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The Revenge of Pythagoras: How a Mathematical Sharp Practice Undermines the Contemporary Design Argument in Astrophysical Cosmology

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ABSTRACT

Recent developments in astrophysical cosmology have revived support for the design argument among a growing clique of astrophysicists. I show that the scientific/mathematical evidence cited in support of intelligent design of the universe is infected with a mathematical sharp practice: the concepts of two numbers being of the same order of magnitude, and of being within an order of each other, have been stretched from their proper meanings so as to doctor the numbers evidentially. This practice started with A. S. Eddington and P. A. M. Dirac in the 1920s and 1930s, but it is still very much alive today.

1 Introduction

Rational speculation about the deep structure of the universe used to be a special hallmark of philosophy, something that identified philosophy against the background of the more specialized empirical and critical disciplines. As cosmology was taken over by mathematical astrophysics, and then empirical astrophysics, during the last century or two, this traditional hallmark has largely faded away. I hope to show that this development has not always been to the benefit of astrophysical cosmology, and that in particular one recent offshoot of astrophysical cosmology owes its current popularity to philosophical naiveté and mathematical sloppiness on the part of the astrophysicists who are smitten with it.

Our story begins in 1919 with the publication of a paper by Hermann Weyl, 'A New Extension of the Theory of Relativity', in which a short section appeared called 'The Problem of Matter' (Weyl [1919]). In this section, Weyl discussed the relation between two of the fundamental physical forces in the universe, gravity and electromagnetism. He noticed that if one were to construct a ratio between the strength of an electron's electromagnetic force and the strength of the gravitational force of its mass—using the appropriate fundamental constants c (velocity of light in a vacuum), e (the fundamental electric charge), and G (Newton's gravitational constant), arranged mathematically so that both force strengths are measured in units of length (Weyl called each a 'radius')—one ends up with a pure number (that is, a number without dimensions such as kilograms, meters, or seconds, because like dimensions in the ratio cancel out) whose value is of the order of magnitude 10^{40}. He further asserted that when the first force strength above is put into a ratio with the radius of the observable universe, a dimensionless number close to 10^{40} is again obtained. Both of these claims are correct. In the case of the first ratio, Weyl had exploited the extreme weakness of gravity relative to electromagnetism. In the case of the second ratio, it was not obvious what importance to place on it. Weyl seemed to have mentioned it because of the striking improbability that two ratios of cosmological importance should converge on the same huge dimensionless number.

Weyl could hardly have suspected what Pythagorean obsessions he would unleash with that paper. Within a couple of years, Arthur Eddington ([1923]) took Weyl's remarks to heart and began moving things in a more questionable direction. Ratios, reciprocals of ratios, and seemingly arbitrary combinations of physical constants were constructed aplenty with ever increasing ingenuity. Eddington was able, by suitable mathematical juggling, to show that this new zoo of supposedly cosmologically significant ratios was composed of pure numbers that clustered into three classes: those close to unity—that is, 1; those close to 10^{40}, and those close to various powers of 10^{40} (but especially its square, 10^{80}). The ancient Pythagoreans long ago reputedly claimed that the ultimate basis of all things—or at least the explanatory key to all things—was numerical, a model of reality made famous to philosophical posterity by Plato in the *Timaeus*. The Pythagorean model fell into disrepute during the slow but steady triumph of a physicalist science over the past two centuries, but here we find Eddington in the 1920s attempting to extract numerological revenge on behalf of Pythagoras. When this number fetish in Eddington's speculations became apparent to some of his professional peers, Hans Bethe, among others, openly spoofed it in a 'hoax' paper published in the journal *Naturwissenschaften* (Beck, Bethe, and Riezler [1931]).

Eddington expected that the pure numbers generated by the ratios should have spread out along the number line—not clustered as they did—and that therefore something important had to be going on cosmologically speaking. He tried to show that the key to the clustering was N, the number of material particles in the universe. Somehow N must factor into the other constants, and thereby into the ratios constructed from them, in such a way as to produce the clustering. This explanatory program was not in general successful. But even Weyl himself was slightly infected by Eddingtonian number crunching, publishing a paper in 1934 in which he expanded on his earlier brief treatment of the matter (Weyl [1934]). Shortly thereafter, Paul Dirac entered the picture, weighing in with a short letter to *Nature* on the topic in 1937, and then with a fuller treatment published in the *Proceedings of the Royal Society* for 1938 (Dirac [1937], [1938]). It is with Dirac that the central theme of this paper really begins.

Dirac's 1938 paper was titled 'A New Basis for Cosmology'. The new basis sought was one in which the clustering of these pure numbers was assumed to be nonaccidental, and for which an explanation of the clustering in cosmological terms was sought. Dirac's attempted explanation was more radical than Eddington's: Dirac abandoned the constancy of the fundamental constants. He argued that the clustering was due to the dependence of at least some of the fundamental constants on the cosmological epoch, on the time elapsed since the beginning of the expansion of the universe. This latter value obviously changes with time; hence, no matter at what epoch one performs the calculations, one would still get the same clustering. Dirac's theory has not in general found favor with most other astrophysicists and cosmologists. But in the course of the paper for the Royal Society in 1938, in the guise of a single sentence, Dirac gave birth to an argumentative device whose subsequent use by a determined clique of astrophysicists I will argue constitutes a 'sharp practice'—especially in the light of recent attempts to resuscitate the design argument in contemporary cosmology—in the sense of the term that comes from law: a practice that, while technically not illegal, is nevertheless shrewdly self-advantageous to the point of being seriously misleading.

2 The birth of a sharp practice

If indeed the various dimensionless ratios constructed from combinations of the fundamental physical constants clustered *exactly* around 1, 10^{40}, and the latter's various powers and the reciprocal of each (i.e. 10^{20}, 10^{60}, 10^{80}, 10^{-40}), it would surely be something that called for a specific explanation, something that indicated a deeply buried rational order to the physical universe. But in fact the clustering is not exact. But what does 'exact' mean in this context? For example, the gravitational fine structure constant, α_G, which is a measure of the strength of gravity that is frequently cited in the cosmological literature, is 5.90499×10^{-39}, not quite precisely 10^{-40}, the reciprocal of 10^{40}.[1] How inexact ought we to count this imprecision for purposes of evaluating the clustering hypothesis? Dirac was perfectly aware of this level of imprecision to the clustering when he wrote his Royal Society paper in 1938. He needed a non-anthropocentric unit—Dirac called it 'atomic time'—for measuring time, and he chose a unit fixed by certain fundamental constants of physics,

$$e^2/m_ec^3$$

the electric charge squared divided by the mass of the electron times the speed of light cubed: 9.39962×10^{-24} seconds. At the time Dirac was writing (1938), Hubble's discovery of the expansion of the universe was less than a decade old, and astrophysicists did not have an accurate measure of the time elapsed since the beginning of the expansion, and so Dirac was under the mistaken presumption that the time elapsed, which he called the 'present epoch', was about 2 billion years (it is in fact between 12–18 billion years). In the non-anthropocentric unit of time Dirac had invented, 2 billion years is 6.71006×10^{39}. Curiously, owing to presumably less accurate values available at that time for the other fundamental constants used in the formula for his time unit, Dirac actually said it was 7×10^{38}. He then pointed out that this figure, 7×10^{38}, is 'of the same order of magnitude' as the ratio of the electric to the gravitational force between an electron and a proton, 2.3×10^{39}. This is followed by a seemingly innocent sentence that I argue counts as the birth of a sharp practice that has grown to prominence in certain quarters of astrophysical cosmology these days:

> If we had used another atomic unit of time in which to express the present epoch, we should have obtained a value differing from the above one [7×10^{38}] by at most a few powers of ten, which would not have affected the agreement with [2.3×10^{39}] as to order of magnitude, when such large numbers as 10^{39} are concerned. ([1938], p. 200)

Dirac then canvassed 6 different non-anthropocentric ('atomic') time units:

[1] Because precision is the issue, I will throughout this paper compute all numbers, where possible and relevant, to 5 figures after the decimal point. Values for all fundamental physical constants are taken from the 1998 recommendations of the Committee on Data for Science and Technology (CODATA), available at www.nist.gov/constants and in the *Journal of Physical and Chemical Reference Data*, **28**, No. 6, 1999. For calculations, the author used Mathcad Plus 6.0 and Sigma Plot 2.0.

e^2/m_ec^3, e^2/m_pc^3, h/m_ec^2, h/m_pc^2, $\hbar/m_ec^2$, $\hbar/m_pc^2$

where m_p, h, and $\hbar$ are the mass of the proton, Planck's constant, and Planck's constant divided by 2π, respectively. These 6 time units are, respectively, in the ratio

1, 0.00054, 861.02311, 0.46893, 137.03639, 0.07463[2]

But something is amiss here. Note that the units differ over a spread of 6 orders of magnitude, 6 powers of 10, 1 million. Yet in the next paragraph of his paper Dirac claimed that the use of any one of the 6 units would still render a value for the present epoch that is in 'close agreement' with the number 2.3×10^{39}. This claim is false unless 'close agreement' is taken to mean 'differs by at most a few powers of ten', and 'few' is taken to mean up to 6 powers of ten.[3] But that is stretching the original meaning of *order of magnitude* well beyond its proper bounds.

A little over two decades after Dirac's Royal Society paper, Robert Dicke ([1961]) published a short note in *Nature*—a paper heavily cited by later cosmologists interested in design arguments—in which he subtly refined the sharpness of Dirac's sharp practice. He did so by suggesting that when two like-dimensioned numbers are of the same order of magnitude in Dirac's loose sense (i.e. within a few powers of ten of each other), then the dimensionless ratio of the two numbers can be said to be of the order of unity, that is, 1, the zero power of every number:

> Dirac noted that most physical and astrophysical dimensionless constants are of the order of magnitude of integral powers (positive and negative) of the number 10^{40}, where such numbers as $m_p/m_e \sim 1800$ and $\hbar c/e^2 \sim 137$ are said to be of the order of unity, the zero power of 10^{40}. ([1961], p. 440)

Dicke cited this practice with apparent approval and went on to apply it within his letter. Yet the proton/electron mass ratio, which is in fact 1,836, not 1,800, is 3 orders of magnitude larger than unity—indeed, 1,836 times unity. What sort of cosmological cavalierness could lead a brilliant and outstanding physicist like Dicke to accept so nonchalantly the idea that 1,836 is pretty much the same as 1? Dicke was sympathetic to Dirac's notion that some of the fundamental constants change with cosmic epoch because he and Carl Brans were at that time working on a theory of gravitation in which G,

[2] The ratio Dirac gives in his paper is slightly off given the usual conventions for rounding fractions: 1, 0.0005, *850*, *0.46*, 137, *0.074*.

[3] Using the inaccurate present epoch figure which Dirac gives of 2 billion years, the 6 different units give the present epoch as: 6.71006×10^{39}, 1.23207×10^{43}, 7.79312×10^{36}, 1.43093×10^{40}, 4.89655×10^{37}, 8.99083×10^{40}, an interval running from 5,356 times the 2.3×10^{39} target figure to 295 times less than the target figure.

the gravitational constant, altered with the epoch, so perhaps he was willing to overlook the looseness in saying that 1,836 is pretty much the same as 1.

In the letter Dicke noted that some of the values of the fundamental constants and the ratios constructed from combinations of them are constrained by the requirement that the universe be sufficiently old to have allowed the evolution of human observers. Some possible values can be ruled out because those values would be inconsistent with the occurrence of supernovae that seed the universe with elements heavier than hydrogen; for the human organism contains a host of elements heavier than hydrogen, and those elements had to be dispersed throughout spacetime by previous supernova explosions where they became incorporated into protoplanetary clouds that eventually contracted into planets like the earth. Or alternatively, some possible values are ruled out because they would be inconsistent with the existence of hydrogen-burning stars that are hydrostatically stable for at least a few billion years, on the assumption that it takes a few billion years minimally for intelligent observers to evolve on a planetary surface supplied with energy from such a stable star. This line of reasoning struck a chord deep within the cosmological community in the sense that many cosmologists began to take seriously the idea that the values of the fundamental constants (and their various combinations into ratios) are *highly constrained* by the contingent existence of human observers. In 1974 Brandon Carter coined the term 'anthropic principle' to give a name to this sort of constraint and make it into an officially recognized methodological axiom in astrophysical cosmology (Carter [1974]). Carter also allied himself with the sharp practice we have been concerned about when, in reference to a 'large number coincidence' that Hermann Bondi had written about, he wrote:

> The first 'large number coincidence' on Bondi's list consists of the observation that although stars come with widely varying sizes and colours—from red giants to white dwarfs (and more recently neutron stars)—they always have a mass M equal in order of magnitude (i.e. within one or two powers of ten) to the *inverse* of the gravitational coupling constant [...]$\sim 10^{40}$. ([1974], p. 292)

The quote from Carter, referencing Bondi, itself contains a prime example of the sharp practice I have identified. The mass of our sun is 1.989×10^{33} grams, and the inverse (reciprocal) of α_G, the gravitational coupling/fine structure constant, is 1.69348×10^{38}. The latter number is 85,142 times larger than the former number—that is 4.93 orders of magnitude—yet the two numbers are said matter-of-factly to be of the same order of magnitude. First Weyl, then Eddington and Dirac, then Dicke, Bondi, and Carter. Since Carter in 1974, unfortunately, the practice has settled even more comfortably into the established methods of some astrophysicists.

3 High tide for the anthropic principle

In 1979 Bernard Carr and Martin Rees published a review paper in *Nature* titled 'The Anthropic Principle and the Structure of the Physical World' that catapulted the anthropic principle out of the murky backwaters of astrophysical cosmology and into the spotlight (Carr and Rees [1979]). The paper is technical and certainly very striking to read. The majority of present-day authors who write on the anthropic principle trace back many of the technical assertions and examples that they use directly to this paper, which is accordingly very heavily cited. It was followed a year later by a similar paper in Russian by the Soviet cosmologist I. L. Rozental ([1980]), also heavily cited ever since its publication, titled 'Physical Laws and the Numerical Values of Fundamental Constants'. Two years later, Paul Davies' *The Accidental Universe* appeared, a readable effort by a mathematical physicist to make the topic more accessible to educated persons in other fields of endeavor (Davies [1982]). A collection of papers appeared a year after that in the *Philosophical Transactions of the Royal Society, London, Series A*. These papers rehashed many of the same mathematical points pioneers like Dirac and Dicke had mentioned, only in greater detail; but they also raised new points by extending the anthropic principle deeper into the biological sphere (Press and Lightman [1983]). The productive results of all this energy invested in uncovering the quantitative deep structure of the universe needed to be brought together in a canonical form. That form arrived in 1986 with the publication of John Barrow and Frank Tipler's *The Anthropic Cosmological Principle* (Barrow and Tipler [1986]). This magnum opus was over 700 pages, and it was not for the faint of mathematical or scientific heart. It was a comprehensive work, ambitiously conceived, and distinguished by a 95-page chapter on the history and structure of design arguments (with 246 footnotes), which was followed by a 95-page chapter on the history and structure of teleological explanations in science (with 343 footnotes). We get philosopher-mystics like Teilhard de Chardin, Henri Bergson, and Samuel Alexander between the same two book covers as no-nonsense geniuses like Einstein, von Neumann, and Hawking—all of them cited for the purpose of supporting a slickly-packaged argument for intelligent design of the universe. A more thorough design argument based on scientific evidence has never been constructed—the book was and remains the Bible of design arguments, so to speak—yet the foreword was by none other than John Wheeler, as sure a sign of the book's scientific legitimacy as anything. The penultimate chapter presented a thorough, if partisan, analysis of the arguments and evidence regarding the probability of extraterrestrial intelligent life, and it came to the conclusion—against the popular view these days—that we humans are almost assuredly the lone intelligent species in the universe. This conclusion was embraced by the authors a little too painlessly for the reader not to be suspicious that mathematical astrophysics was somehow being co-opted to serve the purposes of an ulterior theological agenda. That ulterior theological agenda came out into the open in 1989 with the publication of John Leslie's *Universes*, in which Leslie, a philosopher, helped himself to the accumulated mathematical supermarket of astounding ratios, narrow intervals, and other improbable 'coincidences' presented in books like Barrow and Tipler's in order to construct an elaborate design argument.[4] Leslie's book ([1989]) was ingeniously argued, containing a wealth of creative thought experiments that would stump and frustrate the most intransigent of atheists, but it was in the end still based on the same co-optation of mathematical physics for an ulterior end. The details of how that co-optation works involve the sharp practice I have identified, and to the details we now turn.

4 How not to do things with numbers

I begin with Carr and Rees ([1979]). This is a foundational document in the area, and if the sharp practice infests this paper, then we have uncovered it right where it could have been expected to have a most harmful influence. Carr and Rees constructed a graph, one of whose purposes was to illustrate their claim that the order of magnitude of masses and lengths for every level of physical structure in the universe is fixed by the values of just 4 fundamental constants, the main two being α and α_G, which measure the force of electromagnetism and the force of gravity, respectively. It is instructive to consider what they saw themselves as doing, so I quote the opening sentences of their paper:

> The structure of the physical world is manifested on many different scales, ranging from the Universe on the largest scale, down through galaxies, stars and planets, to living creatures, cells and atoms. Only objects such as quarks and leptons may be devoid of further substructure. Each level of structure requires for its description a different branch of physical theory, so it is not always appreciated how intimately they are related. We will show here that most natural scales are determined (to an order of magnitude) by just a few physical constants. In particular, the mass scale and length scale (in units of the proton mass m_p and the Bohr radius α_0) of all structures down to the atom can be expressed in terms of the electromagnetic fine structure constant, $\alpha = e^2/\hbar c$, the gravitational fine structure constant, $\alpha_G = Gm_p{}^2/\hbar c$ and the electron-to-proton mass ratio, m_e/m_p. The quantity m_e/m_p is related to α due to a coincidence in nuclear physics [i.e. $m_e/m_p \sim 10\alpha^2$]. ([1979], p. 605)

[4] It must be noted that Leslie quite explicitly holds that the deity evidenced by the alleged fine tuning of the physical structure of the universe is *not* the traditional deity of the major world religions, but more like the Neoplatonic *One*: a nonpersonal, supremely rational, purely mathematical intelligence.

This claim if true is surely striking: all masses and lengths, in non-anthropocentric units of the proton mass and the Bohr radius, for every kind of stable material system in the universe, are 'determined' to an order of magnitude by combinations of just four fundamental physical constants. If suitably disposed to do so, one might argue that this represents an effective *means* by which an intelligent deity could have designed a universe such as ours. The deity would not need to fashion material systems piecemeal, one kind at a time—instead, adjust the four constants in question, place them in the same causal nexus with the remaining laws of physical nature, and simply let events unfold of their own accord. To be sure, Carr and Rees themselves had no apparent ulterior agenda—theistic or otherwise—when they wrote their paper, and the chief motivating factor appears to have been curiosity and the search for mathematical order. But that has not stopped other astrophysicists from exploiting the same methodology Carr and Rees pioneered to further explicitly theistic agendas to which those other astrophysicists are seemingly committed.

But we should note that the mass and length scales for stable systems in the universe are *not precisely* determined by the four constants in question. In the table, I evaluate Carr and Rees' claim about mass and length scales quantitatively. The first column is the scale, the second column is the formula Carr and Rees provide for that scale, the third column is the precise value the formula in column two gives, the fourth column is the actual value (in some cases an average within a range of actual values), and the last column gives the accuracy of the match between Carr and Rees' formula from column two and the actual value from column three, expressed as the ratio of the former to the latter. In the case of planetary scales, I take an average of a terrestrial planet and a gas giant planet. I use 'kg' and 'm' to indicate kilograms and meters, respectively.

Carr and Rees note that some of these scales also depend on m_e/m_p, but that one may eliminate that ratio through the order of magnitude equivalence $m_e/m_p \sim 10\alpha^2$—thereby simplifying the formulae further (indeed, m_e/m_p and $10\alpha^2$ are of the same order of magnitude, 0.000545 and 0.000533, respectively). How impressive are the precision levels indicated? The mean of all the accuracies is 19.23328, *over* 1 order of magnitude to the high side. The standard deviation is 50.24032, and the standard error is 8.0516. The minimum and maximum imprecisions are, respectively, 0.02056 and 192.92185 (384.63676 for the terrestrial planetary mass), an interval spanning 9,383 (18,708 using the terrestrial planetary mass). Only 8 of the 14 cases fall inside 1 order of magnitude higher or lower than exact precision, 1.0 (and one of those cases is fixed at 1 by fiat—the proton mass is one of the 4 chosen constants). Hence, a little less than half of the cases (42.8%) are *more than* 1 order of magnitude off from exact precision. These statistical facts reveal the

Table 1

Scale	Formula	Value	Actual Value	Accuracy
Planck mass	$\alpha_G{}^{-1/2}m_p$	2.17665×10^{-8} kg	2.1767×10^{-8} kg	0.99998
Planck length	$\alpha^3\ \alpha_G{}^{1/2}\alpha_0$	1.58018×10^{-36} m	1.61605×10^{-35} m	0.09778
proton mass	None	1.67262×10^{-27} kg	1.67262×10^{-27} kg	1.0 by fiat
proton length	$\alpha^3\alpha_0$	2.05635×10^{-17} m	1 fermi = 10^{-15} m	0.02056
human mass	$\alpha^{3/4}\alpha_G{}^{-3/4}m_p$	1.96045 kg = 4.3 lb	150 lb = 68.03886 kg	0.02881
human length	$(\alpha/\alpha_G)^{1/4}\alpha_0$	0.05579 m = 2.1964 in	5.5 ft = 1.6764 m	0.03328
planetary mass	$\alpha^{3/2}\alpha^{-3/2}m_p$	2.29782×10^{27} kg	Earth: 5.974×10^{24} kg Jupiter: 1.899×10^{27} kg	Earth: 384.63676 Jupiter: 1.21002 ave: 192.92185
planetary length	$(\alpha/\alpha_G)^{1/2}\alpha_0$	5.88266×10^{7} m	Earth: 6.378×10^{6} m Jupiter: 7.1369×10^{7} m	Earth: 9.22336 Jupiter: 0.82426 ave: 5.02381
stellar mass	$\alpha_G{}^{-3/2}m_p$	3.68611×10^{30} kg	solar mass: 1.989×10^{30} kg	1.85325
stellar length	$\alpha_G{}^{-1/2}\alpha_0$	6.88639×10^{8} m	solar radius: 6.9599×10^{8} m	0.98944
galactic mass	$(m_p/m_e)^{1/2}\alpha^5\ \alpha_G{}^2m_p$	4.25343×10^{40} kg	Milky Way mass: 10^{41} kg	0.42534
galactic length	$(\alpha^3/\alpha_G)\ \alpha_0$	3.48239×10^{21} m	Milky Way diameter: 6.1714×10^{19} m	56.42788
Hubble mass	$\alpha^{-2}\alpha_G{}^{-2}m_p$	9.008×10^{53} kg	10^{53} kg (Davies 1982)	9.008
Hubble length	$(\alpha/\alpha_G)\ \alpha_0$	6.53954×10^{25} m	1.5×10^{26} m	0.43597

exaggerated nature of the claim that the formulae Carr and Rees devise determine ‘to an order of magnitude’ the mass and length scales of every kind of stable material system in the universe.

The exaggeration is even better elicited by a further example. Carr and Rees claim that the value of G falls within a narrow interval which allows for the existence of long-lived hydrogen-burning stars that are stable to heat convection—obviously a necessary condition for the evolution of living organisms on planets orbiting such stars ([1979], p. 611). Stable hydrogen-burning stars fall within a fairly narrow mass range centered on a specific mass, call it M_{con}, that serves as the dividing line between giant blue-white stars which release heat by radiation (masses greater than M_{con}) and smaller yellow-red stars which release heat by convection (masses less than M_{con}). The formation of planetary systems is thought to be associated with smaller convective stars like our sun because such stars have less angular momentum than the giant radiative stars.[5] This key dividing mass is very close to 1.4 solar masses. Carr and Rees argue that M_{con} is very close to 1.4 solar masses ‘only because $\alpha_G \sim \alpha^{20}$’ ([1979], p. 611). But this alleged fine tuning is in reality a sham, for α_G is 5.90499×10^{-39}, whereas the 20th power of α is 1.8336×10^{-43}, over 4 orders of magnitude smaller than α_G. And if the electron mass m_e is used to calculate α_G instead of the more standardly used proton mass, the match to the 20th power of α is still over 2 orders off: $\alpha_{Gme} = 1.75147 \times 10^{-45}$.

But matters are even less auspicious when we look at Paul Davies’ attempts to flabbergast us with the finely tuned numbers. Davies claims that α_G is of the order of magnitude of the 4th power of the weak force fine structure constant α_w (Davies [1982], p. 80).[6] This claim isn’t remotely close to being accurate: α_w is 3.03325×10^{-12}, the 4th power of which is 8.46511×10^{-47}, 7 orders of magnitude smaller than $\alpha_G = 5.90499 \times 10^{-39}$. Here Davies may be a victim of mathematical cavalierness. It is customary to use the proton mass when calculating α_G, and Davies himself uses it on page 39 in one of his main tables in which the formula for α_G is given. Using the proton mass yields the standard 10^{-39} order of magnitude value; but if one were to use the electron mass instead (after all, electrons are ordinary matter, and being substructureless they might be held to have a better claim to fundamental status than protons, which are composed of quarks), one would get a value for α_G of 1.75147×10^{-45}, a factor of 20 larger than the 4th power of α_w. Perhaps that is what Davies meant, but nothing in the text suggests that the reader was

[5] Current theory associates the formation of planets with stars that have low angular momentum on the hypothesis that the angular momentum is low in such stars because some of the rotational energy is redistributed among planets surrounding such stars.

[6] The formula Davies uses for calculating the weak force fine structure constant α_w is $g_w m_e^2 c/\hbar^3$, where g_w is the weak force constant, whose value Davies gives as 1.43×10^{-62} joules per cubic meter.

supposed to switch the electron mass for the proton mass in the formula for α_G.

To take another example of slippery number crunching, Davies claims that 10^{15}–10^{16} times the proton mass is of the same order as the Planck mass ([1982], pp. 80–1). But the Planck mass, 2.1767×10^{-8} kilograms, is over 3 orders of magnitude larger than 10^{16} times the proton mass, 1.67262×10^{-11} kilograms—1,301 times larger, to be specific. This claim arises in the context of a discussion of our old friend 10^{40} and the decay of the proton. Under some versions of Grand Unified Theory, protons are not immortal but decay after an astronomically long time, now thought to be about 10^{31} years, which is of order 10^{38} seconds. The proton decay time depends on the mass of the superheavy mediating particle that serves to unify the strong force and the electroweak force, and it is this mass that Davies claims is 10^{15}–10^{16} times the proton mass and of the same order as the Planck mass. The Planck mass enters the picture because it is the key mass in any future theory of quantum gravity, being the mass for which α_G has the exact value of 1, as well as being the mass of the smallest physically possible black hole. Quantum gravity would be the ultimate theory, the one that unifies the GUT force and gravity into a single force. Davies is anticipating deeper and deeper rational structure; the numbers must 'line up' non-randomly, all coincidences must be shown in the end not to be really coincidental. Physicists often write about their love of beauty, about how much finding symmetries and other aesthetically pleasing features buried deep in the mathematics delights and motivates them. Granted such findings would be delightful, we should still insist on two guiding principles: (i) the beautiful, neat, precise model isn't necessarily the true model, and (ii) don't fudge the numbers in pursuit of mathematical beauty.

In the present case, however, the fudging is insidious. One favorite claim of anthropic principle enthusiasts is that the total number of charged particles in the universe, N, was 'chosen' so that the density of matter in the universe would be close to the critical density, the minimum density needed to ensure that the expansion of the universe ceases at some point in the future. This alleged happy balancing would result in an expansion from the initial event that was neither too slow nor too fast—it was just right to allow for the physicochemical conditions conducive to the evolution of intelligent beings. Davies counts himself an advocate of this claim, and he argues that fine tuning N so that the energy density of matter in the universe ρ_u is close to the critical energy density requires that the following formula be of order unity: $\rho_u G t_H^2/c^2$ (Davies [1982], pp. 82–8).[7] What is puzzling about this is Davies'

[7] The total number of charged particles N factors in because the energy density of the universe is given by $N m_p c^2/(c t_H)^3$, where t_H is the Hubble time, the reciprocal of the Hubble parameter H. H is the expansion rate of the universe per unit distance from the earth, a number that is

claim (*Ibid.*, p. 58) that empirical observations indicate that the total energy density of matter in the universe is approximately 10^{-11} joules per cubic meter (he gives no indication of being aware that this conflicts with his own figures for other parameters like the Hubble time). Using this figure in the above formula yields 0.00186, a value 2.73 orders of magnitude below unity. Since when did 18 ten-thousandths become pretty much equal to 1?

Davies must be credited with the virtue of making at least a rudimentary pass at justifying the sharp practice I have identified. In *The Accidental Universe*, he writes:

> Before embarking upon a discussion of the large numbers, a word should be said about the accuracy implied in the symbol $\sim$. Inspection of table 5 shows that $\alpha_G{}^{-1} = 1.7 \times 10^{38}$, so that the use of the relation $\alpha_G{}^{-1} \sim 10^{40}$ might be regarded as somewhat straining the definition of an order of magnitude approximation. However, two points should be born in mind here. The first is that, compared to 10^{40}, even 10^2 is a minute fraction. Secondly, some of the factors that go to make up α_G are purely a matter of convention. For example, we could equally well have used h rather than $\hbar$. The choice in no way affects the general arguments presented here. (*Ibid.*, p. 78)

This attempted justification fails. 10^2 is still a factor of 100 off from exact precision—exact fine tuning—no matter how small a fraction of some other number it may be. Worse, his claim about the conventionality of which factors are used to make up α_G is not in general true: using h instead will destroy some order of magnitude matches involving α_G. For example, using h instead of $\hbar$ renders a value for α_G of 9.39809×10^{-40}, a factor of 6.28318 less than its value when $\hbar$ is used. When powers of α_G other than 1 are involved this difference will undermine some of the standard order of magnitude claims made by cosmologists like Davies, Carr, and Rees. For example, using h destroys the order of magnitude match between the solar mass and the value of the formula for the stellar mass scale in the above table taken from Carr and Rees' graph. Using h, Carr and Rees' formula for the stellar mass scale yields 5.80548×10^{31} kilograms, a factor of 15 larger than the value using $\hbar$, and 29 times the solar mass. The formula for the Hubble mass using h yields 3.55621×10^{55} kilograms, clearly an unwarrantedly high figure on the observational evidence, 39 times larger than the figure yielded by using $\hbar$, and

soft due to uncertainties in measuring galactic distances. Davies is seemingly unaware that his book contains conflicting values for H: a stated consensus value of 50 kilometers per second per 1 million parsecs (4), and a Hubble time of 5×10^{17} seconds ($\sim$15.58549 billion years), which mathematically requires that H be 61.715 kilometers per second per 1 million parsecs ([1982], p. 39). And this conflict in turn entails conflicting values for t_H. It should be noted that the most recent and thorough determination of the Hubble parameter gives its current value as 72±8 kilometers per second per one million parsecs (Freedman *et al.* [2001]). Obviously, such a value would foul up Davies' computations even more. One parsec is 3.2616 light-years.

355 times larger than Davies' own figure of 10^{53} kilograms (Davies [1982], p. 79).

5 The recalcitrant sloppiness of crud

Not all astrophysicists are as sanguine as Davies about the sharp practice we have uncovered. W. H. Press and A. P. Lightman crafted a contribution to the previously mentioned collection of papers published in the *Philosophical Transactions of the Royal Society, London, Series A* titled 'Dependence of Macrophysical Phenomena on the Values of the Fundamental Constants'. In this paper, they try to apply the Carr and Rees method of using combinations of fundamental constants to

> determine the scales of various macroscopic phenomena, including the properties of solid matter; the distinction between rocks, asteroids, planets, and stars; the conditions of habitable planets; the length of the day and year; and the size and athletic ability of human beings. Most of the results, where testable, are accurate to within a couple orders of magnitude. (Press and Lightman [1983], p. 323)

What is interesting about their effort is the degree to which they own up to the considerable sloppiness in the fit between the numbers that their formulae determine and the actual empirically determined values for the scales in question. It turns out that ordinary matter, which they call 'crud' to indicate that it is solid, nonmetallic, and nonsingle-crystalline, is rather recalcitrant to having its nature and properties determined to precision by the fundamental constants. For example, they take the value of the formula

$$[Ry/(2\alpha_0)^3](m_e/m_p)^{1/2}$$

where 'Ry' denotes the Rydberg energy (2.17987×10^{-18} joules), to set the scale of the shear modulus, the tensile strength, of crud. Yet they are quick to admit that the value of this formula, 4.29125×10^{10} newtons per square meter, is not in fact revealing, because 'Real materials always contain structural flaws and are an additional factor of 10 to 100 below this' (*Ibid.*, p. 324). Next they discuss the thermal conductivity of crud—the rate at which ordinary matter transmits heat energy—the scale of which is supposedly given by

$$(Ry/\alpha_0 \hbar)(m_e/m_p)^{1/2}k$$

where k is Boltzmann's constant. This formula yields 125.8588 joules per meter per kelvin per second which, however, the authors admit is 'about a factor of a hundred too large, since real materials are full of dislocations and other photon-scattering unpleasantness' (*Ibid.*, p. 325). You can blame that damned 'real material' again, that ordinary crud with all its sordid microimperfections, for ruining the otherwise pretty mathematics. But things are even worse, say Press and Lightman, for they continue,

> we will need to take cognizance of the fact that an important set of complex chemical phenomena take place with bond energies that are even another factor of ten smaller than the bond energies in crud. This extra factor of about 0.1, which we will denote by the symbol ε, does not arise out of any combination of physical constants, but comes from all the abhorrent details of chemistry that are omitted in this paper. (*Ibid.*)

But how can the details be considered abhorrent in this context? *Design arguments are all about details*, and the potential use of the Carr and Rees methodology for buttressing a design argument is always lurking in the background whenever cosmologists and other anthropic principle acolytes start juggling the fundamental physical constants and spitting out the numbers.

6 How excited can excited carbon-12 be?

One of the most beloved and most often cited of all the alleged cases of anthropic fine tuning involves the excruciatingly complex details of the nuclear fusion processes that occur within the cores of stars.[8] The physics of stellar interiors is mathematically daunting, but the major aspects of what goes on inside a stellar core are now theoretically accessible. Fred Hoyle was among the first theorists, along with Hans Bethe and George Gamow, to work out the basic structure of the fusion process inside stars. A typical star begins its stardom by fusing hydrogen nuclei into helium nuclei. This is a *very* slow process, and an ordinary star only succeeds in burning hydrogen at a rate producing stellar-level luminosities because it contains such a huge amount of hydrogen concentrated in one gravitating body—there are about 10^{57} protons packed into a typical star, almost all of them hydrogen at the start of the star's lifetime. After a star has consumed a critical percentage of the hydrogen in its core, core density and temperature increase and the core starts to fuse helium nuclei into carbon nuclei. In 1953 Hoyle argued that the fusion of helium nuclei to form carbon nuclei would not proceed at a high enough rate to have produced the observable carbon abundance in the universe unless there were a specific energy level of the carbon-12 nucleus that was resonant with—very close to, but not below—the sum of the energies of a beryllium-8 nucleus and a helium-4 nucleus (Hoyle, Dunbar, Wenzel, and Whaling [1953]; Hoyle [1954]). This is because the triple-alpha process, in which a carbon-12 nucleus is produced from three helium-4 nuclei, proceeds

[8] References to it and discussions of it in the literature on the anthropic principle are frequent (Barrow and Tipler [1986], p. 250–5; Carr and Rees [1979], p. 611; Davies [1982], p. 117–8; Leslie [1989], p. 35–6).

via an intermediate step in which two helium-4 nuclei fuse to form a beryllium-8 nucleus, which then fuses with another helium-4 nucleus to form a carbon-12 nucleus. In 1953 there was no such resonant energy level for carbon-12 nuclei known to the physics community, and Hoyle famously predicted that such a resonant energy level would be discovered.[9] Very shortly thereafter, it was shown experimentally that the first excited state of the carbon-12 nucleus has an energy level around 7.68 ± 0.03 million electron volts (MeV), which is 283 to 343 thousand electron volts (keV) above the sum of the energies of a berylium-8 nucleus and a helium-4 nucleus, 7.3667 MeV (Dunbar, Pixley, Wenzel, and Whaling [1953]). This energy level for the first excited state of carbon-12 has since been experimentally refined downward to 7.644 MeV, which is 277.3 keV, above the sum of the energies of a beryllium-8 nucleus and a helium-4 nucleus (Livio, Hollowell, Weiss, and Truran [1989], p. 281). But that is only half the fine-tuning story. All of the carbon-12 nuclei produced by stellar core fusion would in turn be consumed in the production of oxygen-16 nuclei, via a reaction in which a carbon-12 nucleus fuses with a helium-4 nucleus, were it not for the fact that the latter reaction does *not* proceed resonantly; for the energy of an oxygen-16 nucleus at 7.1187 MeV is 42,900 eV *below* the sum of the energies of a carbon-12 nucleus and a helium-4 nucleus, 7.1616 MeV (*Ibid.*). That means that the lion's share of the carbon-12 nuclei produced by stellar core fusion is still present when the star eventually explodes as a supernova, thus seeding the local interstellar medium with an amount of both carbon and oxygen nuclei consistent with the presently observed cosmic abundances. The observed carbon-12 abundance includes the carbon-heavy biosphere of the earth. The biosphere of the earth was able to develop only because there was enough carbon diffused throughout the local interstellar medium by previous supernovae for the earth to form as a planet with a relatively carbon-rich surface. Summing up, carbon is not underabundant in the universe and oxygen is not overabundant in the universe because (i) the fusion production of carbon inside stellar cores is *just barely resonant*, while (ii) the fusion production of oxygen inside stellar cores is *just barely nonresonant*. Because nuclear energy levels are ultimately dependent on the strengths of the fundamental forces, as well as on the masses of constituent particles, this strikes some folks as fine tuning. Indeed, Hoyle himself is reported to have written that the energy resonances in question are so extraordinary that the whole arrangement struck him as a 'put up job', that is, the work of intelligent design. Paul Davies quotes the following passage from an

[9] The contemporary famousness of this supposed case of fine tuning—and of Hoyle's prediction of it—is attested to by Martin Rees ([2000], p. 50) who writes: 'The English theorist Fred Hoyle stumbled upon the most famous instance of "fine tuning" when he was calculating exactly how carbon and oxygen were synthesized in stars.'

unpublished paper he claims Hoyle wrote, which Davies cites as a University of Cardiff preprint,

> If you wanted to produce carbon and oxygen in roughly equal quantities by stellar nucleosynthesis, these are the two energy levels you would have to fix, and your fixing would have to be just about where these levels are actually found to be [...]. A commonsense interpretation of the facts suggests that a superintellect has monkeyed with the physics, as well as chemistry and biology, and that there are no blind forces worth speaking about in nature. (Davies [1982], p. 118)

In 1989, M. Livio, D. Hollowell, A. Weiss, and J. W. Truran, using the power of contemporary computers, further investigated these alleged 'near misses' to see if they are as finely grained as is claimed. Livio and colleagues constructed a computer model of stellar interiors in the spirit of testing how much larger or smaller the resonance could be between the energy of the first excited state of a carbon-12 nucleus and the summed energies of a Beryllium-8 nucleus and a helium-4 nucleus without destroying consistency with the observed carbon and oxygen cosmic abundances. Livio and colleagues reported that, in the context of their computer model, the difference between the two energy levels in question could be increased by 60 keV without destroying consistency with the observed cosmic abundances of carbon-12 and oxygen-16 ([1989], p. 283). Sixty thousand electron volts is 9.61302×10^{-15} joules, the thermodynamic temperature equivalent of which (i.e. dividing it by Boltzmann's constant k) is 696.268 million degrees kelvin. How can a temperature window *that* wide within which the resonant energies can fall count as a case of 'fine tuning' that results in energy levels that are 'just barely' resonant? Furthermore, Livio and colleagues reported that decreasing the difference between the two energy levels by 60 keV would result in a stellar carbon abundance at the end of core helium burning of about 4 times higher than normal (*Ibid.*). Given that Hoyle's original worry was that there would be too little carbon made inside stars—not that there would be too much—this suggests that the window of compatibility might in fact be 120 keV wide, a temperature window of 1.392 billion K. The quantitative details are thorny and depend on the specific model of stellar structure used, but the width of the window of compatibility appears to be wide enough to undermine any claim that we have a case of precision fine tuning on our hands.

7 Is a pile of doubts a doubtful pile?

Finally we come up to the present with John Leslie, the most prominent philosopher among the current cadre of anthropic principle enthusiasts. In his influential book *Universes* ([1989]), Leslie focuses on the key issue of what

I'll call *fantastically* narrow intervals. I mean by this expression the finding—*if* it is in fact a true finding—that certain physical constants, or ratios/combinations thereof, must have the values they do to within intervals of possible variance so narrow as to be *objectively uncanny*, or else certain necessary conditions required for the evolution of living organisms could not have obtained. Collect a sufficiently impressive number of such intervals and a design argument begins to look plausible to some folks.

Leslie highlights an important question buried in this morass of large and small numbers, a question that has to do with explanation. When is a collection of data so objectively uncanny as to call for a 'special' explanation, an explanation that appeals to something outside the realm of ordinary nature? Leslie constructs a number of ingenious thought experiments in which we seemingly are forced to acknowledge—even the hard-nosed no-nonsense types among us—that something out of the ordinary is going on, that a 'special' intentional explanation of some kind is appropriate. And you can't get more intentional than an appeal to intelligent design by a rational intellect. But thought experiments are almost always, by design, non-actual cases. The issue I have raised in this paper is whether the physical and mathematical data that the anthropic principle cosmologists have amassed over the years in fact present actual cases of fantastically narrow fine tuning. Are the intervals of compatibility between the values of various fundamental constants and the necessary conditions for the evolution of intelligent hydrocarbon life which the astrophysicists have uncovered in the actual universe *that* fantastically narrow? The weakest part of Leslie's case may not be the philosophical part—the part in which he argues for the appropriateness of special intentional explanations of fantastically narrow intervals—but the part where he relies on the established consensus of anthropic principle illustrative cases from which I have taken the examples already analyzed in previous sections of this paper. The worry is generated by the fact that the sharp practice I have identified infests a significant proportion of these cases, and it does so in sometimes subtle and cumulative ways that go undetected by those who use them as argumentative ammunition. It is instructive in this light to consider Leslie's take on this issue. Remarking on the possibility that popularly cited cases may in fact contain errors, he writes:

> No doubt some of these claimed facts are mistakes—although many seem as well established as facts about the reality of quarks or black holes or neutron stars, or of the Big Bang itself. Others, again, may be dictated by physical principles so fundamental that they are not fine tunable. But clues heaped upon clues can constitute weighty evidence despite any doubts attaching to each element in the pile. ([1989], p. 6)

A simple inductive counter-argument would seem to refute Leslie here. If each clue in the pile of clues is erroneous, then the entire pile is erroneous—

and this is not to commit the fallacy of composition, for erroneousness is an additive property attributable to the collection itself if every member case in it is erroneous. I'm inclined to think that the same inductive counter-argument holds for the weaker case of each clue being doubtful rather than erroneous—then the entire pile is doubtful, *qua* pile of evidence. Perhaps one could claim that the weaker case in fact escapes my counter-argument on the ground that doubtfulness distributed individually among all the cases in a collection of cases does not warrant the conclusion that the collection is doubtful, *qua* collection. The idea presumably would be that despite the doubts attached to each specific case taken by itself, one is still left with the impression that among this mass of cases *some* must be correct, and 'some' must be enough of them to warrant the inference desired—in this case, an inference to intelligent fine tuning. If that is the line of defense taken, then notice how subjectively impressionistic matters have become. If this kind of fuzzy impression is the best supporting evidence that can be mustered, the inference to intelligent design seems underwarranted indeed.

The fuzziness and impressionistic quality I speak of is suffused throughout the chapter in *Universes* in which Leslie attempts to provide a scientific underpinning for the design argument that it is his book's ultimate purpose to defend. A reader can't help but notice Leslie's habit of expressing the allegedly fantastically narrow intervals, not in precise and specific numerical language, but in fuzzier and more general quantitative language. A given allegedly narrow interval is described as one which could not be 'a trifle greater' without ruining some necessary condition for the development of intelligent life in the universe (p. 35: the nuclear strong force if a trifle greater would lead to nuclei of unlimited size), or else a certain interval would be incompatible with life in the universe were a 'fairly modest change' to be made to some fundamental constant (p. 42: fairly modest changes to the masses of heavy bosons would result in either too many protons or too few—leading either to recollapse of the universe before stars formed or to runaway expansion in which stars do not form). On page 34, the reader is told that the nuclear weak force couldn't be 'much weaker' or else a particularly detailed roadblock to the evolution of life would ensue (an all-helium universe), and that the weak force couldn't have been 'appreciably stronger' without such and such disastrous consequences for the development of living beings such as ourselves (the heat of the Big Bang burns all matter into iron before stars can even form). On page 35, Leslie notes that 'while calculations are hard, it seems a safe bet' that weakening the weak force by a factor of 10 would result in our not being here to discuss the matter; but 'it seems a safe bet' isn't exactly the sort of confidence-inspiring level of scientific support devotees of a design argument surely would prefer to have.

Neil Manson has argued that there is no adequate way to define the notion of being 'fine tuned for life'; i.e. the universe's being fine tuned to be hydrocarbon-life permitting (Manson [2000]). Leslie's book comes under attack in the course of Manson's argument. Manson argues that a purely counterfactual conception of fine-tuning—the conception I have assumed throughout this paper—will not do, for in order for the concept of fine tuning to support an inference to a designer deity, the concept must be defined in the quantitative terms of Bayesian probability theory. Allegedly, it isn't enough merely to say that had the value of a certain constant been different by, say, one part in 10^{40}, then we wouldn't be here to discuss the matter. On the contrary, Manson says, one needs a premise specifying the numerical probability that the constant would have its actual value. This misconstrues Leslie's argument in *Universes*, which is essentially a standard abduction, an argument to the best explanation, not a quantitatively precise probability argument. Leslie is smart enough to know how difficult measuring probabilities is going to be in this kind of cosmological context and therefore how irresolvably imprecise quantitative appeals to probability are going to be in any design argument. Hence, Leslie is concerned for the most part with showing that positing a designer deity is the best explanation, on an overall preponderance of the evidence, for the alleged fine tuning, not with showing that the fine tuning evidence supports belief in a designer deity with probability x for $0 \leqslant x \leqslant 1$, according to formal principles of Bayesian inference.

Manson does consider the possibility of non-Bayesian design arguments but writes them off with respect to the counterfactual interpretation of fine tuning on the ground that claims of fine tuning in such a case are useless without a metric for measuring the fineness of the tuning. He provides an apparent *reductio* argument: on a length scale of light-years, Michael Jordan's height is fantastically finely tuned for basketball greatness, for if he was smaller by merely one part in 10^{16} on that scale (i.e. about 1 meter), he would not have been so great a basketball player. The implication of Manson's *reductio* is that just about any measured quantity can be shown to be fine tuned in the counterfactual sense by choice of an appropriate scale of measurement. Manson's argument here is weak because the length scale of measurement used has no theoretically fundamental justification. A light-year is not a fundamental unit of length in physics, and for a good reason. It doesn't play a role in measuring the fundamental force strengths, for example, because two of the fundamental forces (strong nuclear and weak nuclear) have such exceptionally short ranges, and a third (gravity) is so weak even on more pedestrian scales that using light-years instead of meters would result in unnecessary methodological hardship due to ever more exotic orders of magnitude. For example, the gravitational constant G would be of order

10^{-59} instead of the standard 10^{-11}, and Planck's constant h would be of order 10^{-66} instead of the already exotic enough 10^{-34}. And the hardship risks being substantive: the value of G, for instance, might be so small as to be out of reach of our available technical means for confirming it by laboratory measurement. Manson's argument might be strengthened if the 10^{-16} difference claim was tied in some way to a pure number that is calculated from a ratio of theoretically fundamental constants whose dimensions cancel each other out. Parties to the debate such as Leslie make a point of using dimensionless pure numbers that are calculated from ratios of fundamental constants whose units cancel, like α and α_G, wherever they are available, in part to tone down the anthropocentrism of referring to humanly-concocted dimensions like kilograms, meters, and joules, but mostly to avert blatant measuring-scale biases. If a particular dimension is rescaled consistently throughout both numerator and denominator of such a ratio, then the ratio remains unchanged. For example, rescaling the values of G, $\hbar$, and c with length in light-years instead of meters while keeping mass in kilograms and time in seconds leaves α_G ($Gm_p{}^2/\hbar c$), the gravitational fine-structure constant, unchanged in value. Barrow and Tipler were explicit to the point of hyperbole about this issue when they wrote: 'The only meaningful quantities are *dimensionless* ones' ([1986], p. 292). Yet even dimensionless pure numbers can be made to appear larger or smaller if one is willing to allow eccentrically artificial maneuvering. All one need do is to invent names for specific cardinal numbers. Is an interval of variance compatible with hydrocarbon life that is no larger than 10^{-40} fantastically narrow? Not on a scale of hawkings, where one hawking (I named it after Stephen Hawking) is 10^{-46}; for, on that scale, the interval of variance in question is a million hawkings wide. This is mathematically eccentric, certainly, if not in fact perverse, but it makes the point effectively that even dimensionless pure numbers can be made *to appear* larger or smaller by changing the scale of measurement. I say made 'to appear' larger or smaller because I think a strong case can be made that the scales of measurement that matter epistemically and scientifically for us *are* dependent on, because they are constrained by, our epistemic endowments, e.g. they are dependent on what is big or small to us given our contingent size niche in the universe—it is we who are trying to do the science and thereby come to know physical reality, after all. It is as objective as any truth can be for us that we are not nanometer-sized beings, for example, we are much bigger than that, so it is as objective as any scalar-valued empirical fact can ever be for us that a nanometer (one-billionth of a meter) is indeed a very small size. If this is correct, the eccentric maneuver ultimately fails, for a million hawkings is unquestionably a fantastically small number come time to do human science. This latter point is what theorists like Barrow, Tipler, Leslie, Davies, Carter, Carr, and Rees rely on when they draw their inferences from the allegedly fantastic numbers revealed by modern physics. But exploring this issue of measurement scales in full would be another paper. In the meantime, I believe it is a mistake to see any virtue in trying to construct formal Bayesian probability arguments in the present context. To his credit, Leslie does not do so. He formulates his argument as an abductive one in which the mathematical data on the allegedly fantastically narrow intervals of variance are not used in a technically formal way. But we have seen that even left at that more informal level, his argument still has many questionable features to it.

One of the most questionable features of Leslie's argument is that, as one would have predicted, he makes use of many of the same alleged fine tuning cases whose problematic relation with the sharp practice identified we have investigated in previous sections of this paper. On page 35, Hoyle's famous argument about resonant nuclear energy levels in helium burning is used as evidential support for a general fine tuning claim. Leslie's book was written before the work by Livio and colleagues was published showing that the resonance window, on one computer model at least, is not all that narrow. On page 37, Press and Lightman's work on the determination of macrophysical scales by the fundamental constants is cited for the same purpose, without any acknowledgment by Leslie that Press and Lightman themselves confess to the inaccuracy of some of their formulae as applied to ordinary crud. On page 39, Carr and Rees' argument that the dividing mass between radiative stars and convective stars is close to 1.4 solar masses 'only because' α_G is of the order of magnitude of α^{20} is cited nonchalantly as further evidence of fine tuning, even though a check of the math shows that the order of magnitude match is off by over 4 orders.

8 Conclusion

I have identified a mathematical sharp practice at work within a subcommunity of theorists who are smitten with the anthropic principle in contemporary astrophysical cosmology. The concepts of two or more numbers being *within an order of magnitude* of each other, and of being *the same order of magnitude* as each other, have each been stretched from their original meanings. The stretched meanings have been used by certain theorists to 'cook' the astrophysical numbers in the interest of buttressing a design argument for the existence of a deity who chose the values of key physical constants so that the universe would be hydrocarbon-life permitting. Design arguments have a long history. They used to crop up mostly in the context of the life sciences, where their dismal fate was sealed by the arrival of Darwinian theory within scientific biology 150 years ago. Design arguments applied to biological cases seem to avoid the real issue; for the biological possibilities inherent in the structure of a universe are complex outcomes of its basic physics. Change the basic physics and you change the biological possibilities. It is important, I believe, that this newly-resurgent design argument has made its appearance in the domain of astrophysical cosmology; for that is the appropriate context in which a genuine design argument must live or die in the end. But the evidence that has been marshaled to date by devotees of the anthropic principle does not suffice to justify the claim that the universe was designed by an intelligent deity. I have not claimed in this paper that every single alleged case of fine tuning cited in the literature is bogus or infected by the sharp practice I have identified. But enough of the more popular cases are tinged with the sharp practice to warrant the strong skepticism I have defended.

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