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BALLOONS ON A STRING: A CRITIQUE OF MULTIVERSE COSMOLOGY[1]

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> We can have some confidence in the story of the evolution of the universe from the time of electron-positron annihilation to the present. . . . About earlier times, so far we can only speculate.
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> —Steven Weinberg (2008)

> If a philosopher, deep within his study, should try to move matter, he can do with it what he wishes: nothing resists him. This is because the imagination sees whatever it wishes to, and sees nothing more. But such arbitrary hypotheses throw light on no verity; on the contrary, they retard the progress of science and become most dangerous through the errors they lead us to adopt.
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> —Étienne Bonnot de Condillac (1715–80)

Is the ultimate explanatory principle of the universe to be found in matter or mind? Perhaps no topic moves to the heart of this question more quickly than that of the origin of the universe and the fine-tuning of many of its physical parameters for the existence of life.[1] It is obvious that any answer to this question will be influenced by philosophical assumptions about the nature of reality, science, and legitimate explanatory principles. In this respect, rather than asking whether methodological naturalism is a necessary or desirable constraint on science,[2] I will simply argue that an *adequate* explanation of the origin of the universe and its properties cannot be had if the constraints of methodological naturalism are retained. So reserve the designation "science" as an honorific for whatever you wish, and persist in maintaining its heuristics are methodologically naturalistic if you are persuaded you must, the fact remains that the word "science" has *never* been coterminous with all that is true—indeed, historically it has encompassed a good deal that we now recognize to be false. Having set this issue aside, therefore, we are left to consider the work of various cosmologists who are about the business of fabricating a purely naturalistic explanation of cosmological origins and fine-tuning. I will argue that, by any reasonable standard of assessment, they are not succeeding in this effort, and that this lack of success is not in the least surprising, because it has a principled basis.[3]

Since we must concern ourselves with naturalistic cosmological models that claim resources sufficient to explain not just the origin, but *also* the fine-tuning of the laws and constants of nature, our focus here will be on the explanatory adequacy of various concatenations of quantum cosmology, inflationary cosmology, and the embarrassment of riches constituted by the solutions (vacua) of string theory. Our examination of universal origins and fine-tuning will begin with a discussion of inflationary scenarios grafted onto Big Bang cosmology and the proof that all inflationary spacetimes are past-incomplete. After diverting into a lengthy critical examination of the "different physics" offered by quantum cosmologists at the past-boundary of the universe, we will proceed to dissect the inadequacies of inflationary explanations and string-theoretic constructs in the context of three cosmological models that have received much attention: the Steinhardt-Turok cyclic ekpyrotic model (which does not invoke inflation), the Gasperini-Veneziano pre-Big Bang inflationary model, and the inflationary string landscape model advanced by Susskind, Polchinski, Bousso, and Linde. We will argue that none of these highly speculative string cosmologies removes the necessity of a beginning to the process of universe generation, and we will emphasize the implications of this fact. Then, since the inflationary "mechanism" only really addresses the fine-tuning of the *initial* conditions of the universe and *not* the conditions embodied in its finely tuned laws and constants, we will analyze the adequacy of the string multiverse in its three versions (cyclic ekpyrotic, pre-Big Bang, and landscape) for explaining the nomological structure and values of these precisely tuned life-compatible universal parameters. When all is said and done, it will be clear that transcendent intelligent agency is not just the *only causally sufficient* and therefore *metaphysically sound* explanation for universal origins and fine-tuning, but it is also much more parsimonious, elegant, and resonant with meaning than all of the ad hoc machinations of multiverse cosmology.[4]

1. Universal Origins and Inflationary Cosmology

As is common knowledge, the "Big Bang theory" of the origin of the universe was widely accepted on the basis of its theoretical description in general relativity and the Hawking-Penrose singularity theorems,[5] as well as its empirical confirmation in the discovery of Hubble expansion, the cosmic background radiation permeating the universe, and the massive energies required for the nucleosynthesis of deuterium, helium-3, helium-4 and lithium-7, which exceed even those found on the interior of stars. The wide acceptance of the theory did not relieve the unease with which many cosmologists received it, however. Fred Hoyle states the reason for this unease about the universe's absolute beginning rather bluntly:

> Many people are happy to accept this position. . . . The abrupt beginning is regarded as *meta*physical—i.e., *outside* physics. The physical laws are therefore considered to break down at $\tau = 0$, *and to do so inherently.* To many people this thought process seems highly satisfactory because a "something" outside physics can then be introduced at $\tau = 0$. By a semantic maneouvre, the word "something" is then replaced by "god," except that the first letter becomes a capital, God, in order to warn us that we must not carry the inquiry any further.[6]

As William Craig remarks,[7] it seems clear that it was Hoyle's desire to avoid the potential intrusion of theism that led him to defend steady-state models well beyond the bounds of plausibility. This motivation is alive and well in cosmology today: it galvanized the (now failed) hope that inflationary processes might be regarded as past-eternal,[8] and it infuses life into fantastical mathematical constructions involving universal quantum-gravitational wavefunctions quantum-tunneling from imaginary time, eternally oscillating 3-brane collisions, everlastingly ancient string perturbative vacua, and infinitely many bubble universes with different initial conditions and countless variations of laws and constants. Since much of this recent speculation rests on the postulation of cosmic inflation as a solution to the horizon and flatness problems,[9] we begin with a consideration of how inflationary cosmology got started.

INFLATIONARY COSMOLOGY

One aspect of the homogeneity and isotropy of our universe is the uniformity of the cosmic microwave background radiation (CMB), which has the same temperature throughout the observable cosmos to within one part in a hundred thousand. This is regarded as a puzzle in standard Big Bang cosmology because until about 300,000 years after the Big Bang, the photons in the CMB would have been interacting with electrons in the hot plasma that filled the entire universe as it expanded. At about 300,000 years, the universe cooled enough for electrically neutral atoms to form and release the background radiation to travel unfettered, thus giving us a picture of the universe at this early stage. But the uniformity of this radiation, which has the same temperature in every direction to within a small fraction of a degree, requires the aboriginal plasma itself to be extraordinarily uniform. This in turn would require *very* precise initial conditions, since calculations in standard Big Bang cosmology tell us that radiation arriving from opposite directions in the sky at that time would have been separated by about 100 horizon distances, that is, by 100 times the distance light could have traveled since the beginning of the universe. This thermal equilibrium can only be explained in standard Big Bang cosmology by postulating an initial state of almost perfect uniformity.

Another aspect of the uniformity of the universe is its flatness. Homogeneous universes are called *flat* if they are on the borderline between eventual gravitational collapse and eternal expansion; in such a case, their geometry is precisely Euclidean. If the *actual* mass density in the universe is very close to the *critical* mass density required to gravitationally halt the expansion, that is, if their ratio is close to one, the expansion rate of the universe will asymptotically approach zero. WMAP (Wilkinson Microwave Anisotropy Probe) data reveal our universe to have an actual mass density that is extremely close to the critical mass density, with indications of an ever-so-slight positive curvature that would imply a geometrically closed universe, but other recent observations show there to be an exceedingly small *positive* cosmological constant. As a result of this positive cosmological constant our universe's expansion is accelerating, which would seem to suggest that the universe will continue to expand without gravitational collapse.[10] Nobody knows for sure. But because actual and critical mass densities are so precisely balanced, space itself has hardly *any* overall curvature. The precisely balanced character of these quantities is again surprising from the standpoint of standard Big Bang cosmology, since it also requires very precisely tuned initial conditions.

Inflationary cosmology tries to alleviate this puzzlement by proposing that the horizon and flatness problems are resolved if the observable universe underwent an exponentially rapid rate of expansion in the first fraction of a second after the Big Bang; this rapid inflation then halted abruptly and universal growth settled down to the less frenetic pace we observe today. In current models, inflation is hypothesized to have begun around 10^{-37} seconds (or so) after the Big Bang and lasted until 10^{-35} seconds (or so), during which time the space constitutive of our observable universe expanded by a factor of 10^{60} (or so). At the beginning of the inflationary epoch, the observable universe was, say, about 10^{-60} meters in size, and at the end of it, therefore, about a meter across. In this scenario, the horizon size at the start of inflation would have been 10^{-37} light-seconds, which is far *larger* than the tiny patch postulated to grow into our observable universe. There was thus plenty of time *before* inflation started for the aboriginal observable universe to thermalize uniformly, whence the inflationary process stretched this homogeneous region immensely, and the patch constituting our visible universe then continued to expand more sedately out of this inflated volume. Any residual inhomogeneities, if they exist, would therefore lie beyond the bounds of what we can see.

In respect of the flatness problem, given the assumption that the universe began as a de Sitter space that then transitioned (somehow) to a Friedmann-Lemaître-Robertson-Walker (FLRW) metric, the effect is thought to be similar. During the inflationary epoch, all the distances in the region that became our observable universe increased by a measure of 10^{60} or so, which means the radius of the observable universe increased by this factor as well. To illustrate the effect of this, suppose four-dimensional space-time prior to inflation had positive curvature, like the surface of a balloon does in three dimensions, and that its radius was a billionth of a meter (a nanometer). After inflation, its radius would be 10^{51} meters, or about 10 billion trillion trillion light years (the radius of the observable universe is on the order of 13.7 billion light years). Just as inflating a balloon to larger and larger sizes makes a small patch on its surface look flatter, so inflating the entire universe makes the patch we can see look quite flat. This, at least, is how the inflationary explanation is intended to work; as we shall see momentarily, whether it realizes the intentions of its inventors is questionable.

According to the currently dominant "chaotic eternal inflationary model,"[11] the rapid expansion of the early universe was driven (as in all inflationary models) by the false vacuum of a hypothesized scalar field called an *inflaton field,* which represents the effect of a massive *repulsive* gravitational force. After an initial phase of expansion, this field is assumed to have decayed *locally* to produce our universe. In the chaotic scenario, however, it is necessary to suppose that the inflaton field starts fairly high up in a range of energies (the "energy landscape") having *no* upper bound, and so (by quantum-mechanical description) the field continues to oscillate chaotically outside the local area for a time much greater than the inflationary doubling time. This assumption entails that inflating regions multiply faster than they decay, with the consequence that inflation continues eternally into the future and produces a boundless expansion of space into which other universes are birthed as the ever-expanding inflaton field decays at other locations. So it is that current inflationary cosmologists postulate the decay of the inflaton field as a "mechanism" by which a potentially infinite number of "bubble universes" can be created. Since the chaotic inflaton field continues to expand at a rate vastly greater than the bubble universes growing within it, none of these bubbles will ever encounter each other, so we can never empirically confirm the existence of any bubble universe save our own. The hypothesized aboriginal inflaton field therefore gives birth to endless bubble universes, a scenario Alexander Vilenkin picturesquely describes as "many worlds in one."[12]

The BGV Theorem and Its Significance

One of the hopes expressed by Andrei Linde and other advocates of chaotic eternal inflation was that it could be conceived as eternal into the past as well as the future, thus obviating the implications of an absolute beginning to the universe. Results indicating the falsity of this hope emerged in the mid-1990s and were established beyond reasonable doubt in 2003. The earliest theorem demonstrating that inflationary models are past-incomplete, which depended on a weak-energy condition that allowed for exceptions,[13] has now been established instead by an argument that needs no energy condition.[14]

This stronger proof of geodesic past-incompleteness, put forward in 2003 by Arvind Borde, Alan Guth and Alexander Vilenkin (henceforth BGV), considers spacetimes satisfying the condition that the *average* Hubble expansion in the past is greater than zero, i.e., $H_{av} > 0$. It is shown that a suitable construction of the Hubble parameter, H, allows it to be defined for arbitrary (inhomogeneous, anisotropic) cosmological models in a way that reduces to its standard definition in simple models. With this generalized Hubble parameter in hand, a demonstration is given that its integral along any null or timelike geodesic is bounded, so that any backward-going null or timelike geodesic with $H_{av} > 0$ must have finite length, i.e., be past-incomplete. The class of cosmologies satisfying the assumption that the Hubble parameter has a positive value when averaged over the affine parameter of a past-directed null or non-comoving timelike geodesic also includes cosmologies of *higher* dimensions, which is why the BGV result is applicable to Steinhardt's and Turok's cyclic ekpyrotic string cosmology as well as the inflationary string landscape model. We will examine string cosmology in due course, but, for now, the importance of the BGV result is its demonstration that all inflationary spacetimes (or merely those expanding on average) have a beginning in the finite past, at which point some different kind of physics allegedly applies.[15] This "different kind of physics" is usually taken to be a universal nucleation event via some kind of quantum cosmological construct[16] that mitigates the breakdown of physical theory that classical general relativity requires at the Big Bang singularity.

Apart from theoretical and observational considerations on expanding spacetimes that imply an absolute universal origin, other arguments against an actual temporal infinity leading up to the present are exceedingly strong: given the reality of temporal progression, if reaching the present required traversing an infinite temporal past, the present would never have been reached; but the present (obviously) has been reached, therefore the temporal past is *not* infinite. Considered in terms of historical events or instants of time, an actual infinity is metaphysically nonsensical and incapable of coherent positive construction—it would require, for instance, that the number of events in a proper subset of universal history could be set in one-to-one correspondence with that history as a whole, an ontological state of affairs that is internally contradictory. David Hilbert provided the first trenchant expression of this argument,[17] which might be rendered as "an infinite cannot be actualized by any finitary algorithmic process."[18] The mathematical description of an infinite past is therefore a theoretical limit that does not correspond to any reality, an extrapolation that, quite apart from its ontological impossibility, founders on the necessary *meta*-stability of the primordial state in cosmological models generating universes, like our own, that are not static.

By the impeccable metaphysical logic of the *kalām* argument,[19] the BGV theorem implies that spacetimes expanding on average throughout their histories are *caused*: they are caused because they began to exist, and everything that begins to exist requires an ontologically and logically—though not always temporally (as demonstrated by the case of space-time itself)—prior cause.[20] What is more, this cause cannot be mathematical in character, for mathematical descriptions are both abstract and causally inert—or rather, they are causally inert *because* they are abstract. To ascribe efficient material causality to them is to commit what Whitehead has called the "fallacy of misplaced concreteness."[21] This, in part, is the problem with Max Tegmark's remarkable assertion that every consistent mathematical structure is physically instantiated.[22] His claim lacks any discernible metaphysical basis and, advanced as an "explanation" for cosmological fine-tuning, undercuts the possibility of rational explanation altogether by entailing *every* possible state of affairs and undermining *every* claim of improbability.[23, 24]

In regard to the principle that everything that begins to exist must have a cause, some have alleged that the failure of efficient material causality in quantum theory is a counterexample—no less so in the case of universal origins since any quantum cosmological constructs or inflaton fields embody *quantum* behavior. But this conceit begs the very question at issue by assuming that every efficient cause must be material and concluding that since there is no material cause for various quantum behaviors, no explanation of *any* kind is necessary. As I have argued elsewhere,[25] since the explanatory resources of naturalism are restricted to material objects, causes, events, and processes, and since neither nonlocal quantum correlations nor (in light of nonlocalizability) the nature of the fundamental constituents of "material reality" can be explained or understood when the explanatory constraints of naturalism are preserved, and since these quantum phenomena require a rational explanation, what must be rejected here is *naturalism,* not explanatory demand.

When we further reflect on the nature of the cause that brought the universe into existence, it is evident that it must be *transcendent* in nature. Space-time and mass-energy do not conceptually entail any principle of self-causation, so prior to the existence of all space, time, matter, and energy there was *no* universe to be described, and hence *no* physical laws or initial conditions that could have played a role in its genesis. Instead, space-time and mass-energy came into existence out of nothing, so a transcendent *immaterial* cause must have acted.

A "Different Physics" at the Past Boundary?

There are many in the community of cosmologists who, like Fred Hoyle, do not like the implications of an absolute beginning requiring a transcendent cause, and who therefore argue that a "different physics" is required at the past boundary. What is meant by this, for good reason, is not always clear, but usually involves some form of quantum cosmology like the Vilenkin tunneling model[26] or the Hartle and Hawking "no boundary" proposal.[27] We will start with Vilenkin's quantum origination theory, then focus on the Hartle-Hawking scenario, which has received much more attention as a consequence of the public awareness generated by Hawking's popular book *A Brief History of Time* (1988).[28]

Let's begin with a rough-and-ready definition of superspace, which is the domain of the hypothesized universal quantum-gravitational wavefunction Ψ. Superspace is the *mathematical* space, S, of all curved 3-dimensional spaces, which, when matter is present, is extended to include the set of all pairings of curved 3-spaces and matter configurations on those spaces.[29] This infinite-dimensional space plays a central role in quantum cosmological *descriptions* of universal origins.[30] The quantum-gravitational wavefunction Ψ assigns a complex number to every point in S. Each path in S describes a 4-dimensional spacetime and its matter configuration, and *any* parameterization of a path that is strictly increasing provides an admissible measure of time for the spacetime represented by a given path and is, therefore, a possible "history" of the universe.[31]

So far so good, one might suppose, but now we need to discuss quantum "origination" scenarios. These origination scenarios deviate considerably from paths representative of classical spacetimes because Ψ must oscillate rapidly in certain directions within S in order to establish as highly probable the "right" quantum-mechanical correlations between the curvature and matter variables and their velocities in S. These correlations do not generate unique classical histories of the universe but rather whole *families* of classical histories in superposition—in short, they instantiate the measurement problem on a universal scale.

Setting questions of the plausibility of this scenario momentarily aside, even if one were able to select a *unique* universal wavefunction, and even if one granted credence to it and adopted a consistent histories approach[32] to the path-integral formalism in which a stable "classical" world was a possible result, there would still be an infinite number of other solutions that were not classical at all. Furthermore, the consistent histories approach allows for a world that is classical right *now,* but was an arbitrary superposition of classical states in the past and will return to this jumbled state in the next instant.[33] Taken by itself, the consistent histories formalism implies at best that the universe as a whole is comprised of *many* different internally consistent but mutually incompatible (in the sense that they cannot be simultaneously experienced) histories. Within the formalism, each possible history is equally real and the experience of any one of these histories as actual is something that is radically context dependent. If we are trying to explain the origin of the universe and this is the representation foisted upon us, we are off to a rather poor start. Insofar as we take the formalism to be an instrumental expedient it provides no explanation, and since it has no other discernible use, we have no reason to continue indulging in the mathematical fantasy it offers; on the other hand, insofar as we suggest that the formalism be interpreted realistically, we are saddled with an infinite expansion of reality that is as untestable as it is fantastical and ontologically profligate. What such an approach needs, one might surmise, is supplementation in the form of an external cause and constraints that guarantee a *unique* real history and a future that, when it happens, *will also be unique.* I argue elsewhere that the fact that quantum physics, on pain of empirical contradiction, provides *no* such causes or constraints indicates that the basic reality it describes is not self-sufficient.[34]

Be this as it may, faced with an infinitely split reality in a universal wavefunction that is compounded by worries of its infinitely arbitrary decomposition into orthogonal states, quantum cosmologists have at least tried to make headway by inventing "natural" constraints on the boundary of superspace or a "natural" algorithm for computing Ψ that would contribute to the uniqueness of the wavefunction itself. In the tradition of Bryce DeWitt,[35] Vilenkin's approach is to invent constraints on superspace. While this procedure has analogues in ordinary physics—for example, Maxwell's equations uniquely determine the electromagnetic field inside a charge-free region of normal space once the values of the field on the boundary are specified—what is being attempted here is not ordinary physics but rather highly mathematicized *meta*physical construction. Both S and its boundary are infinite dimensional and there is no guarantee, even if we ever find halfway coherent quantum gravitational equations, that the metaphysically dubious Ψ thereby obtained will be amenable to this procedure. Furthermore, all this arbitrariness is symptomatic of the deeper, unresolvable difficulty that quantum cosmology is not an observational science and its theories will forever remain untestable.[36] In light of these realities, those interested in playing the infamous demarcation game—where *everyone* loses or *everyone* wins—might like to try their hand at questioning the status of quantum cosmology as a "science."[37]

Before discussion can proceed, we need a conception of the boundary of superspace. A point on the boundary of superspace is the limit of a sequence of points in S that converge to something that is *not* in S. Boundary points thus represent universal configurations that are singular in some respect, as, for example, where the curvature of the 3-space is infinite, or a matter variable possesses infinite density, or where the 4-dimensional spacetime associated with a curve in S is singular (as in the classical Big Bang scenario). Quantum cosmologists distinguish between *singular* and *regular* boundaries of superspace. A curve in *S* representing a classical universe beginning from a Big Bang would spring from one of the 4-dimensional spacetime singularities constitutive of the singular boundary of superspace, whereas a singular spatial 3-geometry that does not coincide with a 4-dimensional spacetime singularity, but rather one with finite curvature, is classified as part of the regular boundary of *S.*

Bryce DeWitt was the first to attempt the requisite constraining of Ψ by suggesting that a unique wavefunction might be obtained by requiring it to *disappear* on the boundary of superspace.[38] If the amplitude of Ψ were zero on the boundary, then the probability of any singular configuration would be zero and a breakdown of "physical" description avoided. This prescription turned out not to work well at all, but Alexander Vilenkin later offered a slightly better construction.[39] At the singular boundary of *S,* Vilenkin proposed that the suitably defined flux of Ψ (roughly, the oscillatory behavior restricted to include only the paths of a family of classical solutions of Einstein's equations) be oriented so it is moving *out* of *S.* This means (by the theoretician's fiat) that classical spacetimes are allowed to end in a singularity, but not to begin in one. Under these conditions, a variety of approximate calculations have been made that predict a unique Ψ, but as Christopher Isham observes:

> [T]hese approximations involve ignoring all but a small number of the infinite possible modes of the universe and it is by no means clear that uniqueness will be preserved in the full theory. The problem is compounded by the fact that the equations for Ψ that we are trying to solve are mathematically ill-defined. . . . [A]ny proper resolution of this issue must await the discovery of a fully consistent unification of general relativity and quantum theory.[40]

As Isham also notes, proponents of the competing Hartle-Hawking scenario (which we will discuss momentarily) have conceded that their approach definitely does *not* predict a unique universal wavefunction.[41]

If the universe does not originate in a singularity, however, where *does* it come from in Vilenkin's construction? It has to originate from a location within superspace, and Vilenkin's suggestion is that it emerges from the rather ill-defined boundary internal to *S* between regions where Ψ oscillates (and hence where an underlying classical picture is possible) and regions where it does not (which are purely quantum-mechanical in character). These regions in *S* where no oscillatory behavior is possible depend on the parameterization of Ψ by a complex time variable (imaginary time) and a precise choice of matter and its interactions. Real time therefore "begins" at the internal boundary between the non-oscillatory and oscillatory regions with the acausal "quantum tunneling" transition of the wavefunction from imaginary to real time, after which the flux of Ψ, constrained to include only oscillations involving classical spacetimes, then moves outward through superspace to terminate on its external (singular and regular) boundaries. Geometrically, imaginary time amounts to the *spatialization* of time in the form of a Euclidean rather than a Lorentzian metric. In the Euclidean domain, there is no special ordering of events as described in the real time of general relativity; a typical exact solution of Einstein's equations in this region is a 4-sphere, as opposed to the conic real-time solutions of general relativity. The geometry of the Hartle-Hawking origination scenario is similar, which is why it is often represented as a round bowl fused to the bottom of a cone with its point removed (a badminton shuttlecock), or a flared conic flask fused to a large bulbous bottom (an old-fashioned bicycle horn).

We turn, then, to a discussion of the famous Hartle-Hawking "no boundary" proposal. Rather than proceeding by first specifying conditions on the boundary of superspace in an effort to extract a unique universal wavefunction, the Hartle-Hawking procedure instead chooses a specific algorithm for the computation of Ψ: a Euclidean path integral summing over compact (closed and bounded) 4-geometries that interpolate between a point and a finite 3-geometry, where the "boundary conditions" correspond to a specification of the class of histories over which the sum is taken.[42] As a first approximation, this latter condition involves restricting the number of degrees of freedom of the gravitational and matter fields in superspace to a finite number and then solving the Wheeler-DeWitt equation on this "minisuperspace."[43] Since this is just an approximation and what is ultimately needed is the wavefunction on the *whole* of superspace, a further step can be taken by using a "midisuperspace" approximation in which the action is considered to all orders for a finite number of degrees of freedom, and to the second order for the remaining degrees of freedom. When this is undertaken, the picture that emerges out of the WKB approximation to the oscillating part of the wavefunction is that of a universe tunneling out of the "minimal temporal radius" in imaginary time, expanding in an inflationary and then matter-dominated fashion to a maximum radius, then *recollapsing* to a singularity.[44] While recent calculations based on WMAP data *seem* to indicate a minute positive curvature that hints of a closed universe, the simultaneous existence of a minuscule positive cosmological constant accelerating its expansion suggests that it might expand forever, even with a closed geometry. If the universe has negative curvature—or more likely is flat—and will continue to expand forever (at a rate asymptotically approaching zero in the flat case), then insofar as the Hartle-Hawking proposal and these approximations can be taken seriously, they are based on false premises and will have to be reworked with a different algorithm and boundary conditions. Regardless, the game of mathematical brinksmanship such calculations represent is just so much whistling in the dark—a case of highly malleable mathematical descriptions adaptable to the exigencies of the moment and therefore devoid of geniune empirical content and explanatory power.

Let's backtrack briefly and fill in some of the details. The whole "no boundary" approach was motivated by Hawking's earlier work on black hole radiation. In 1974, Hawking discovered that black holes would radiate particles via a quantum-mechanical process and these particles would have a thermal spectrum.[45] The re-derivation of these results using thermal Green's functions that, in standard quantum field theory, involve substituting for the time-coordinate an imaginary number inversely proportional to the temperature, inspired Hawking to take a Euclidean approach to quantum gravity in which Lorentzian metrics are replaced by Riemannian ones via a Wick rotation in which the time coordinate t is "rotated" by a complex transformation into $\tau = it$.

Specifically, Hawking proposed to study functional integrals having the form

$$\textbf{(1)} \qquad Z(\mathcal{M}) := \int \mathcal{D}g \, e^{\frac{1}{\hbar}\int_{\mathcal{M}} |\det g|^{1/2} R^4(g)} ,$$

where the integral is taken over all Riemannian metrics g on a 4-manifold $\mathcal{M}$, with $R^4(g)$ being the curvature of g, and $\det g$ the determinant of the metric.[46] This expression can be generalized to a weighted "quantum topology" where every 4-manifold M has a weight $w(\mathcal{M})$ that it contributes to expressions of the type:

$$Z := \sum_{\mathcal{M}} w(\mathcal{M})\, Z(\mathcal{M})\,. \tag{2}$$

If applied to a manifold with a single 3-boundary Σ, **(2)** will represent a functional $\Psi[h]$ as long as the functional integral is taken over all 4-metrics g on $\mathcal{M}$ that induce the requisite 3-metric h on Σ. So defined, the functional of h can be taken to satisfy the Wheeler-DeWitt equation,[47] and by including matter fields ϕ, we may write

$$\Psi[h,\varphi_0,\Sigma] = \sum_{\mathcal{M}} w(\mathcal{M}) \int \mathcal{D}\varphi\, \mathcal{D}g\, \mathrm{e}^{-\frac{1}{\hbar} I(g,\varphi,\mathcal{M})}, \tag{3}$$

where I is the Euclidean action. Equation **(3)** is the basis of the Hartle-Hawking quantum cosmological "wave-function of the universe."[48] The "no boundary" proposal requires that the sum in **(3)** be taken just over compact (closed and bounded) manifolds $\mathcal{M}$ that have the connected 3-manifold Σ (carrying the 3-geometries of quantum geometrodynamics) as their only boundary. What is meant by suggesting that this represents the universe coming into existence by "tunneling from nothing" is summarized well by Butterfield and Isham:

> The word "nothing" just reflects (very obscurely!) the idea that $\mathcal{M}$ has only Σ as its boundary. The word "tunneling" refers to the facts that (i) moving from a Lorentzian to a Riemannian manifold corresponds, roughly, to moving from a time variable that is a real number to one that is purely imaginary (in the sense of complex numbers); and (ii) in normal quantum theory, a good approximation to the probability of tunneling through a potential barrier can be found by computing the action I for a solution to the *classical* equations of motion with an *imaginary* time; the probability amplitude in question is then proportional to exp $-I / \hbar$.[49]

The computational expedient of Euclideanization in quantum cosmology is used solely for the purpose of constructing a convergent path integral[50] and is *not* applied to the *background space* in Hawking's appropriation, but to the *individual spacetimes* constitutive of *each path* in the path integral. When this imaginary time coordinate is retained in the final answer, the singularity at $\tau = 0$ disappears, yielding mathematical representations of universes with no temporal beginning but just a "minimal temporal radius." In his popular book,[51] Hawking suggests that this procedure provides a model in which the universe has no beginning and hence is completely self-contained: without a beginning or an end, it just *is*. His remark is more than a little disingenuous, however, since a "realistic" solution using this procedure requires completing the transformation back to a Lorentzian metric and the *real time* in which we live, since none of the Riemannian universes in the path integral are capable of being models of our Lorentzian spacetime. Once this is done, however, the initial singularity reappears, and all the spacetimes in the sum again have a beginning. Hawking knows this, of course, and says as much in passing: "When one goes back to the real time in which we live, however, there will still appear to be singularities. . . . Only if [we] lived in imaginary time would [we] encounter no singularities . . . In real time, the universe has a beginning *and an end* at singularities that form a boundary to space-time and at which the laws of science break down."[52] It seems clear, therefore, that the "no boundary" proposal does not genuinely remove universal beginnings from its descriptions, but introduces the device of "imaginary time" as an intermediate computational expedient interpolating between a real-time singular beginning and (probably contrary to fact) singular end. Furthermore, even if it did remove the beginning of time, the logically and metaphysically unnecessary existence and structure of such a spacetime would still create an explanatory demand only satisfiable by something like the cosmological argument from contingency.[53]

If we pause to take stock of what has been offered, we can see clearly that any claim that quantum cosmology provides an explanation of the origin of the universe that renders intelligent agency otiose either as a cause or a constraint is false. The mathematical expressions of quantum cosmology cannot describe any real process without an external (transcendent) activation of some sort: they are *causally inert* mathematical descriptions predicated of what is falsely referred to as "nothing" so the pretense may be sustained that quantum cosmologists have explained how nothing can turn, unaided, into a universe.

Let me expand on this point, because it is critical: contrary to the zealous assertions of some who maintain that quantum cosmology succeeds in conjuring a universe out of nothing—just like the proverbial rabbit pulled out of a hat, except that there's no hat and no magician doing the pulling—the mathematical description proffered belies the claim made on its behalf. If the universe really had begun from absolutely nothing, the original "state" would not have *any* positive properties. You certainly could not predicate quantum mechanical commutation relations of it or describe it by some artfully gerrymandered universal wavefunction. Such a predication assumes the existence of positive structural content that absolute nothing, by definition, does not possess. This is why the remark of some theoretical physicists (Frank Wilczek and Michio Kaku most prominent among them) that "nothing is unstable" is the assertion of an ontological absurdity. To the contrary, there isn't anything more stable than absolute nothing, which can be expected to *do* exactly what it *is*: absolutely nothing.

Furthermore, since the original state and boundary conditions in quantum cosmology do have positive structural content, what might this imply? Even if you postulate the eternal existence of superspace and various quantum-theoretic mathematical relations as platonic forms, these abstract objects are *causally inert*: they cannot act or bring into existence concrete realities that satisfy their descriptions. To suppose otherwise would be another instance of Tegmark's temptation: the fallacy of misplaced concreteness. What this means is that the proposals of quantum cosmologists, if they describe anything at all, describe processes that are *transcendently caused*. The reason is simple: if we are going to get space, time, matter, and energy out of absolutely nothing, we require a cause that is not dependent upon any of these things and is also capable of acting. What must lie behind these scenarios, insofar as they can be taken seriously, is a transcendent, immaterial, timeless, intelligent, and hence personal cause of immense power. Without recourse to such an agent, quantum cosmology as an enterprise is a metaphysical non-starter, pure and simple. The Parmenidean dictum that nothing comes from nothing (*ex nihilo, nihil fit,* in its common Latin rendering) is as true today as when it was first stated.

That such a transcendent cause must of necessity be intelligent is evident from the finely tuned parameters we will discuss shortly. In the present context, it is also evinced by the background structure assumed. The quantum cosmological constructions being examined invoke a number of hugely restrictive intelligent choices involving geometrical, quantum-theoretic, and material configurations. The universe under these descriptions is thus neither the metaphysical nor informational "free lunch" that would-be quantum cosmological conjurors portray it to be. Rather, such universes originate under highly specified mathematico-structural constraints that are, by themselves, causally impotent descriptions. Universal ontogenesis, therefore, cannot credibly be ascribed to "nothing," nor can the constraints it requires credibly be left to "chance." The ineluctable and proper conclusion is that the universe was brought into being by a transcendent intelligent cause.

Truthfully, we could entirely bid goodbye to any pretense of a naturalistic explanation for cosmological origins and fine-tuning at this juncture, for the points just made apply to the whole edifice of cosmological research under discussion. Nonetheless, by pressing onward we can reinforce the certainty of this metaphysical conclusion.

Popping the Balloon of Cosmic Inflation[54]

The inflaton field has been offered as the panacea for any aboriginal inhomogeneity and anisotropy in the universe, but propaedeutic and evaluative questions really need to be asked. First, is inflationary cosmology free from arbitrary assumptions and gerrymandering? And second, does inflation really solve the problems it was invented out of whole cloth to address? The answer to the first question is a resounding *no*; and the answer to the second is a highly cautionary *only under very special assumptions.*

Inflation was initially proposed for the purpose of solving three problems: the horizon problem illustrated by the uniformity of the cosmic microwave background (CMB) radiation, the flatness problem constituted by the precision with which the universe's actual mass density approximates its critical mass density, and the absence of the magnetic monopoles predicted by favorably regarded grand unified theories (GUTs). Yet these three problems do not have to be addressed by the assumptions of the contemporary inflationary model.

First, the multiple scalar fields postulated by chaotic inflation are arbitrary. They constitute false vacua that bear no relation to any other known fields in physics and have properties invented solely for the purpose of making inflation work. In short, the explanation they offer is completely ad hoc.[55]

Secondly, Hawking and Page have shown that when an inflaton field is grafted onto standard FLRW cosmology, while the measure of the set of models that inflate is infinite, so is the set of models that do *not* inflate.[56] This is not an inconsequential observation. As Earman and Mosterin have observed,[57] even when inflation is restricted to the class of homogeneous and isotropic cosmologies, inflationary cosmologists have not been able to show, without invoking highly speculative hypotheses, that inflationary mechanisms actually resolve the fine-tuning issues associated with the hot Big Bang model that prompted their invention.

Thirdly, and this is related to the previous point, inflation may not be an adequate solution to the flatness problem. The matter density (ordinary and dark) in the universe is very close to the critical density that would imply a perfectly flat universe. Exceedingly precise measurements in 1998 demonstrating a very small positive vacuum energy (cosmological constant) led cosmologists to conclude that the universe will expand forever, though recent calculations based on WMAP data seem to indicate very slight positive curvature, which would imply it has a closed geometrical structure. No one knows for sure—it is that close—but the general bet is for a flat universe. Inflation is put forward as an explanation for this flatness, but so far serious attempts to calculate inflationary consequences for flatness have assumed an FLRW metric and have not addressed what would happen in the generic case. As Penrose points out,[58] expansion from a generic singularity can become whatever type of irregular universe we please, independent of whether there is an inflationary phase. As a consequence, unless a special metric and other special assumptions are in view, inflation is not an adequate explanation of flatness.

Fourthly, as Thomas Banks explains, any suggestion that inflation resolves the problems created by applying the Second Law of Thermodynamics to cosmology—primarily, the recognition that the universe had to be created in a state of very low entropy—is mistaken.[59] The initial inflationary patch would have had a very small number of degrees of freedom describable by effective field theory; most of the degrees of freedom in the observable universe are not capable of description using quantum field theory until a large number of e-folds have occurred.[60] To handle this deficiency, the standard approach to these degrees of freedom, in its most sophisticated form, begins with the assumption that they were in the ground state of some slowly varying Hamiltonian that approaches the conventional field-theoretic Hamiltonian in the inflationary background, comoving mode by mode, as the physical size of each mode crosses the Planck scale. As Banks notes, this approach involves many ad hoc assumptions, including a low-entropy initial condition that is smuggled in by assuming the system was in its ground state. Furthermore, the excited states of every known large quantum system are highly degenerate, and the adiabatic theorem[61] does not apply to generic initial conditions chosen as a linear combination of highly degenerate states. What this means is that the standard assumption in inflation of a very special state for a huge number of degrees of freedom is completely unjustified, because we do not have a reliable dynamical description of these variables. As Banks concludes, therefore, inflationary cosmology does not, in this sense, solve the problem of the homogeneity and isotropy of the early universe.[62]

Fifthly, inflation is regarded as explaining why the monopoles predicted by various favorably regarded grand unified theories have yet to be observed by effectively diluting their density in the observable universe. Invoking inflation in this context, however, is using it as an ad hoc measure to spare other favored yet unconfirmed theories from disconfirming evidence. That inflation can be used in this way is not evidence of its merit. If the GUTs do not stand the test of time and additional empirical evidence, then there will be no need to explain why magnetic monopoles have not been detected by appealing to inflation—or any other rescue strategy, for that matter.[63]

Finally, while inflationary cosmology has made some predictions about the distribution of the CMB at various wavelengths that are independent of its original motivations in terms of a "solution" to the horizon and flatness problems, and while some of these predictions seem to hold, there are also some anomalies that haven't been resolved. Inflation predicts an isotropic distribution of the CMB at all frequencies on a large scale, yet analysis of WMAP data has yielded a preferred direction for large-scale modes of the CMB that disagrees with such a prediction.[64] This issue is still being resolved and looks like it may have been mitigated,[65] but if anistropy holds up, not only will inflation's theoretical basis remain woefully insufficient, it will fail observational testing in its only real area of empirical contact.

Deflation: The Fine-Tuning of Initial Conditions Revisited

Given that inflation was invented as a strategy for explaining the fine-tuning of certain initial conditions in our universe, it is highly ironic that the inflaton field requires very special assumptions and exquisite fine-tuning itself. Let's look at a few telling examples.

The mechanism for bubble formation in the inflationary multiverse is Einstein's equation in general relativity, which, even though there is no intrinsic connection between the theories, is assumed to constrain the process of inflation in such a way that bubbles will form from local decay of the inflaton field while the field itself continues to expand. In the creation of these bubbles, however, the inflaton field must be shut off and "converted" to normal mass-energy. This shut-off point is delicate, operating in the first 10^{-37} to 10^{-35} seconds (or so) of the universe's existence, while causing space to expand by a factor of around 10^{60} (or so). The conversion from the inflation to the preheating era necessary to bring about particle production in an initially cold and empty universe involves a variety of highly speculative models with inflaton-preheating coupling parameters that have to be finessed to produce the right results.[66] Furthermore, depending on the inflationary model under consideration, the initial energy of the inflaton field is anywhere from 10^{53} to 10^{123} times the maximum vacuum energy consistent with our universe having the properties it does. This means that the energy decay of the inflaton field also has to be fine-tuned to at least one part in 10^{53} and possibly as much as one part in 10^{123}.[67] In short, the decay of the shut-off energy needs to be fine-tuned at a *minimum* to one part in a hundred thousand trillion trillion trillion trillion. Compared to such levels of precision, the fine-tuning of the Big Bang inherent in the so-called horizon and flatness problems, like an unruly friend, seems rather manageable.

There is another massive fine-tuning problem that turns out to be affected by inflation: the incredibly precise value of universal entropy needed at the Big Bang to produce a universe consistent with our observation. As Roger Penrose points out,[68] inflation solves the horizon problem only by exponentially increasing the fine-tuning of the already hyper-exponentially fine-tuned entropy of the Big Bang. The event that initiated our universe was precise almost beyond the point of comprehensibility.

How precise? The fine-tuning of the initial conditions for universal entropy can be calculated as follows.[69] In the observable universe there are about 10^{80} baryons (protons and neutrons). The *observed* statistical entropy per baryon in the universe can be estimated by supposing that the universe consists of galaxies populated mainly by ordinary stars, where each galaxy has a million solar-mass black hole at its center. Under such conditions, the entropy per baryon (a dimensionless number inclusive of the entropy in the cosmic background radiation) is calculated to be 10^{21}, yielding an observed universal entropy on the order of 10^{101} ($10^{80} \times 10^{21}$). If we run the clock backward to the beginning of time, thus mimicking universal collapse, the entropy per baryon near the resulting "big crunch" is calculable from the Bekenstein-Hawking formula for black-hole entropy by considering the whole universe to have formed a black hole. Performing this calculation leads to a value of 10^{43} for the entropy per baryon, yielding a total value of 10^{123} ($10^{43} \times 10^{80}$) for universal entropy. Since this number also indicates the possible entropy for a universe our size emerging from a Big Bang singularity, we can compare it with what we now observe to estimate how fine-tuned the Big Bang had to be to give us a universe compatible with the Second Law of Thermodynamics and what we now observe to be the case. Since 10^{123} is the natural logarithm of the volume of the position-momentum (phase) space associated with all of the baryons in the universe, the volume itself is given by the exponential: $V = e^{10\exp(123)}$; similarly, the observed total entropy is $W = e^{10\exp(101)}$. For numbers this size, it makes little difference if we substitute base 10 for the natural logarithm, so Penrose does that. Following his lead, the required precision in the Big Bang is therefore given by:

$$W/V = 10^{10\exp(101)}/10^{10\exp(123)} = 10\exp[10^{101} - 10^{123}] \approx 10\exp(-10^{123}).$$

In other words, to satisfy the observed entropy of our universe, the Big Bang had to be fine-tuned to *one part* in 10exp(10^{123}). This latter number is difficult to grasp; suffice it to say that with 10^{80} baryons in the observable universe, if we attached a zero to every one of them, it would take 10^{43} universes the size of ours just to write it out![70]

So how is this result affected by inflation's "resolution" of the horizon problem? Again, the fundamental strategy is for inflation to push beyond the observable universe the particle horizons that would preclude explaining the uniformity of the CMB on the basis of thermalization. But, as Penrose has observed, if thermalization serves the role of driving background temperatures to equilibrium in the inflationary context, then it represents a definite *increase* in universal entropy that requires the Big Bang to be even *more* finely tuned to account for its current observed value, because the universe exponentially inflates into a normal expansion the initial entropy of which is fine-tuned to one part in 10exp(10^{123}). In other words, if inflation explains the horizon problem through thermalization, it turns a hyper-exponentially fine-tuned initial entropy into a *hyper*-hyper-exponentially fine-tuned quantity. On the other hand, if thermalization plays *no* role in explaining the horizon problem, then inflationary cosmology is completely *irrelevant* to its solution.

2. UNIVERSAL ORIGINS AND STRING COSMOLOGY

Having catalogued the reasons for profound skepticism where quantum cosmology and the inflationary multiverse are concerned, we must turn to the subject of string theory and its invocation in the cosmological context. It is by conjoining the resources of quantum and inflationary cosmology with the landscape of string vacua that multiverse theorists hope to obviate the fine-tuning of the laws and constants of the universe along with that inherent in its initial conditions. As mentioned earlier, the string cosmological models that have received the most attention are the Steinhardt-Turok cyclic ekpyrotic model (which does not invoke inflation but satisfies the conditions of the BGV theorem), the Gasperini-Veneziano pre-Big Bang inflationary model (which circumvents the BGV theorem despite employing inflation, but nonetheless has a beginning in the finite past due to the meta-stability of its primordial state), and the inflationary string landscape model advanced by Susskind, Polchinski, Bousso, and Linde (which invokes inflation and is subject to the BGV result). In this section, we document the fact that none of these highly speculative string cosmologies remove the necessity of a beginning to the process of universe generation. A brief primer on string theory will help to facilitate our discussion.

A PRIMER ON STRING THEORY

String theory was initially proposed in the mid-1960s as a description of the strong nuclear force generating mesons and baryons, but it lapsed into obscurity after the success of quantum chromodynamics. The fundamental constituents of string theory are one-dimensional filaments existing as open strings or closed loops on the scale of the Planck length (10^{-33} cm). The theory was revived in the late 1970s when John Schwarz and other researchers discovered that the spin-2 particle that had thwarted its nuclear ambitions could be reinterpreted as the quantum of the gravitational field, producing a theory that, when the demands of quantum-theoretic consistency were satisfied, reconciled gravity with quantum mechanics in a ten-dimensional spacetime. The extra six spatial dimensions of string theory require compactification into Planck-scale Calabi-Yau manifolds to suggest any connection with reality as we know it, and this division of the spatial dimensions into three large and six small transforms some of the N=1 SUSY gravitational modes in nine large dimensions into a variety of non-gravitational bosonic and fermionic vibrations.[71]

Just what *kind* of non-gravitational forces (spin-1 bosons) and matter (fermions and supersymmetric scalar partners) are produced by this transformation depends on the size and shape of the compactified dimensions[72] and, alas, there is an *unlimited* number of ways of compactifying them. This embarrassment of riches was once regarded as a vice, but increasing appreciation of the degree to which the laws and constants of our universe are fine-tuned for life has led some to extol it as a virtue, speaking instead of the "landscape" of string solutions.[73] We will examine the string landscape hypothesis in more detail presently.

One of the most recalcitrant technical problems in the early stages of the string revival was solved in 1984 by John Schwarz and Michael Green.[74] Ten-dimensional string theory exhibited a quantum anomaly resulting from unphysical longitudinal modes that were shown to be eliminable if the strings obeyed a specific gauge symmetry, SO(32). It was subsequently shown in fairly quick order that there were actually *five* anomaly-free classes of ten-dimensional string theories characterized by different gauge symmetries: Type I, Type IIA, Type IIB, $E_8 \times E_8$ heterotic, and SO(32) heterotic, all Calabi-Yau compactifiable in the six extra spatial dimensions and each with countless numbers of models.

In the 1990s evidence began to collect that these five classes of string theories were not, in fact, independent of each other. This suspicion was given life in 1995 when Edward Witten demonstrated the equivalence of heterotic SO(32) string theories with low energy effective string field theories of Type I.[75] Subsequently, the community of string theorists found dualities expressing the equivalence of all five classes of string theories as well as eleven-dimensional supergravity. The key to these equivalences proved to be a string with finite *width* in addition to its length—in essence a two-dimensional membrane—which therefore existed in *eleven* rather than ten dimensions. Thus was born eleven-dimensional "M-theory."

The additional spatial direction in M-theory potentially plays a different role than the others. The ten-dimensional spacetime of string theory is a slice of the eleven-dimensional bulk of M-theory. Since the new spatial dimension is orthogonal everywhere to the other nine, it can be regarded as a line segment connecting two ten-dimensional string universes (9-branes), each hidden from the other and having only the gravitational force in common.[76] Since six of the extra ten spatial dimensions are compactified throughout the eleven-dimensional bulk, the effective picture is that of a five-dimensional spacetime bulk with two four-dimensional universes (3-branes) at the ends of a line segment. Since gravity would vary as the inverse cube of the distance in four spatial dimensions and the inverse square law has been tested down to 55 micrometers,[77] if this M-theoretic model had any basis in reality, this minuscule distance would provide the current maximum separation between our universe and its twin. Additional tests of this highly speculative scenario have been proposed and are being pursued.[78]

Steinhardt-Turok Cyclic Ekpyrotic Universes

M-theory also permits the possibility of freely moving universes (branes); it is this possibility that is explored in the cyclic ekpyrotic models of string cosmology.[79] In this scenario, a bulk of four spatial dimensions exists between two 3-branes. The collisions between these branes, which happen on average once every trillion years, release sufficient energy to catalyze the hot Big-Bang stage of new universes.[80] Because of Planck-scale quantum fluctuations neither 3-brane remains perfectly flat, so energy release is greatest at points of first contact. Steinhardt and Turok estimate that on each bounce cycle such brane-brane collisions have the potential to produce staggering numbers of new Big Bang regions (10^{100} to 10^{500}) that are causally isolated from each other.

Of course, each such universe has a beginning in a quantum string nucleation event induced by a brane-brane collision and so has a finite past. The original brane spacetimes were postulated to be nonsingular, however, and this served to ground the claim that the cyclic ekpyrotic scenario did *not* require initial conditions and could be past-eternal.[81] This turned out not to be the case, however, as Borde, Guth and Vilenkin made clear and Steinhardt and Turok have now acknowledged.[82] An essential feature of the ekpyrotic model, which enables it to deal with the thermodynamic objection that defeats conventional cyclic cosmologies,[83] is that the volume of the universe consisting of the aboriginal bouncing branes increases with each cycle while the energy released into the branes by each collision gets renewed by the inexhaustible resource of gravitational potential energy. This entails that on average the cyclic universe is expanding, i.e., $H_{av} > 0$, and so the BGV theorem requires its geodesic incompleteness—in short, it has a beginning in the finite past.[84]

Gasperini-Veneziano Pre-Big Bang Inflationary Scenarios

Another pre-Big Bang scenario in string cosmology that merits our attention was proposed by Maurizio Gasperini and Gabriele Veneziano.[85] Anachronistically speaking, it sidesteps the $H_{av} > 0$ condition governing the BGV result and, from a *purely* mathematical standpoint, can be geodesically extended into the infinite past. The Gasperini-Veneziano pre-Big Bang inflationary (PBBI) model proposes that the universe started its evolution from the simplest possible string-theoretic initial state, namely, its perturbative vacuum, which corresponds to a universe that, for all practical purposes, is empty, cold, and flat. This string perturbative vacuum (SPV) phase is neither expanding nor contracting in whole or in part; in this sense, it is static. Since the spacetime manifold of this state has models in which timelike and null geodesics can be past-extended for infinite values of their affine parameter, it is proposed that this phase could have been of infinite duration, which would mean that the universe did not have a beginning.

The assumption that the primordial universe was a string perturbative vacuum means that the dilaton field[86] started very large and negative, which allows the early history of the universe to be treated classically.[87] The assumption of virtual flatness also enables employment of the low-energy approximation to string theory. This means the evolution of the universe can be described using classical field equations for the low-energy effective action,[88] from which, under the assumptions of homogeneity and flatness, inflationary behavior automatically follows from the hypothesis that the primordial universe was an SPV.[89] Of course, homogeneity and flatness are fine-tuning conditions. If the assumption of homogeneity is relaxed and replaced with generic initial conditions approximating the perturbative vacuum, it can be shown that it is possible for a chaotic version of the pre-Big Bang scenario to arise through dilaton-driven inflation in patches of the primordial SPV[90] *as long as* the kinetic energy in the dilaton is a non-negligible fraction of the critical density.[91] One of the controversial features of this latter scenario is that in order to have sufficient inflation in a patch, dilaton-driven inflation has to last long enough to reach a hot big bang nucleation event. Since PBBI is limited in the past by the initial value of spatial curvature, it has to be extremely small in string units if sufficient inflation is to be achieved.[92] In other words, no matter which approach to PBBI one takes, *considerable fine-tuning is necessary*.[93]

A word is in order about a feature of PBBI model that some may find puzzling: how is it that an inflationary phase *leads* to a Big Bang rather than *following* from it? This result is a consequence of one of the peculiar features of string theory called *T-duality,* which relates small and large distance scales. T-duality implies that, at some deep level, the separation between large and small distance scales in physics is fluid. In the "inflationary phase" of the PBBI model, spatial expansion is taking place in the *string frame* coordinates while, in the classical *Einstein frame* coordinates, matter is collapsing into trapped surfaces, i.e., black holes.[94] At the conclusion of this dilaton-driven inflationary phase, a transition is supposed to take place to an FLRW phase typical of the standard hot Big Bang model—though models for *how* this happens are, to say the least, not well-understood.[95]

What shall we say, then: does the PBBI model do an end run around the BGV theorem and provide a viable picture of a universe with no beginning? Not really. While the null and timelike geodesics of the SPV phase can in theory be extended into the infinite past, asymptotically approaching exact equilibrium, the fact remains that at every point in the finite past the string perturbative vacuum is unstable.[96] Quantum fluctuations of the background fields, particularly the dilaton, move the SPV from equilibrium, so that at any given finite physical time, the system is in a *non*-equilibrium state. Since each patch of the SPV has a non-zero probability of decaying into dilaton-driven inflation, quite apart from issues of metaphysical incoherence stemming from the non-traversability of an infinite past, a realistic interpretation of the model, however implausible in itself, requires acknowledging that the SPV phase has finite duration. Since the other two phases of the model (inflationary and FLRW) are also finite in duration, the universe has a beginning. So, even in Gasperini-Veneziano PBBI scenarios, the universe begins to exist—and as we saw earlier, since it begins to exist, it must have a transcendent cause.

The String-Theoretic Landscape Hypothesis

As we observed earlier, the laws and constants of different string-theoretic universes are determined respectively by the shape and size of their compactified dimensions. If there were a mechanism for navigating around the "landscape" of these moduli, each combination describing a different solution (vacuum) of the string-theoretic equations, there would be a way to *generate* universes with different laws and constants—at least 10^{500} of them, in fact, if we restrict ourselves to versions of string theory having a positive-valued cosmological constant, as required by our own universe.

Bousso, Kachru, Kallosh, Linde, Maldecena, McAllister, Polchinski, Susskind, and Trivedi *all* contributed to devising a mechanism that might do this by finding a way to combine inflationary cosmology with the string landscape:[97] bubbles of lower energy string vacua nucleate when moduli decay at random locations throughout higher energy string vacua that continue to inflate forever, so the whole landscape (they contend) gets explored as a series of nested bubble universes. Interior bubbles inflate at a slower rate than their parent universes, and bubbles of still lower energy nucleate inside of them, while all of the vacua so created inflate eternally. According to this picture, we live in one such bubble universe.

Note that the BGV theorem applies to the string landscape hypothesis because the inflationary mechanisms on which it is premised require its overall expansion. The landscape is thus past-incomplete, so if it existed, it too would have a beginning in the finite past that required a transcendent catalyst.

An Original Requirement

So where does this leave us? Even if inflation were ultimately upheld as theoretically viable, empirically sustainable, and metaphysically and epistemologically credible—an unlikely outcome in my estimation—a beginning and hence a transcendent cause would be required in all models subject to the BGV theorem. As we have seen, this applies to every higher-dimensional cosmology, inclusive of cyclic ekpyrotic and landscape models, that involves spacetimes satisfying the condition that the average Hubble expansion in the past is greater than zero, i.e., $H_{av} > 0$. Furthermore, inflationary models such as the one proposed by Gasperini and Veneziano, to which the BGV result does not apply, do not ameliorate the need for a beginning because their realistic interpretation, however implausible, still requires the meta-stability of the primordial state, which means that the earliest phase has finite duration. Since subsequent phases must also be of finite duration, any universe satisfying this scenario will have a beginning as well.

But what if inflation is not upheld as a viable explanation? Then, assuming the universe isn't suffering from noninflationary cyclic ekpyrosis, which also requires an absolute beginning, we revert from multiverse scenarios to a single universe again. In this context, the singularity theorems of classical general relativity regain their traction—qualified, perhaps, by a different quantum cosmological physics at the past boundary that, as we have seen, does not alter the final metaphysical verdict—and lead to the conclusion that our universe has an absolute beginning in the finite past, and thus the necessity of a transcendent cause for space-time, energy, and matter.

It appears, therefore, that a beginning and a transcendent cause of the universe (or multiverse) are unavoidable.

3. Cutting the Gordian Knot of String Cosmology

We now turn to an examination of the assumptions governing string multiverse cosmologies and an evaluation of their effectiveness as explanations of cosmological fine-tuning.

Fine-Tuning and the Cyclic Ekpyrotic Model

Khoury, Steinhardt, and Turok[98] have shown that the phenomenological constraints on the scalar field potential in cyclic ekpyrotic models necessitate a degree of fine-tuning comparable to that of inflationary models—the number of degrees of freedom, the number of tunings, and the quantitative degree of tuning are similar.[99] While the claim to be just as good as inflationary models might be received with favor in some quarters, our discussion to this point has established grounds for a somewhat less sanguine attitude.

Kallosh, Kofman, Linde, and others take an even less sanguine view, arguing that the ekpyrotic model faces additional problems.[100] For instance, they point out that the Hořava-Witten version of string theory on which the ekpyrotic scenario is based requires the 3-brane of our universe to have positive tension, but the ekpyrotic model requires negative tension. To make the ekpyrotic scenario workable, therefore, they argue that the problem of the negative cosmological constant on the visible brane must be solved and the bulk brane potential fine-tuned with an accuracy of 10^{-50}. Furthermore, they contend that the mechanism for the generation of density perturbations is not brane-specific; rather, it is a particular limiting case of the mechanism of tachyonic preheating, which exponentially amplifies not only quantum fluctuations, but any initial inhomogeneities.[101] As a result, to solve the homogeneity problem the ekpyrotic scenario would require the branes to be parallel to each other with an accuracy of better than 10^{-60} on a scale 10^{30} times greater than the distance between the branes. With some gerrymandering assumptions, Steinhardt and Turok have managed to ameliorate some of these difficulties,[102] but significant technical problems and fine-tuning issues remain—in particular, Veneziano and Bozza[103] have shown that a smooth bounce cannot generate a scale-invariant density perturbation spectrum via the mode-mixing mechanism advocated by Steinhardt, Turok, and others;[104] and Kim and Hwang have argued that it is not possible to obtain the requisite near Harrison-Zel'dovich scale-invariant density spectrum through a bouncing world model as long as the seed fluctuations were generated from quantum fluctuations of the curvature perturbation in the collapsing phase—rather, the spectrum is significantly blue-shifted in comparison with what is needed.[105]

It is worthwhile considering whether the cyclic ekpyrotic scenario has the probabilistic resources to address the one in 10exp(10^{123}) fine-tuning of the Big Bang entropy of our universe.[106] It does not. It is *not* an inflationary model—though it does involve dark energy—so it does not invoke an unending chaotic cascade of string vacua.[107] Rather, each trillion-year cycle produces 10^{100} to 10^{500} Big Bang events with opportunities for finely tuned entropy. This means that with each new cycle there is *at best* a {10^{500}/10exp(10^{123})} = 10exp(500 – 10^{123}) ≈ 10exp(-10^{123}) chance that the requisite entropy condition will be met. In short, the ekpyrotic universe would have to go through a significant fraction of 10exp(10^{123}) trillion-year cycles for there to be any reasonable probability of getting a universe like ours. But we have already seen that such cyclic models are geodesically incomplete and, as Steinhardt and Turok admit,[108] the most likely story is that the cycling stage was preceded by a singular beginning. Furthermore, even if this picture were true, there is in principle no measurement that could be made to determine how many cycles have taken place. It would be a highly unwarranted assumption, therefore, to presume that the model has the probabilistic resources necessary to resolve the problem of universal entropy; in fact, the incomprehensibly large number of trillion-year cycles required inspires deep skepticism, especially when the logico-metaphysical necessity of a transcendent cause for the singular beginning of any ekpyrotic universe brings with it the far more plausible scenario of intelligently directed fine-tuning.

While the ekpyrotic model confronts some extraordinary fine-tuning issues of its own, we may nonetheless reasonably ask whether it resolves any. Steinhardt and Turok have recently claimed that it does,[109] most specifically that it offers a credible explanation for why the cosmological constant (vacuum energy) is small and positive. What they essentially do is engineer a "relaxation mechanism" that can be incorporated into the cyclic model that slowly decreases the value of the cosmological constant over time, while taking account of contributions to the vacuum density over all energy scales. The mechanism works by allowing the relaxation time to grow exponentially as vacuum density decreases, generating asymptotic behavior in which every volume of space spends the majority of time at a stage when the cosmological constant is small and positive—just as it is observed to be today. Again, the solution is ad hoc: a mechanism was *invented* to produce the desired behavior and then declared to be a virtue of the model simply because a way was found to make it work. Furthermore, there is no reason intrinsic to the ekpyrotic scenario, which as we have seen is subject to the BGV theorem, that explains why it must start with a vacuum energy greater than what we observe today, yet invoking a relaxation mechanism must assume that it does, since this condition is needed in order to "explain" the value it now has.[110]

As a last consideration, Alexander Vilenkin argues that the cyclic relaxation mechanism provides no explanation for the fact that the vacuum density, which is fine-tuned to 120 decimal places, is roughly twice the average energy density of matter in the universe.[111] These two densities behave very differently with cosmic expansion—the former stays constant while the latter decreases—so why do we live in an epoch when the values are close? This is known as the "cosmic coincidence" problem. The ekpyrotic model provides no answer to it, but Vilenkin contends that standard inflationary cosmology conjoined with the string landscape does: the universe on the largest scale is postulated to be in a state of high-energy expansion that is spawning lower energy bubble universes like our own, having, in virtue of the string landscape, *all* possible values for a wide variety of "universal" constants. Since galaxies and observers only exist in those rare bubbles where the vacuum energy is small and a variety of other parameters are appropriately adjusted (the anthropic principle), and since analysis reveals that during the epoch of galaxy formation—which includes *our* present time—most galaxies will form in regions where vacuum and matter densities are about the same, he contends this cosmic coincidence is thereby "explained."

FINE-TUNING AND THE PRE-BIG BANG INFLATIONARY MODEL

How does the Gasperini-Veneziano PBBI model fare in relation to issues of cosmological fine-tuning? Turner and Weinberg have shown that pre-Big Bang dilaton-driven inflation of an SPV patch has to last long enough to reach a hot Big Bang nucleation event,[112] but since the PBBI period is tightly constrained by the initial value of spatial curvature, this curvature has to be extremely small in string units if sufficient inflation is to be achieved to "solve" the flatness and horizon problems. It is not completely obvious on this account, however, just how strong this fine-tuning has to be, and others have argued that it may be possible to mitigate this conclusion if the universe is open[113] or if the pre-Big Bang conditions are restricted in just the right way.[114]

More tellingly, Kaloper, Linde, and Bousso have shown that PBB dilaton-driven inflation can address the horizon and flatness problems *only if* the primordial SPV is extremely large and homogeneous from the outset[115]—in short, the fine-tuning of our universe is "explained" by pushing *all* the fine-tuning into the SPV era. Let me elaborate. The authors show that if our universe appeared as the result of PBBI then it had to originate from a homogeneous domain of exponentially large initial size, with enormously large initial mass and entropy at the onset of inflation. Furthermore, if this PBB universe is *closed,* then at the time the SPV becomes describable by the low-energy effective action, it can be shown that it must consist of at least 10^{24} causally disconnected regions of nearly equal density. Needless to say, this is extremely improbable and is a re-expression of the horizon problem with a vengeance—one of the very problems the PBBI scenario was intended to solve.

On the other hand, if the universe in the SPV era is *open,* then in order to account for the homogeneity of our part of the universe, it must start as a Milne universe (roughly, an infinitely large patch of Minkowski space) in the distant past with an infinitesimally small and spatially homogeneous dilaton kinetic energy density of infinite extent. In order for the PBB era to be of infinite duration, it would be necessary for the SPV universe to shrink uniformly for an infinitely long time until the dilaton density grows sufficiently large to cause the scale factor to bounce and undergo super-inflation. Of course, such an SPV state is highly unstable and can be completely destroyed by quantum fluctuations of the dilaton field, which is why, as we saw earlier, the PBBI universe cannot be of infinite duration and must have a beginning. Nonetheless, even if the exquisitely fine-tuned homogeneity required of an open PBB universe were explainable, Kaloper, Linde and Bousso demonstrate that the possibility of resolving the flatness problem depends on being able to explain the unlikely existence and value of two very large dimensionless parameters on which this flatness depends: $g_0^{-2} > 10^{53}$ and $B > 10^{38} g_0^{-2} > 10^{91}$.

Finally, Kaloper, Linde and Bousso demonstrate that the dynamics of PBB cosmology preclude the possibility of self-reproduction and hence do not lead to a period of eternal inflation because quantum fluctuations during the inflationary stage are never large enough to overtake the rolling of the dilaton-field. As a consequence of this, not only is the PBBI scenario incapable of alleviating the fine-tuning of its own initial conditions, it has no resources for addressing the one in $10\exp(10^{123})$ fine-tuning of the Big Bang entropy of our universe.[116]

Fine-Tuning and the String-Theoretic Landscape Model

As a final case, let's evaluate the explanatory power of the string landscape to account for cosmological fine-tuning.[117] The "landscape" of string theory is the brainchild of Leonard Susskind, Joseph Polchinski, Raphael Bousso, and Andrei Linde.[118] It aims to turn the vice of the countless moduli associated with the Calabi-Yau compactification of the higher dimensions in string/M-theory into the virtue of a probabilistic resource for anthropic explanations of cosmological fine-tuning.

As explained earlier, the idea is that bubbles of lower energy string vacua nucleate when moduli decay at random locations throughout higher energy string vacua, which continue to inflate forever. It is suggested that the whole landscape is eventually explored by this means as a series of nested bubble universes. Since only the tiniest fraction of such bubbles exemplify laws and constants hospitable to life, and since observer selection (the weak anthropic principle) places us in just such a bubble, the *anthropic principle* becomes the fundamental "explanation" for cosmological fine-tuning, that is, for why our universe has the laws and constants that it does.

Setting the debatable legitimacy of anthropic explanations aside, what should we make of the string landscape as an entity and of the proposed mechanism for exploring it? Just as with inflationary cosmology, there are some very serious reasons to doubt the tenability of string theory;[119] conjoining the two in one picture would seem to provide twice the ground for skepticism. There is no question that string theory has produced some beautiful and interesting mathematics, but there are some very good reasons to question whether it has told us anything about the universe. First of all, string theory does not make any *unique* predictions that are testable by current experiments (the hypothesis of extra dimensions to reality is separable from its string-theoretic embodiment). Secondly, if models with *non*-positive values for the cosmological constant are also included, string theory comes in an infinite number of versions. With an appreciative nod toward the cleverness of string phenomenologists who have found a set of models consistent with the minimal supersymmetric standard model (MSSM),[120] we still have no idea whether any of these match our reality, and there remain an impossibly large number of them.[121] Thirdly, it is also the case that nobody knows whether eleven-dimensional M-theory, which provides the necessary connection among the five anomaly-free classes of ten-dimensional string theory, is itself mathematically consistent, that is, whether it avoids assigning infinite values to physical quantities. Finally, since we don't really have a clue what the underlying M-theory *is,* we don't even know whether a complete and coherent framework exists that would justify calling the web of conjectures and approximations about strings a unified "theory." This assessment is not the isolated view of a few cranks; it is the considered judgment of a healthy portion of the physics community and it deserves serious consideration.

Even if we grant string theory as a working hypothesis, however, there are reasons internal to it that cast doubt on the tenability of the landscape.[122] Michael Dine argues that if a string landscape of meta-stable ground states exists, it is likely to lead to a prediction of low energy supersymmetry. But in the discretuum of the landscape, he contends, the parameters of low energy physics seem to be *random* numbers, and if this is true, the landscape is *not* a correct description of physics as we know it and so must be rejected. Alternatively, there might be some set of principles in the landscape that explain those laws of nature which do not seem to be anthropically constrained, but it is far from obvious what such principles might be, so even if the landscape were a coherent entity, we would have no key that would enable us to interpret it properly.

Susskind and Douglas think this criticism is very serious and do their best to counter it.[123] Susskind argues, somewhat weakly, that the string landscape is unexplored territory and it is possible that the gauge hierarchy does *not* favor low energy supersymmetry. Douglas's argument is stronger. Building on earlier work,[124] he argues that the vast majority of string vacua do not produce exponentially small symmetry breaking scales and that, given many supersymmetry breaking parameters, adding together the positive breaking terms will produce a distribution weighted toward high scales. It is true that models of supersymmetry breaking driven by a single parameter favor low scale breaking, but models involving more than one independently distributed parameter lead to an expectation of high scale breaking. Nonetheless, the idea of "favoring" one type of vacuum over another is not a strong result. Since we do not yet have the mathematical wherewithal to provide a definitive answer to how the SUSY-breaking scale is distributed in a complete ensemble of phenomenologically viable vacua,[125] Dine's observations remain solid, casting doubt on the intrinsic coherence and phenomenological tenability of the string-theoretic landscape.

Setting these additional doubts aside, we still need to ask whether the proposed inflationary mechanism reifying exploration of the landscape is sufficient to the task. As we know, the landscape is subject to the BGV theorem and has an absolute beginning in the finite past. It therefore has a transcendent cause. But in which string false vacuum state did it begin? Scattered throughout the landscape are at least 10^{500} relative minima constitutive of meta-stable false vacua in which the string moduli can get stuck for a very long time. There is no reason intrinsic to the landscape that *necessitates* that it began with a false vacuum energy greater than what we observe today—indeed, there is no necessity to the supposition that the universe started off in an inflationary state at all, save the convenience of such an assumption for anthropic explanations.[126] Furthermore, the quantum tunneling mechanism by which modulus decay leads to the nucleation of bubble universes with different vacuum energies is exponentially suppressed for transitions to higher energies (and can only occur in the presence of gravity), so it is vastly more likely in the landscape scenario that higher inflationary energy states cascade to lower ones.[127] The assumption of such a cascade is theoretically expedient for the purpose of anthropic explanations, but again not guaranteed; there is in principle no way of knowing whether it is true. Given the exponential suppression of transitions to higher energy states, the only way to ensure that the entirety of the landscape gets explored is either to assume it starts in its highest possible energy state, or if in a lower energy state, to assume that the first string vacuum that came into existence is exponentially older than today's Hubble time. If it started off in a state of low enough energy, however, the hypothesized landscape would have no relevance to the explanation of our finely tuned cosmological constant. So even if some version of string/M-theory were true and reification of the landscape were legitimate—an overly generous concession by any measure—there is no way, even in principle, to determine what proportion of space lands in vacua of each type and hence no reason to think that the whole landscape could or would be explored by such means.

It is worth observing too that a cosmological model that randomly varied the laws and constants of nature in the universes it generated would itself have to be subject to lawful constraints were it not to break down. Such lawful constraints, presumably, fall to string/M-theory functioning as a "meta-theory" that governs which laws and constants, and hence which vacua, are possible. In other words, the principles governing the string/M-theoretic process of variation (whatever they may be) would have to remain stable for the description to be coherent. Of course, were such an explicit meta-theoretic construction to prove consistently realizable, the carefully structured variation process it exemplified would be subject to non-negotiable meta-laws and fine-tuned meta-parameters indicative of design at this higher level—unless, of course, we entertain the absurd notion of an infinite regress of meta-theoretical constructions.[128]

We may also, briefly, raise the issue of whether assuming the existence of 10^{500} universes with different laws and constants generates enough probabilistic resources for anthropic explanation of the fine-tuning of the universe in which we live. The cosmological constant (vacuum energy) of our universe is fine-tuned to 120 decimal places.[129] Given the forty orders of magnitude difference in coupling strengths between the gravitational force and the strong force, plus the absence of any theoretical justification for the size of Newton's gravitational constant, it is reasonable to assume that it might have varied over this range. In consideration of the effects of such a variation, we may conclude that the gravitational constant is fine-tuned to one part in 10^{40} of its physically possible range.[130] Similar considerations lead to the recognition that the weak force is fine-tuned to one part in a billion.[131] The proton/neutron mass difference is fine-tuned to at least four decimal places.[132] As Spitzer notes, there are at least seventeen other independent constants and factors that are fine-tuned to a high degree of precision,[133] some of them requiring a cooperative assignment of values to achieve effects necessary for the existence of life that would be unattainable separately. The cumulative effect of all of these fine-tunings significantly erodes the probabilistic resources inherent in the landscape. A precise calculation of cumulative fine-tuning on the basis of current theory has not yet been made, though significant work continues to be done.[134]

This leaves us to consider the fine-tuning of universal entropy. Unfortunately, the one in $10\exp(10^{123})$ probability—rendered exponentially smaller by the inflationary mechanism—that would swamp the resources of 10^{500} or more string vacua is not a fine-tuning of the laws and constants characteristic of the vacua themselves, but rather a fine-tuning of the *initial conditions* of bubble nucleation. In the inflationary picture, assuming a cascade down the string landscape from an initial vacuum with an energy higher than our own that produces inflationary bubbles decaying at random locations while continuing an eternal expansion, the landscape advocate will contend that there is an unbounded number of instantiations of each string vacuum in the cascade.[135] Given an unbounded number of instantiations of the vacuum characteristic of our universe, so the argument goes, we would expect the one in $10\exp(10^{123})$ initial entropic condition it exemplifies to be instantiated an unbounded number of times. So it is that we encounter the standard but startling claim from practitioners of inflationary cosmology that there are "infinitely many" universes just like our own. A typical example is Alexander Vilenkin,[136] who contends that "[i]n the worldview that has emerged from eternal inflation, our Earth and our civilization are anything but unique. Instead, countless *identical* civilizations are scattered in the infinite expanse of the cosmos." Indeed, clones of each of us are endlessly reproduced throughout the inflationary universe, for "the existence of clones is . . . an inevitable consequence of the theory."[137]

The less sanguine among us might be inclined to remark that if it is a consequence of the theory that endless copies of ourselves exist holding every conceivable opinion and involved in every conceivable activity, then *so much the worse* for inflationary (string) cosmology: it has successfully reduced itself to an absurdity. In this regard, it is worthwhile to ask what the consequences of embracing this theory would be for science itself. A fundamental implication of the theory is that every possible event, no matter how improbable (say, one in $10\exp(10^{123})$, just to pick a number) will happen countlessly many times. Indeed, this conclusion has led to a flurry of articles by cosmologists discussing the string landscape in relation to "Boltzmann Brains" and the question of our universe's "typicality"[138]—a discussion so fantastical that it drew the incredulous attention of the *New York Times*.[139]

If, as inflation standardly assumes, the de Sitter space in which our universe began is a thermal system,[140] then a free-floating "Boltzmann Brain" (BB) can spontaneously appear in this space due to thermal fluctuations.[141] Since quantum fluctuations into large volumes are vastly more improbable than fluctuations into small ones, the overwhelmingly most probable configuration would be the smallest fluctuation compatible with our individual awareness, which is presumed to be a universe containing nothing more than a single brain with external sensations fed into it. Under standard conditions for bubble universe generation in the string landscape,[142] the problem formulated by Dyson, Kleban and Susskind[143] giving rise to the BB phenomenon becomes quite serious.[144] In fact, some calculations lead to free-floating BBs swamping the number of normal brains,[145] in which case it becomes a virtual certainty that we *ourselves* are free-floating BBs rather than persons with a history living in an orderly universe 13.7 billion years old. Not to put too fine a point on it, the BB issue suggests that the multiverse is falsified because the persons we take ourselves to be are not typical observers within it.

Inflationary cosmologists recognize the absurdity of their predicament and are trying to circumvent it, but they cannot agree on how or whether progress on the problem is being made.[146] While there is a sense in which anything with a nonzero probability of happening *will* happen in an infinite eternally inflating multiverse—and an infinite number of times at that—from the perspective of these cosmologists, a viable typicality condition would nonetheless succeed in privileging events that we take to be preconditions of our existence. One idea in this regard has been to finagle the decay time of the inflaton fields in an ad hoc manner so that bubble universes don't get large enough to make BBs more likely than ordinary observers. Of course, setting aside the complete arbitrariness and the principled impossibility of evidence for this strategy of convenience, what results at best is the *relative* typicality of observers like us in an infinite universe where the set of Boltzmann Brains and the set of normal observers have equicardinality and Hilbert's Hotel is open for business. But desperate straits require desperate measures and the fate of universal naturalistic explanation hangs in the balance.[147]

Given what has been wrought, it is perhaps unsurprising that the inflationary multiverse has recently been invoked by a prominent molecular biologist as an "explanation" for the intractably improbable origin of life:

> Despite considerable experimental and theoretical effort, no compelling scenarios currently exist for the origin of replication and translation, the key processes that together comprise the core of biological systems and the apparent pre-requisite of biological evolution. . . . The MWO [Many Worlds in One] version of the cosmological model of eternal inflation could suggest a way out of this conundrum because, in an infinite multiverse with a finite number of distinct macroscopic histories (each repeated an infinite number of times), emergence of even highly complex systems by chance is not just possible but inevitable. . . . Specifically, it becomes conceivable that the minimal requirement (the breakthrough stage) for the onset of biological evolution is a primitive coupled replication-translation system that *emerged by chance.* That this extremely rare event occurred on Earth and gave rise to life as we know it is *explained by anthropic selection alone*. . . . By showing that highly complex systems, actually, can emerge by chance and, moreover, are inevitable, if extremely rare, in the universe, the present model sidesteps the issue of irreducibility and leaves no room whatsoever for any form of intelligent design.[148]

It is not hard to see that anthropic explanation in an infinite multiverse, were it to become the standard default when naturalistic mechanisms have reached the end of their tether, would spell the end of science as a rational enterprise. By providing an all-too-easy explanation for anything that has happened or may happen, the multiverse ends up explaining nothing at all.

Whatever else may be said, it is clear that the string landscape hypothesis is a highly speculative construction built on assumptions that strain the limits of credulity. Even if taken seriously, the reality is that: (1) the mechanisms of the landscape will *require meta-level fine-tuning* themselves; (2) there are substantial reasons to think the landscape as a whole may be *intrinsically incoherent* and *phenomenologically untenable*; (3) the mechanism for exploring the landscape may be *unequal to the task* required of it, and beyond this—like all quantum-theoretic constructs—it lacks an immanent principle of sufficient causality, thus pointing to its metaphysical incompleteness and *need for ongoing transcendent catalyzation*;[149] (4) even if the whole landscape were capable of being explored, the number of string vacua compatible with a positive cosmological constant *may not ultimately prove sufficient* to account for the actual fine-tuning of the laws and constants of our universe; and (5) given its reliance on the equally dubious mechanism of eternal inflation, the string landscape contains the seeds for *destroying science altogether* as a rational enterprise. Such are the follies of scientism.

4. End Game: Mind over Matter

Given this sobering assessment, one wonders why the string landscape has provoked so much enthusiasm. Leonard Susskind provides a revealing answer:

> If, for some unforeseen reason, the landscape turns out to be inconsistent—maybe for mathematical reasons, or because it disagrees with observation . . . [then] as things stand now we will be in a very awkward position. Without any explanation of nature's fine-tunings we will be hard pressed to answer the ID critics.[150]

Indeed, and if Eugene Koonin is to be believed, this inability to avoid intelligent design will carry over into origins of life research if the inflationary multiverse fails.[151] But what gives rise to this reticence about intelligent design? Its detractors mutter about a "god of the gaps" and "arguments from ignorance," but such objections miss the mark and deflect back on their own appeals to chance, especially in contexts such as these where, in the absence of any causally sufficient story, blind luck is invoked as as *deus ex machina* for naturalistic explanations. Intelligent design, by contrast, provides an argument from what we know intelligent causes are sufficient to produce and, furthermore, only intelligent causes are known to be sufficient to produce: structures incredibly rich in complex specified information.[152] Having satisfied the conditions of causal sufficiency and causal uniqueness for the phenomenon in question, therefore, an inference to intelligent design as the best explanation for cosmological origins and fine-tuning is conspicuously warranted.

Nonetheless, reticence remains, and the evolutionary biologist and geneticist Richard Lewontin helps to put a finger on one source of it:

> Our willingness to accept scientific claims that are against common sense is the key to an understanding of the real struggle between science and the supernatural. We take the side of science in spite of the patent absurdity of some of its constructs, in spite of its failure to fulfill many of its extravagant promises of health and life, in spite of the tolerance of the scientific community for unsubstantiated just-so stories, because we have a prior commitment, a commitment to materialism. It is not that the methods and institutions of science somehow compel us to accept a material explanation of the phenomenal world, but, on the contrary, that we are forced by our *a priori* adherence to material causes to create an apparatus of investigation and a set of concepts that produce material explanations, no matter how counter-intuitive, no matter how mystifying to the uninitiated. Moreover, that materialism is absolute, for we cannot allow a Divine Foot in the door. The eminent Kant scholar Lewis Beck used to say that anyone who could believe in God could believe in anything. To appeal to an omnipotent deity is to allow at any moment the regularities of nature may be ruptured, that miracles may happen.[153]

Setting aside possible motivations arising from a desire for freedom from transcendent moral constraints and accountability, there is little doubt that Lewontin is right about the motivation and the reasoning behind scientistic fear of the miraculous, but in articulating the matter so clearly he has exposed a central irony: in their theophobic flight, scientific materialists have found it necessary to affirm a universe in which anything can happen—fully functioning brains popping out of the quantum vacuum, for instance—without a sufficient causal antecedent and for no rhyme or reason. So who believes in miracles *now*? What is more, the naturalist believes in *random* miracles. In a theistic universe, on the other hand, nothing happens without a reason, and while nature is not self-sufficient and therefore not causally closed, any miracles constituted by intelligently directed deviations from purposefully maintained regularities are also expressions of divine purpose. In the ultimate irony, therefore, what we see is that the purposes of scientific naturalism cannot survive the purposelessness they create, for out of the random void is birthed the end of scientific rationality itself.

Stephen Hawking once asked, somewhat poetically, "What is it that breathes fire into the equations and makes a universe for them to describe?"[154] He intended the question rhetorically, but it both deserves and has a genuine answer. Mathematical descriptions may have ontological implications, but they do not function as efficient causes, either metaphysically or materially. They are causally inert abstract objects. If quantum cosmology describes string vacua tunneling into existence from a highly structured faux-nothingness or from another vacuum state, or if relativistic quantum field theory describes evanescent matter scintillating in the quantum vacuum or manifesting nonlocally correlated behavior, neither mathematical construction provides an explanation, let alone an efficient cause, for these events. To believe otherwise is to be guilty of an ontological category mistake. So with all due respect to Leonard Susskind and his coterie of devout string landscape naturalists,[155] there is no landscape of mathematical possibilities that gives rise to a megaverse of actualities and provides a *mindless* solution to the problem of cosmological fine-tuning, for even an infinite arena of mathematical possibilities lacks the power to generate one solitary universe.

The mindless multiverse “solution” to the problem of fine-tuning is, quite literally, a metaphysical non-starter. What the absence of efficient material causality in fundamental physics and cosmology reveals instead is the limit of scientific explanations and the need for a deeper metaphysical understanding of the world’s rationality and orderliness. That explanation has always been, and will forever be, Mind over matter. When the logical and metaphysical necessity of an efficient cause, the demonstrable absence of a material one, and the realized implication of a universe both contingent and finite in temporal duration, are all conjoined with the fact that we exist in an ordered cosmos the conditions of which are fine-tuned beyond the capacity of any credible mindless process, the scientific evidence points inexorably toward *transcendent intelligent agency* as the only sufficient cause, and thus the only reasonable explanation. In short, a clarion call to intellectual honesty and metaphysical accountability reverberates throughout the cosmos: release the strings of nihilism and let the balloons of naturalism drift unaccompanied into their endless night. If anyone has ears to hear, let him hear.

Notes

1. My thanks to Fr. Robert Spitzer, David Berlinski, Arthur Fine, Don Page, and most especially Gerald Cleaver, James Sinclair, and Robin Collins for comments on an earlier draft of this essay. I am solely responsible for any residual infelicities.

2. This question is the focus of the essays by Numbers, McMullin, and Meyer in Part I of this volume.

3. I do not mean to suggest that such research should not be pursued; something invariably is learned from the attempt, and the shortcomings of such efforts contain lessons of a more profound sort.

4. There is, of course, always the third option, viz., maintaining that some demands for explanation may well be excessive or unreasonable, and that seeking an explanation for the origin of the universe and its properties is an instance in which explanatory demand can and should be rejected. To the contrary, I would maintain—in the company of the vast majority of Western scientists and intellectuals up through the end of the nineteenth century—that the correct explanation is perfectly obvious and evidentially supported beyond reasonable doubt*: transcendent intelligent causation.* Moreover, it is clear from conceptually related historical considerations that Judeo-Christian monotheism provided the basis and impetus for the quest for order in nature by modern science, as well as the confidence that such order would be found. Indeed, a belief of this kind is justifiably regarded as the *transcendental ground* for the very possibility of science as a rational truth-conducive enterprise; evolutionary naturalism certainly does not provide grounds for science, in fact, just the opposite (see Plantinga's and Koons's contributions to this volume). Far from the Middle Ages being the "Dark Ages," therefore, they were the period during which the foundations and expectations of modern science were planted, nurtured, and eventually blossomed. This historical corrective to conventional conceits regarding the "folly" of medieval scholasticism receives ample documentation in Edward Grant's *The Foundations of Modern Science in the Middle Ages* (1996) and Rodney Stark's *For the Glory of God: How Monotheism Led to Reformations, Science, Witch-Hunts, and the End of Slavery* (2003) and *The Victory of Reason: How Christianity Led to Freedom, Capitalism, and Western Success* (2005). Insofar as obviation of the supernatural is indeed the motivation for current efforts in multiverse cosmology, the consequence, foreseen or not, is that the very foundations of rationality and morality are undermined (in the latter regard, see Dallas Willard's contribution to this volume). Much more than the simple truth is at stake, therefore, in the inference to transcendent intelligent agency as the best and only rational explanation for the data of cosmology. Since the *causal sufficiency* and *causal uniqueness* of transcendent intelligent agency as a cosmological explanation justly inspire confidence in the truth of what is independently recognized to be essential to the grounding of rationality itself, to rest content with the brute factuality of the universe is to recommend a form of skepticism without merit—both baseless and destructive. For a more extensive discussion of these matters, see my essay "The Rise of Naturalism and Its Problematic Role in Science and Culture" in Part I of this volume.

5. Einstein 1916, 1917; Friedmann 1922; Lemaître 1927; Hawking and Penrose 1970; Hawking and Ellis 1973: 256–98.

6. Fred Hoyle 1975: 684–85.

7. Craig 1993: 46.

8. Linde 1986b.

9. Guth 1981; Linde 1982.

10. It is worth noting the difference in the singularities characteristic of spatiotemporally finite versus spatiotemporally infinite universes in classical general relativity. Finite (elliptic) universes begin with a singular point of infinite density from which they expand to produce a universe that has a finite but unbounded geometry (like the surface of a sphere). Universes that may be conceived as infinite (flat or hyperbolic) are thought of as

having begun from a state of infinite density that is also *infinite in extent* and from which they expand *everywhere at once.* This is why general relativists sometimes speak of open universes as being infinite in extent: in the mathematical model, the singularity from which they began may be conceived as *already infinitely extended;* it is *not* the case, *per impossible,* that such universes grow to infinite size in finite time. If a certain air of unreality should seem to the reader to pervade such mathematical modeling, he may be credited with an admirable degree of metaphysical astuteness. It is the metaphysical absurdities and ineluctable causal incompleteness frequently exhibited by the constructs of fundamental physical theory that, among other things, pose insurmountable problems for ontological naturalism and require radical metaphysical recontextualization before sense can be made of them (see my essay "A Quantum-Theoretic Argument against Naturalism" in this volume).

11. Linde 1986a.
12. Garriga and Vilenkin 2001; Vilenkin 2006a.
13. Borde and Vilenkin 1994: 3305–309; Borde and Vilenkin 1997: 717–23.
14. Borde, Guth, and Vilenkin 2003.
15. See Alan Guth's essay in this volume.
16. Vilenkin 1982, 1988, 1994, 2002; Hartle and Hawking 1983; Hawking 1987, 1988.
17. Hilbert 1925.
18. See Spitzer 2009 (Chapter 5, Section III) for a more complete discussion.
19. Craig 1979; Craig and Smith 1993; Copan and Craig 2004: 147–266.
20. One might also argue that contingent entities, like our universe, even if there were no time $\tau = 0$ at which they began to exist, would still require an explanation of their existence in virtue of their *contingent* character. In respect of the universe as a whole especially, this explanation would have to be given in terms of something that existed *transcendently* and *necessarily* and was capable of *activity* (and hence not an abstract object). Since cosmological models addressing the issue of the fine-tuning of the initial conditions and the laws and constants of nature do not lead us in this direction, we will not pursue this train of thought any further. Those interested in a rigorous development of the cosmological argument from contingency should consult Rob Koons's 1997 essay "A New Look at the Cosmological Argument" and also consult Alexander Pruss's book *The Principle of Sufficient Reason: A Reassessment* (Cambridge: Cambridge University Press, 2006).
21. Whitehead 1925.
22. Tegmark 1998, 2003.
23. A more thorough refutation of Tegmark can be found in Robin Collins's (2009) essay "The Fine-Tuning Argument for Theism."
24. In another vein, this latter argument might also be advanced against the "many worlds" interpretation (MWI) of quantum mechanics, which is based on the idea that quantum wavefunctions never collapse; rather, every possible outcome of every quantum process is realized in actuality, but each occurs in a different "parallel" universe empirically inaccessible to our own. Aside from the ontologically profligate, completely untestable, generally unwarranted and deeply implausible character of this proposed resolution of the measurement problem, it also suffers from some intractable technical difficulties. There is a serious problem with the concept of probability in the MWI context. If I am going to perform a quantum experiment with two possible outcomes such that standard quantum mechanics predicts probability 1/3 for outcome A and 2/3 for outcome B, then, according to the MWI, *both the world with outcome A and the world with outcome B will exist.* It is then *meaningless* to ask "What is the probability that I will observe A instead of B?" because *both* events will happen and parallel versions of myself will observe each outcome in its associated world. So whence the "probabilities" of quantum theory? Furthermore, quantum theory allows *infinitely* many ways to decompose the quantum state of the whole universe into a superposition of orthogonal states. So the question arises for the many worlds interpretation: "Why choose *this* particular decomposition and not any other?" Since alternate decompositions might lead to very *different* pictures, the whole construction is *arbitrary* and *devoid of empirical content.*

25. See my article “A Quantum-Theoretic Argument against Naturalism” in this volume; also footnote 4.
26. Vilenkin 1982; 1988; 1994; 2002.
27. Hartle and Hawking 1983.
28. *A Brief History of Time* (1988).
29. Isham 1993a: 68.
30. For a short discussion of the conceptual differences among description, prediction, and explanation, see my paper “A Quantum-Theoretic Argument against Naturalism” in this volume. Mere descriptions, even when accurate, do not function as explanations of that which they describe; the description provided by the quantum-gravitational wavefunction—which, apart from an MWI interpretation (see footnote 24 above), must collapse *acausally* to give us the reality in which we live—is no exception.
31. For a discussion of the “problem of time” in quantum gravity, see Butterfield and Isham (1999; 2001) as well as many of the essays in Callender and Huggett (2001).
32. Griffiths 1984, 1993; Omnes 1994: 122–43, 268–323; Gell-Mann and Hartle 1990, 1996.
33. Dowker and Kent 1996, Gell-Mann and Hartle 1996.
34. Again, see my essay “A Quantum-Theoretic Argument against Naturalism” in this volume.
35. DeWitt 1967.
36. Vilenkin 2002: 12–13.
37. See Stephen Meyer’s essay “Methodological Naturalism and the Failure of Demarcation Arguments” in this volume.
38. DeWitt 1967.
39. Vilenkin 1988.
40. Isham 1993a: 72–73.
41. Isham 1993a: 72n38.
42. Hartle and Hawking 1983; Vilenkin 1994.
43. Hawking 1987: 640–45.
44. Hawking 1987: 646–47.
45. Hawking 1975.
46. See Butterfield and Isham 1999.
47. DeWitt 1967.
48. Hartle-Hawking 1983.
49. Butterfield and Isham 1999.
50. Hawking 1987: 640.
51. Hawking 1988: 140–41.
52. Hawking 1988: 139.
53. See footnote 20 above; also Koons 1997 and Pruss 2006.
54. For further discussion of the shortcomings of inflationary cosmology see Hawking and Page 1987: 789–809; Penrose 1989b: 249–64; Rees 1997; Earman and Mosterin 1999; Martin and Brandenberger 2001; Hollands and Wald 2002: 2043–55; Holder 2004: 130–43; Penrose 2005: 746–57, 762–65; and van Elst 2008.
55. Penrose 2005: 754.
56. Hawking and Page 1987.
57. Earman and Mosterin 1999.
58. Penrose 1989b: 249–64; 2005: 746–57.
59. Banks 2007: 4.
60. Standard quantification of the inflaton field is given by the number of its “e-foldings,” *N,* which provide a way of measuring the inflationary expansion. If standard slow-roll inflation is operative, then $N = \ln(a_f/a_i)$,

where "*i*" and "*f*" denote respectively the initial and final values of the scale factor of the universe (the global multiplier to universe size). For other cases, such as oscillating inflation, this definition must be modified. See section III of Liddle and Mazumdar (1998) for a brief discussion.

61. The adiabatic theorem states that a quantum mechanical system, subjected to *gradually* changing external conditions, can adapt its functional form; in the case of *rapidly* varying conditions, though, there is no time for the functional form of the state to adapt, so its probability density remains unchanged. See Messiah 1999: 739–50.

62. See also Martin and Brandenberger 2001.

63. Rees 1997: 185; Earman and Mosterin 1999; Holder 2004: 130–43.

64. Land and Magueijo 2005.

65. Land and Magueijo 2007. The worry is that the anisotropies are the result of insufficient subtraction of Milky Way polar-aligned contributions, since the preferred direction seems to be aligned with the Milky Way pole. Further research should shed definitive light on this issue, especially data from the Planck satellite launched in spring 2009.

66. For a *small* sample of these discussions, see Kofman 1996; Boyanovsky, Cormier, de Vega, Holman, Singh, and Srednecki 1997; Bassett 1997; Boyanovsky, Cormier, de Vega, Holman, and Kumar 1998; Bassett and Viniegra 2000; Tsujikawa, Bassett and Viniegra 2000; Felder, García-Bellido, Greene, Kofman, Linde, and Tkachev 2000; Felder, Kofman, and Linde 2001; Green and Malik 2002; Watanabe and Komatsu 2007; and Brandenberger, Frey, and Lorenz 2008.

67. Collins 2003; Cohn 1998; Sahni and Starobinsky 2000: 373–444.

68. Penrose 1989b: 249–64; Penrose 2005: 746–57, 762–65.

69. Penrose 1981: 245–72; Penrose 1989a: 423–47; Penrose 2005: 726–32, 762–65.

70. Penrose offers another quite powerful entropy-based argument against the anthropic inflationary universe. I will not discuss it here, but I commend it to the reader's consideration (Penrose 2005: 762–65).

71. Since even when compactified, bosons remain bosons and fermions remain fermions, it takes compactification of the gravitino to produce spacetime fermionic matter. I thank Gerald Cleaver for this clarification.

72. Green, Schwarz and Witten 1987.

73. Bousso and Polchinski 2000; Kachru, Kallosh, Linde and Trivedi 2003; Kachru, Kallosh, Linde, Maldecena, McAllister and Trivedi 2003; Susskind 2003; Susskind 2004; Freivogel and Susskind 2004; Bousso and Polchinski 2004: 60–69; Ashok and Douglas 2004; Douglas 2004a; Kobakhidze and Mersini-Houghton 2004: 869–73; Ooguri and Vafa 2006; Riddle and Urena-Lopez 2006; Barvinsky and Kamenshchik 2006; Susskind 2006; Vanchurin and Vilenkin 2006; Denef and Douglas 2006; Kumar 2006: 3441–472; Polchinski 2006; Cleaver 2006. Indeed, the embarrassment of riches is so extreme that, were cosmological fine-tuning not so *incredibly* stringent, one might be inclined to modify William Unruh's quip that he could fit any dog's leg you handed him with inflation (as reported in *Science,* August 30, 1996) to state "I'll fit any dog's leg you hand me with string theory."

74. Green and Schwarz 1985: 93–114; Green, Schwarz and Witten 1987.

75. Witten 1995.

76. Arkani-Hamed, Dimopoulos, and Dvali 1998: 263–72.

77. Adelberger, Heckel, and Nelson 2003: 87–100; Kapner, Cook, Adelberger, Gundlach, Heckel, Hoyle, and Swanson 2007.

78. Adelberger, Heckel, and Hoyle 2005; Giddings and Thomas 2002.

79. Khoury, Ovrut, Steinhardt and Turok 2001a; Steinhardt and Turok 2002a; Steinhardt and Turok 2002b; Khoury, Ovrut, Seiberg, Steinhardt and Turok 2002; Turok, Perry and Steinhardt 2004; McFadden, Turok and Steinhardt 2005; Steinhardt and Turok 2007.

80. Khoury, Ovrut, Steinhardt and Turok 2001a.

81. Steinhardt and Turok 2002a.

82. Borde, Guth and Vilenkin 2003; Vilenkin 2006a; Steinhardt and Turok 2005: 43–7; Steinhardt 2004.

83. Steinhardt and Turok 2007; Vilenkin 2006a; Steinhardt 2004.

84. Borde, Guth and Vilenkin 2003; Vilenkin 2006a; Steinhardt and Turok 2005; Steinhardt 2004.

85. Gasperini and G. Veneziano 2003: 1–212; Veneziano 1998; Hawking and Penrose 1970: 529–48; Veneziano 1995; Veneziano 1997: 297–303; Feinstein, Lazkoz and Vazquez-Mozo 1997; Barrow and Dabrowski 1997; Saygili 1999: 225–40; Buananno, Meissner, Ungarelli and Veneziano 1998; Barrow and Kunze 1997; Gasperini 1999; Turner and Weinberg 1997: 4604–609; Maggiore and Sturani 1997: 335–43; Kaloper, Linde and Bousso 1999; Brustein and Veneziano 1994: 429–34; Gasperini, Maharana and Veneziano 1996: 349–60; Rey 1996: 1929–32; Gasperini, Maggiore and Veneziano 1997: 315–30; Gasperini 2000; Brandenberger, Easther and Maia 1998; Foffa 2003; Gasperini 2007; Gasperini 2008.

86. In string theory, *dilatons* (radions, graviscalars) are quanta of a massless scalar field ϕ that obeys a generalized Klein-Gordon equation and is always linked with gravity. Perturbative string theories automatically contain dilatons in ten dimensions, but M-theory doesn't include them in its spectrum *unless* it's compactified. The dilatonic coupling constant is a dynamical variable in string theory. If supersymmetry is *un*broken, these scalar fields can take arbitrary values (they are *moduli* characteristic of *different* string solutions); supersymmetry breaking, however, creates a potential energy for scalar fields that localizes near a minimum value that is, at least in principle, calculable.

87. Veneziano 1998.

88. Hawking and Penrose 1970: 529–48.

89. Veneziano 1995.

90. Veneziano 1997: 297–303; Feinstein, Lazkoz and Vazquez-Mozo 1997; Barrow and Dabrowski 1998: 7204–22; Saygili 1999: 225–40.

91. Veneziano 1998; Veneziano 1997: 297–303; Feinstein, Lazkoz and Vazquez-Mozo 1997; Barrow and Dabrowski 1998: 7204–22; Saygili 1999: 225–40.

92. Turner and Weinberg 1997: 4604–609.

93. Turner and Weinberg 1997: 4604–609; Maggiore and Sturani 1997: 335–43; Kaloper, Linde and Bousso 1999; Brustein and Veneziano 1994: 429–34; Gasperini, Maharana and Veneziano 1996: 349–60; Rey 1996: 1929–32; Gasperini, Maggiore and Veneziano 1997: 315–30; Gasperini 1999: 1059–66.

94. Gasperini and Veneziano 2003: 1–212.

95. Veneziano 1998; Brustein and Veneziano 1994: 429–34; Gasperini, Maharana and Veneziano 1996: 346–60; Rey 1996: 1929–32; Gasperini, Maggiore and Veneziano 1997: 315–30; Gasperini 2000; Brandenberger, Easther and Maia 1998; Foffa 2003; Gasperini 2007.

96. Veneziano 1998; Veneziano 1995; Veneziano 1997: 297–303; Feinstein, Lazkoz and Vazquez-Mozo 1997; Barrow and Dabrowski 1997: 7204–22; Saygili 1999: 225–40; Buananno, Meissner, Ungarelli and Veneziano 1998: 2543–56; Barrow and Kunze 1998.

97. Bousso and Polchinski 2000; Kachru, Kallosh, Linde and Trivedi 2003; Kachru, Kallosh, Linde, Maldecena, McAllister and Trivedi 2003; Susskind 2003; Susskind 2004; Freivogel and Susskind 2004; Bousso and Polchinski 2004: 60–69.

98. Khoury, Steinhardt and Turok 2004.

99. Khoury, Steinhardt and Turok 2004; Khoury, Steinhardt and Turok 2003; Gratton, Khoury, Steinhardt and Turok 2004.

100. Kallosh, Kofman and Linde 2001; Linde 2001: 89–104; Felder, Frolov, Kofman and Linde 2002; Lyth 2002: 1–4; Räsänen 2002: 183–206; Heyl and Loeb 2002.

101. Felder, García-Bellido, Greene, Kofman, Linde and Tkachev 2000; Felder, Kofman and Linde 2001.

102. Turok, Perry and Steinhardt 2004; Khoury, Ovrut, Steinhardt and Turok 2001b; Donagi, Khoury, Ovrut, Steinhardt and Turok 2001; Steinhardt and Turok 2002c; Khoury, Ovrut, Steinhardt and Turok 2002; Tolley, Steinhardt and Turok 2004; Erickson, Gratton, Steinhardt and Turok 2006.

103. Bozza and Veneziano 2005a: 177–83; Bozza and Veneziano 2005b; Bozza 2005.

104. Gratton, Khoury, Steinhardt and Turok 2004; Khoury, Ovrut, Steinhardt and Turok 2002; Tolley, Steinhardt and Turok 2004; Erickson, Gratton, Steinhardt and Turok 2006.

105. Kim and Hwang 2007.

106. Not that Steinhardt and Turok would recommend this course of action, since they deplore anthropic arguments (see Steinhardt and Turok 2007: 231–36).

107. Steinhardt and Turok 2002c.

108. Steinhardt and Turok 2005: 43–47.

109. Steinhardt and Turok 2006: 1180–82.

110. For a slight qualification of this assertion, see footnote 126.

111. Vilenkin 2006b.

112. Turner and Weinberg 1997.

113. Veneziano 1998; Buananno, Meissner, Ungarelli and Veneziano 1998: 2543–56.

114. Maggiore and Sturani 1997: 335–43.

115. Kaloper, Linde, and Bousso 1999.

116. Veneziano (1999) suggests that gravitational contraction is a scale-free phenomenon in that regional patches of perturbed SPV of all different sizes will contract to create Big Bang events. He then argues that an anthropic explanation of entropic fine-tuning is possible on the basis of a multiverse created by regional contractions. There are two responses to be made here. The *first* is that the fine-tuning considerations that make the contraction of *any* SPV patch exponentially unlikely make the contraction of *multiple* patches to create a multiverse *hyper-exponentially unlikely.* The hyper-exponential unlikeliness of multiple contractions will far outrun any probabilistic resources that multiple contractions might generate to address entropic fine-tuning, especially when the meta-stability of the SPV guarantees an origin in the finite past. The *second* is that Gasperini and Veneziano often talk (and rightly so) as if they regard an infinite past to the SPV phase in the PBBI model as an idealization that has *no* real existence. If it has no real existence, however, as we have just argued, it cannot provide the resources to explain away entropic or other kinds of cosmological fine-tuning.

117. Bousso and Polchinski 2000; Kachru, Kallosh, Linde and Trivedi 2003; Kachru, Kallosh, Linde, Maldecena, McAllister and Trivedi 2003; Susskind 2003; Susskind 2004; Freivogel and Susskind 2004; Bousso and Polchinski 2004: 60–69; Ashok and Douglas 2004; Douglas 2004a; Kobakhidze and Mersini-Houghton 2004: 869–73; Ooguri and Vafa 2006; Riddle and Urena-Lopez 2006; Barvinsky and Kamenshchik 2006; Susskind 2006; Vanchurin and Vilenkin 2006; Denef and Douglas 2006; Kumar 2006: 3441–72; Polchinski 2006; Cleaver 2006.

118. Bousso and Polchinski 2000; Kachru, Kallosh, Linde and Trivedi 2003; Kachru, Kallosh, Linde, Maldecena, McAllister and Trivedi 2003; Susskind 2003; Susskind 2004; Freivogel and Susskind 2004; Bousso and Polchinski 2004: 60–69.

119. Krauss 2005; Smolin 2006; Woit 2006.

120. Cleaver, Faraggi and Nanopoulos 1999: 135–46; Cleaver 2008.

121. Kumar 2006.

122. Banks, Dine and Gorbatov 2003; Dine 2004; Robbins and Sethi 2005.

123. Susskind 2004; Douglas 2004b.

124. Denef and Douglas 2004.

125. Kumar 2006.

126. Some would suggest that it is "natural" to start off with an order 1 cosmological constant since the most straightforward calculation of the vacuum energy in quantum field theory comes to roughly one Planck mass per cubic Planck length, which exceeds the *actual* value by 120 orders of magnitude—the worst prediction in the entire history of physics! Others argue that, given a probability distribution of cosmological constants for *possible* universes over the *whole* landscape, an order 1 cosmological constant is not an unreasonable assump-

tion. My basic point, however, is that the landscape hypothesis *needs* this condition to generate anthropic explanations and there is nothing that guarantees it, rather it is an additional and unjustified postulate required for explanatory traction.

127. See Linde 2007; also Coleman and De Luccia 1980 and Guth and Weinberg 1983.

128. This point has also been made quite powerfully by both Robin Collins and John Polkinghorne.

129. Bousso and Polchinski 2004.

130. Collins 2003: 189–90.

131. Collins 2003: 188–89.

132. Collins 2003: 186–88.

133. Spitzer 2009.

134. See, for example, Collins 2003, 2007, 2009 and *The Well-Tempered Universe* (forthcoming); Carter 1967; Carr and Rees 1979; Davies 1982; Barrow and Tipler 1986; Leslie 1989; Hogan 2000; Oberhummer, Csótó and Schlattl 2000; Rees 2000; Gonzalez and Richards 2004; Carr (ed.) 2007; and Spitzer 2009.

135. As we discussed earlier and is worth reinforcing by repetition, this assumption is *not* mandated by the landscape hypothesis and, even though the exponentially suppressed transitions to higher energy states render an uphill climb possible in a timespan exponentially *longer* than today's Hubble time, a sufficiently low-energy genesis to the landscape would completely vitiate the landscape's utility for anthropic explanations. Even on the unlikely assumption that the landscape exists, therefore, we have no way of knowing (apart from our own universe) in what it consists, and there is no principled way to tell what proportion of space lands in vacua of which type, and hence no reason to think that the whole landscape could or would be explored.

136. Vilenkin 2006a: 117, 114.

137. Indeed, Vilenkin's "many worlds in one" model (Garriga and Vilenkin 2001; Vilenkin 2006a) has the consequence that *all* macroscopic sequences of events not forbidden by physical conservation laws not only occur *somewhere* in an eternally inflating universe, but occur over and over again *without limit* as inflation endlessly spawns new expanding regions of spacetime. For instance, the model suggests there is an *unlimited* number of macroscopically exact copies of the Earth and everything that exists on it, even though the probability of any given observable region of the universe containing such a copy is vanishingly small.

138. Dyson, Kleban and Susskind 2002; Albrecht and Sorbo 2004; Page 2006; Ceresole, Dall'Agata, Giryavets, Kallosh and Linde 2006; Linde 2006; Bousso and Freivogel 2006; Page 2006; Carlip 2007; Hartle and Srednecki 2007; Giddings and Maroff 2007; Page 2007a; Page 2007b.

139. Overbye 2008.

140. Dyson, Kleban and Susskind 2002.

141. Linde 2006; Bousso and Freivogel 2006; Page 2006.

142. Kachru, Kallosh, Linde and Trivedi 2003.

143. Dyson, Kleban and Susskind 2002; Albrecht and Sorbo 2004; Page 2006.

144. Bousso and Freivogel 2006.

145. Dyson, Kleban and Susskind 2002.

146. Bousso and Freivogel 2006; Page 2006; Carlip 2007; Hartle and Srednecki 2007; Giddings and Maroff 2007; Page 2007a; Page 2007b.

147. A more rigorous treatment of the Boltzmann Brain issue can be found in Collins (2009).

148. Koonin 2007. Indeed, the probabilistic difficulties attending the undirected production of life in a *life-compatible* universe would be comparable to (and in some cases even exceed) the unattended production of a universe with the finely-tuned properties of our own if the raw "mechanisms" of universe production were capable of autonomous operation. The reader is referred to Stephen Meyer's *The Signature in the Cell* (2009) for an extensive introduction to these issues in origin of life research, as well as to the essays by Meyer, Axe, Dembski and Marks, and Behe in Part III of this volume. For ongoing scientific research into this and related

issues in biological science, the reader is referred to the work of Biologic Institute (http://www.biologicinstitute.org).

149. Once more, see my paper “A Quantum-Theoretic Argument against Naturalism” in this volume.

150. Susskind, as quoted in *New Scientist* magazine, December 17, 2005.

151. Koonin 2007.

152. See Dembski (1998; 2002; 2005), Dembski and Marks (2009a, 2009b), and especially the contribution to this volume by Dembski and Marks.

153. Lewontin 1997: 31.

154. Hawking 1988: 174.

155. Susskind 2006.

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