DLO since it has caused the universe to expand about 20% more than it otherwise would, thereby weakening the CMB by a factor of about two. Such would be the case if there were not at least two positive discoverability effects from a small dark energy density. First, the positive dark energy density has made the Hubble parameter about 50% larger than it would otherwise be. The Hubble parameter determines the rate at which galaxies appear to be moving away relative to distance; the larger the Hubble parameter, the faster they are receding for the same distance away. If one looks at Hubble's original data, it is clear the Hubble parameter was just large enough to keep Hubble's original data from being swamped by the local (peculiar) motion of galaxies within galactic clusters. So, the dark energy helped with both our discovering the expansion of the universe, and then later with establishing a reliable relation between the distance of a galaxy and its redshift, something very important for galactic astrophysics. Second, arguably if the effective dark energy density were much smaller, it would not yet have been – and perhaps never would be – detected. Detection of the dark energy has mostly relied on the universe's having undergone accelerated expansion starting approximately six billion years ago; as is, it was only until the late 1990s that we had precise enough instruments to detect this accelerated expansion. It is easy to show that if the dark energy density were less than about ¼ its value in our universe, the universe would yet to begin this accelerated expansion phase. Yet knowledge of this dark energy density tells us many important things about the universe (over and above merely the knowledge that the universe contains dark energy.) For example, it lends credence to one of the most speculative, yet crucial, postulate of inflationary cosmology – the possibility of a large effective dark energy density at the beginning of the universe. Further, it tells us that there is no fundamental symmetry that requires that the effective dark energy density be zero, a symmetry that would have solved the anthropic fine-tuning problem of the cosmological constant mentioned at the beginning of this paper. Thus, the detection of the dark energy has kept cosmologists from mistakenly pursuing such a solution and has rightly kept the problem on the table. Finally, the attempt to understand the origin of this dark energy has given a significant boost to cosmology.

Given these positive discoverability contributions are significant, the DLO renders it unsurprising that the effective dark energy density would be large enough to guarantee its positive discoverability contribution, but no larger because of the negative discoverability contribution to the

CMB. [1] This is precisely what we find. Thus, it has not only passed another potential disconfirmation, but has shown once again its potential explanatory power.

Finally, it should be emphasized that the explanations given above are not in competition with a deeper scientific explanations. Even if we found a deeper set of laws or parameters that explained the values for photon to baryon ratio and the dark energy density, the DLO would provide an ultimate explanation of why the universe has these set of laws and parameters instead of some other that yields different values for the photon to baryon ratio and the effective dark energy density.

## Appendix B: Brief Physical Arguments for the Cases Above

<u>1. Light Microscope</u>

The basic reason for the dependence of the resolving power of a light microscope on α goes as follows. First, the maximum resolving power of a light microscope is approximately ½ the wavelength of the light being used. Second, in atomic units, decreasing α does not significantly affect the size and

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[1] What about a negative effective dark energy density? In that case, the universe would switch from expanding to contracting when the dark energy density was equal to the matter density. This would leave two possibilities: either observers occur before the switchover in an expanding phase or after the switchover in a contracting phase. If they occur in an expanding phase, then observers would observe a greater deceleration of the universe than in a pure matter universe. Even if the effective dark energy density was negative enough to be detectable, such a greater deceleration would likely not be as convincing evidence for dark energy as an accelerating universe, partly because it is not qualitatively different from what the universe is already doing (decelerating), but also because positive curvature can cause a greater deceleration. Even if such a greater deceleration could be as direct or convincing evidence for dark energy as the acceleration that has occurred in the last six billion years, the Hubble parameter would have to be considerably smaller than in a pure matter universe, with the amount by which it is smaller being greater for nearby galaxies. This would create worse conditions for measuring the Hubble parameter, which would have at least impeded obtaining evidence for the big bang along with many other aspects of cosmology that rely on the Hubble parameter. If observers occur in a contracting phase, then the Hubble parameter could be as large as in our universe, but light from nearby galaxies would be blue-shifted whereas light from galaxies farther away would be redshifted. This would likely make it much more difficult to establish the big bang theory, and much more difficult to establish the relationship between distance and degree of redshift or blue-shift.

chemical properties of atoms involved in biochemistry, since written in these units the non-relativistic Schrödinger equation is not dependent on $\alpha$; thus, the size of living cells would not change. Finally, in atomic units the minimum wavelength of light eyes can see is inversely proportional to $\alpha$. Thus, for instance, if $\alpha$ were 1/100 its current value, the maximum resolving power would be 20 microns, not 0.2 microns.

To see why the minimum wavelength that observers can see is inversely proportional to $\alpha$ first note that I atomic units, the speed of light = $c = 1/\alpha$. However, the energy of a photon = $E = hf$, where h is Planck's constant and f is the frequency of light. ($h = 1$ in atomic units). But, a photon of visible light cannot have more energy than the bonding energy of typical biochemical molecules, otherwise it would destroy the molecules in an organism's eye. In our world, this requires that for light microscopes, $f <$ 800 trillion cycles per second. Since this bonding energy remains the same with a change in $\alpha$, $f < 800$ trillion cycles per second in the alternative world.

Now, the wavelength of light = $\lambda = c/f$. In our world, the above restriction on frequency means that $\lambda > 0.35$ microns. Since $c = 1/\alpha$, as $\alpha$ decreases, c increases, which causes the minimum wavelength of light for a light microscope to increase; this in turn means that the resolving power of light microscopes will decrease.

## 2. Radioactive Dating

Radioactive dating is dependent on the strength of gravity being sufficiently large. The strength of gravity is commonly given by the dimensionless gravitational fine-structure constant $\alpha_G = G(m_p)^2/\hbar c$, where $m_p$ is the mass of the proton. If $\alpha_G$ is decreased, to retain an atmosphere the radius, $R_h$, of a habitable planet must increase: specifically, $R_h \propto (1/\alpha_G)^{1/2}$. Now, the ratio of volume to surface area of a planet is proportional to its radius. Since the amount of heat produced in a planet via radioactive decay is proportional to the volume of the planet, unless the density of radioactive elements decreases with a decrease in $\alpha_G$, the amount of heat energy per unit area exiting the planet's surface – and hence the amount of volcanic activity per unit area – will increase as $\alpha_G$ decreases, at some point drastically decreasing the ability of the planet to support observers that can engage in advanced science. Thus, to retain a world livable enough for science, the density of radioactive elements in the crust must at some point decrease, making the world worse for radioactive dating. (It is assumed here that ratio between the density of radioactive elements in the crust and in the interior of the planet does not substantially increase as the planet gets larger.)

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[i] More accurately, it is the fine-tuning of the *effective dark energy density* of the universe, which is the sum of Einstein's original cosmological constant with various energy fields that of themselves would cause an accelerated expansion or contraction of the universe. However, the cosmological literature has typically talked about it in terms of the fine-tuning of the cosmological constant.

[ii] In the Privileged planet (2003), Gonzalez and Richards cite a significant number of examples where what they call habitability (the condition under which a planet can exist and be habitable) appear to coincide with the conditions under which the universe is optimally discoverable. In their treatment, however, they provide no methodology for determining whether the universe is more discoverable than would be expected by chance.

[iii] In this definition, "non-accidental" is to be taken in the minimalist sense that is used in philosophical discussions of the metaphysical status of the laws of nature. In these discussions, an accidental regularity is one such that observed instances of the regularity do not give us any reason to believe that the regularity will continue in unobserved cases. For example, if I ask five people in my class whether they have a dime in their pockets, and they all answer yes – but having such a dime was not prearranged but just occurred by chance – this would give me no reason to think the next person I ask would have a dime in their pockets. Or, if I flip a coin ten times in a row, and each time it comes up heads, and I check the coin and it is a two-sided, perfectly symmetrical coin (except one side

has heads engraved on it and one side has tails engraved on it), I assume this just occurred by accident. Thus, the fact that it came up heads the first ten times gives me no reason to believe it will continue. In contrast, suppose that I freeze a certain substance – call it substance X – ten times and every time it freezes, it contracts. That would give me good reason to believe that the 11th time it freezes it will contract. Why? Because I take the regularity to be non-accidental – the result of underlying laws.

In philosophical discussions of the metaphysical nature of the laws of nature, everyone agrees that a distinguishing mark of accidental versus non-accidental regularities is the ability of observed instances of a non-accidental regularity to give us good reason to believe that unobserved cases (in relevantly the same circumstances) will also fall under the regularity. In the language of Nelson Goodman, non-accidental regularities could be said to be *projectable*. The theories divide on what they think accounts for this projectability, specifically when it comes to the most fundamental regularities in the world. Two prominent views are those of the so-called necessitarians and those of the regularists. Necessitarians think non-accidental regularities – the regularities expressed by the laws of nature -- are ultimately the result of underlying necessities in nature. For example, assuming that regularity that masses always attract each other cannot be explained by any deeper regularity, a necessitarian would say that they must attract each other due to some underlying property of the world that is beyond science to discover. On the other hand, advocates of the regularity theory claim that the non-accidental regularities expressed by are must fundamental theories are just brute facts, without any deeper explanation. Since advocates of the regularity theory hold that all regularities are merely brute facts, they then must give an account of what distinguishes accidental regularities from non-accidental (lawlike) regularities. Typically, such accounts appeal to the role such regularities play in our models of the world. The point of the above summary is not to resolve the dispute between the various accounts of the laws of nature but to simply clarify what I mean by non-accidental. Thus, the discoverability hypothesis entails that the fact that the world has been found to be highly discoverable can give us strong reason to believe the pattern will continue.

[iv] I only considered parameters in models one level above the standard model of particle physics. However, the fact that they passed the test in this case strongly suggests that they would at a deeper level if we could do the calculations.

[v] The way this hypothesis would be disconfirmed is similar to the way that the hypothesis that animals were optimally constructed was disconfirmed by anatomical studies in the nineteenth and twentieth centuries, namely by showing how an organ (such as the back) could be constructed better to fulfill its function.

[vi] The idea that non-abstract reality is non-accidentally structured so that moral (and aesthetic) value is positively, or optimally, realized is what has become known as the *axiarchic thesis*, a thesis that dates back to Plato and has been taken up recently by other philosophers, such as John Leslie (1979). Theism entails axiarchism, but axiarchism does not entail theism; so one can be an axiarchist without being a theist, but not vice versa; further, it is only via its entailing the axiarchic thesis that theism leads to any expectations about the structure of the universe, and hence it is only via its entailment of this thesis that it can explain the fine-tuning.

For our purposes, the significance of axiarchism is that with some auxiliary assumptions about what kinds of things are likely to be of moral and aesthetic value, it entails certain expectations about the structure of the universe without making any metaphysical commitments about realities beyond the universe. Specifically, if can glimpse how discoverability could be of value, then the axiarchic thesis would render it unsurprising that the universe is highly discoverable.

[vii] It is not its mere seeming improbability that makes it cry out for explanation, since there are many occurrences in the world that are enormously improbable. Rather, it is a combination of being seemingly enormously improbable with its being special – e.g., required for the existence of embodied conscious agents.

[viii] "Why Most Cosmologists Are Atheists," page __. In file).

[ix] *Dreams of a Final Theory*, pp. 253-254.

[x] Sean Carroll, "Does the Universe Need God," in *The Blackwell Companion to Natural Theology*, J. B. Stump and Alan Padgett, editors, Wiley-Blackwell, Malden, MA, 2012, p. 192 (185-197).

[xi] Sarah Charley, "Through a muon's eyes," Symmetry: A joint Fermilab/Slac Publication, June 12, 2012, available at http://www.symmetrymagazine.org/cms/?pid=1000961. Accessed July 20, 2012.
[xii] op. cit., pp. 192 – 193.
[xiii] John Barrow and Frank Tipler, *The Cosmological Anthropic Principle*, 1986, p. 380.
[xiv] Our second response notes that even if we would not have known the difference in some cases, that does not affect the claim that it is coincidental that we have the tools to discover the domain in question. To see, consider the following example. Suppose a government a nation of a billion people has what they call a *grace-lottery*, which only the highest level government officials and the past winners know about. Without even buying a ticket, a million dollars is given to one person a year, supposedly chosen at random among the entire population; part of the requirements for receiving the money is that one is to tell no one where the money came from, but offer an official "lie" about its source. Now, suppose some poor farmer – call him Omaz -- receives a million dollars from this program. He not only finds out about the program, but when he uses several thousands of dollars of the money to check into his family history, he discovers that he has a half-brother who is now a high official in the government and the primary person in control of the lottery.
Omaz now becomes suspicious that the lottery was rigged, reasoning as follows:

Corruption is rampant in this government, and we are taught from birth that one's happiness in the afterlife depends on taking care of one's closest blood relatives. Consequently, it is not unlikely that my half-brother was responsible for me receiving the million dollars through this program. It is very, very unlikely – around one in a twenty million over a fifty year life span – that I would have received this money by chance. Hence, my receiving the money strongly confirms that my brother had a role in this over the chance hypothesis.

Certainly Omaz's reasoning seems correct. If Omaz had not been selected, however, he would not have known about the lottery, and thus that he was not selected. Yet, this does not take away from the confirmation that receiving the money gives to his rigging hypothesis.