On efforts to decouple early universe cosmology and quantum gravity research

Mike D. Schneider
Department of Philosophy
University of Illinois at Chicago
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The Big Bang singularity in standard model cosmology suggests a relationship between early universe cosmology and quantum gravity phenomenology. Inflation is usually thought to undermine that relationship by means of a dynamical diluting argument, but this argument has recently been disputed in the form of a ‘trans-Planckian censorship’ conjecture. Ijjas and Steinhardt [1, 2] implicitly advocate an alternative approach: ‘generalized cosmic censorship’. I contrast generalized cosmic censorship with the logic of its namesake: the cosmic censorship conjectures. I also remark on foundational concerns in the program of research beyond the standard model, which would be based on such a principle — a program I dub ‘cosmology done as effective field theory’, or the empirical study of an ‘effective cosmos’.

I. INTRODUCTION

The initial singularity in standard model cosmology suggests a special relationship between theorizing in early universe cosmology and quantum gravity phenomenology. At sufficiently early moments in our cosmic history according to the standard model (‘at the Big Bang’), the cosmos occupied a UV physical regime in which we expect methods from semiclassical gravity to fail, including the approximation of quantum gravity states by classical spacetime geometries. One therefore expects empirical traces of UV quantum gravity in the ensuing cosmological record; hence, early universe cosmology serves as a phenomenological window into UV quantum gravity. This general form of reasoning is nothing new. It is on display, for instance, in the Weyl curvature hypothesis initially proposed by Penrose [3] (see also the discussion in [4]). And it is a natural extension of the reasoning commonly employed in the sub-discipline of early universe cosmology, to infer conditions in the early universe from evidence timestamped at later stages [5].

Still, it is possible that our empirical access to conditions in the fundamental gravitational state immediately following the Big Bang is sufficiently weak as to undermine hopes of treating the early universe as a window into quantum gravity. Inflation would seem to make this likely: any traces of UV quantum gravity in the cosmos following the Big Bang are substantially diluted through the proposed inflationary epoch, so that whatever evidence we recover today of the early universe is very likely (merely) evidence of conditions during inflation and onward. But as was initially pushed in [6], empirically viable models of inflationary cosmology would seem to suffer a trans-Planckian problem, so that claims about an inflationary epoch would commit one to claims about UV quantum gravity at the onset of inflation as well. In recent years, this framing has given way to a ‘trans-Planckian censorship’ conjecture [7, 8]: effective field theories that showcase a trans-Planckian problem in cosmology, like many of the empirically viable models of inflation, are conjectured to violate principles of UV quantum gravity. In this respect, empirically successful models of inflation that are shown to be UV quantum gravity compatible amount to positive examples of UV quantum gravity phenomenology in the early universe.

Proponents of trans-Planckian censorship have taken this state of affairs to motivate work on alternative early universe scenarios. (One of the two initial papers on trans-Planckian censorship was in fact dedicated to this subject [8].) Unsurprisingly, many of these alternative early universe scenarios directly implicate UV quantum gravity in explanations of downstream cosmic structure formation. So one can understand interest in trans-Planckian censorship as all around renewing the prospects of a program in ‘early universe’ quantum gravity phenomenology, which ties together empirical work on the formation of large-scale structure with ongoing theorizing about quantum gravity.

But Ijjas and Steinhardt [1, 2] advocate yet a further alternative: a “classical (non-singular)” bounce can altogether resolve the Big Bang singularity that features in the standard model. Resolving the Big Bang singularity classically (from an effective field theory perspective) amounts to decoupling early universe cosmology from quantum gravity research. And crucially, unlike in the case of inflation, this decoupling is not claimed to be achieved by (dynamically) diluting any and all traces of UV quantum gravity throughout the cosmos. Rather, the decoupling occurs by fiat of the effective field theory framework employed: one supposes that UV quantum gravity is forever screened off from the dynamics of the (bouncing) effective cosmos.

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1 For philosophical discussion on the underlying logic of trans-Planckian censorship conjecture, see [3, 4].
In [1], this view is implicit; explicit is the author’s endorsement of a semiclassical and phenomenological approach to (non-singular) cosmology beyond the standard model. But in the conclusion of [2], the implicit view just sketched is elevated to a proposed ‘generalized cosmic censorship’ principle. This is quite significant: the authors’ general approach to cosmology beyond the standard model, situated opposite both inflationary cosmology and those alternative early universe scenarios that appeal directly to UV quantum gravity, evidently rests on the suitability of the principle as applied to our cosmic evidence, within our cosmological inquiry.

Why might one endorse the principle? One thought is that it is a natural extrapolation from its namesake, the cosmic censorship conjectures, which are themselves broadly popular. But the generalized cosmic censorship principle differs from cosmic censorship precisely in virtue of the former’s consequence of decoupling cosmology and quantum gravity research. By contrast, the cosmic censorship conjectures are usually understood in terms of the paramount importance of predictability in our classical physics, as the latter are to provide approximate descriptions of an ultimately quantum world. The conjectures constrain the physically viable subset of solutions to the classical dynamics of general relativity, on the basis of underlying considerations about unitary quantum gravity spoiling the formation of classically naked singularities.

In this regard, the cosmic censorship conjectures are much more similar to the trans-Planckian censorship conjecture just mentioned, which was initially proposed in [7] in connection with work on the quantum gravity swampland in string theory. In the case of trans-Planckian censorship, one conjectures that UV features of quantum gravity in our cosmos place constraints on physically viable effective field theories within theoretical cosmology. (The architecture of the swampland, initially developed in string theory, merely makes the constraint claim a bit more precise.) The similar characters of trans-Planckian censorship and cosmic censorship — that each moves from an anticipated feature of UV quantum gravity to contouring a low-energy landscape of effective dynamics — indicate that traditional appeals to cosmic censorship in the literature tie descriptions of black holes in low-energy regimes directly to underlying facts about UV quantum gravity.

By contrast, the generalized cosmic censorship principle supposes that UV features of quantum gravity in our cosmos fail to constrain effective field theory techniques deployed freely in theoretical cosmology. And this difference amounts to a crucial dis-analogy in the context of ongoing quantum gravity research. Whereas trans-Planckian censorship and cosmic censorship are conjectures within and pertinent to ongoing quantum gravity research, the generalized cosmic censorship principle is essentially inert. While it is quite possible that the physical cosmos is unrevealing of an underlying theory of quantum gravity, and it is possible that the low-energy landscape of a future quantum gravity theory includes effective dynamics consistent with a classical (non-singular) bounce, the latter possibility would be of little consequence in ongoing quantum gravity research. In particular: it does not amount to an empirical cosmological constraint on quantum gravity research. The only exception would be if all possible early universe alternatives allowed by the quantum gravity theory, which would explicitly draw on UV features of the theory to explain downstream cosmic phenomena, are ruled out on further empirical grounds. (This seems wildly infeasible.)

Still, it is of some interest what such a program in early universe cosmology would look like, which claims to be forever in cosmic time decoupled from quantum gravity research, as a matter of underlying principle. In the remainder of this letter, I consider such a ‘cosmology done as effective field theory’ program, which is based on the discussion found in [1]. This program generalizes from the new cyclic cosmology endorsed by the same authors in [2], which represents just one explicit witness of their generalized cosmic censorship principle. I end by drawing attention to the importance of foundational studies of the fates of information couriers through spacetime, were we to pursue the general program — this is, I will suggest, where the UV quantum gravity details about the universe inevitably slip into the study of an effective cosmos.

II. COSMOLOGY DONE AS EFFECTIVE FIELD THEORY

The central contribution in Ijjas and Steinhardt [1] is not theory. Rather, the authors are primarily interested in introducing a diagrammatic tool to help study how cosmologies that feature a “classical (non-singular) bounce” can plausibly do problem-solving work regarding familiar empirical problems of import in standard model cosmology. But implicit in this focus is a monumental change in tack within theoretical cosmology beyond the standard model. Previous work focusing on bouncing

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2 This view is closely connected to the black hole evaporation paradox [12, 13]. As is pointed out in the “Open Issues” section of [11], if quantum gravity is not unitary, classical gravitational singularities (that witness violations of cosmic censorship) could represent absolute information loss scenarios — surely an important clue in ongoing quantum gravity research.

3 In fact, motivation for trans-Planckian censorship has been tied directly to familiar thinking about cosmic censorship [12].

4 Notably, trans-Planckian censorship has been discussed in relation to an aspect of the new cyclic cosmology other than the bounce: the end of de Sitter-like expansion within each cycle, as relates especially to solving the coincidence problem familiar in the standard model [14]. This point will be significant at the end of the letter.
resolutions to the Big Bang singularity in the context of quantum gravity research had established that bouncing resolutions could be cosmologically interesting. And that work involved various demonstrations, which were model-specific and sensitive to possibly idiosyncratic UV features of quantum gravity (see references in the Introduction of their article).

Whether UV quantum gravity model sensitivity is good or bad in theoretical cosmological practice is surely a matter of affect. Ijjas and Steinhardt [1] evidently find it unsatisfying. They suggest, instead, that a satisfying bouncing resolution is rather easily achieved simply as a matter of modeling at the level of the effective cosmos. One needs only to speculate that certain scalar field theories or Horndeski modifications to an effective field theory treatment of classical general relativity fall out of the as-yet unknown quantum gravity theory, restricted to suitably high energy levels as are thought to become relevant in the very early universe, and given ordinary cosmic conditions there (e.g. approximate spatial homogeneity). Crucially, these modifications are speculated to become relevant at energy scales that are still well below the UV scale at which it is standard to expect that the leading-order local description of a gravitationally coupled system, whose gravitational state is given in terms of metric perturbations around a background, will simply fail to be apt. The hope, in short, is to evade our ever actually arriving at the UV physical regime associated with the Big Bang, within an effective treatment of the early universe. This would relieve the difficulties inherent in relating phenomenological descriptions of the evolution of the cosmos with the breakdown of background spatiotemporal descriptions, as is otherwise characteristic of UV quantum gravity.

The result of this change in tack is an emphasis on how a “classical (non-singular)” bounce, plausibly consistent with any sufficiently developed theory of quantum gravity to come, can be put to work in theoretical cosmology. The idea is to take a more phenomenological approach to leveraging new physics in theoretical cosmology, and this phenomenological turn presages the proposal ultimately sketched by the same authors in [2] for the new cyclic cosmology. That proposal, which is for a program of research in cosmology beyond the standard Big Bang model, is advertised to resolve the Big Bang singularity by supplying, in its stead, one of an indefinite series of bounces. Crucially, the new cyclic cosmology is claimed to everywhere locally feature classical spacetime structure, to leading order — even through each bounce.

As noted in the conclusion of [2], the new cyclic cosmology witnesses a possible ‘generalized cosmic censorship’ principle. According to this principle, UV effects of quantum gravity are forever (i.e. for all cosmic time, including through a bounce) locally screened off from the low-energy scales that characterise semiclassical cosmological modeling, or cosmology done as effective field theory. Unlike in inflation, interpreted as an effective field theory dynamics for a specific cosmic epoch within a singular quantum cosmos, quantum cosmologies satisfying generalized cosmic censorship allow for an effective field theory interpretation of the entire history of the cosmos. This is why, unlike in inflation, the new cyclic cosmology amounts to a programmatic thesis about the decoupling of quantum gravity research from semiclassical approaches to cosmological modeling, including phenomenological problem solving in the early universe.

But the program of research encapsulating this thesis is ultimately much more general than just the new cyclic cosmology. It includes all semiclassical cosmologies that witness the generalized cosmic censorship principle. Plausibly, these include all bouncing resolutions to the Big Bang singularity for which the diagrammatic tool presented in [1] is descriptively apt. And it may include other solutions to the Big Bang singularity, so long as the resolution is, in the authors’ nomenclature, “classical” [3].

In the next section, I lean into this insight: that a cosmology done as effective field theory program requires a “classical” resolution to the Big Bang singularity. And I aim to do so by drawing attention to a certain bogeyman within the exposition of [1] — alternative semiclassical bouncing resolutions to the Big Bang singularity, which are sharply distinguished from the kind of bouncing resolution exhibited in the new cyclic cosmology. In the authors’ nomenclature, these are semiclassical bouncing cosmologies that exhibit (what we might call) singular bounces, such that the resolution is itself not classical, and beyond effective field theory [14]. Here, the semiclassical cosmos would seem, as a matter of phenomenology, to undergo a bounce in the early universe like in the classical cases, but where the bounce itself occupies a UV quantum gravity regime. Examples include the initial Ekpyrotic scenarios and Pre-Big-Bang model in string theory, string gas cosmology (at least, in the absence of finding an effective action that implements it), and perhaps as well the matter bounces studied in the context of loop quantum cosmology and group field theory.

In the context of semiclassical cosmologies that possibly include singular bounces, it would seem that there are two closely related assumptions about the local fundamental physics in the vicinity of a bounce for the diagrammatic tool presented in [1] to be apt. These are discussed in the next section, and clarify the constitutive assumptions behind the cosmology done as effective field theory program: the generalized cosmic censorship principle simply is a joint affirmation of these two assumptions, near or far from any possible cosmological bounce.

5 Here, “classical” indicates apt approximations of quantum gravity states by classical spacetime geometry, for all times. The singularity theorems in general relativity imply that there are likely not satisfying classical resolutions to the Big Bang singularity, in the sense of semiclassical cosmologies everywhere obeying the dynamics of classical gravity, given typical energy conditions on the matter contribution.
III. INFORMATION COURIERS IN SPACETIME

In [1], the authors are concerned with bouncing resolutions to a certain class of nearly Bianchi cosmologies: globally hyperbolic and singular Big Bang spacetimes that satisfy the dynamics of classical general relativity for various familiar matter sources, which admit Cauchy foliations that approximate homogeneous spatial sections near the initial singularity. As discussed in [13] (by partially overlapping authors), provided that one restricts attention to these settings, one can employ certain conformal techniques to “lift” past-incomplete maximal causal geodesics therein, so as to then consider geodesic extensions of those lifted curves. Notably, this procedure can be done to a sufficient number of such geodesics as to cover the underlying spacetime, as one approaches the initial Big Bang singularity. The upshot is that one can think of those extensions, taken altogether, as pushing the underlying spacetime that they quasi-locally cover “beyond” the Big Bang singularity, and into previous epochs. All it costs is the lift.

As just stated, this is merely a formal trick — not so unlike older formal approaches that associate the Big Bang singularity with definite boundary points (which one might then regard as two-sided, and embedded in something larger). But in the class of cosmologies considered in [1], which feature a period of slow contraction followed by a bounce, and then by a period of expansion, something suitably similar to this technique can provide a means of identifying the expanding period therein with the standard model (that is, despite the latter’s singular structure). Hence, one can understand these cosmologies to resolve the Big Bang singularity in the standard model by (quasi-locally) lifting a sufficient number of standard model geodesics near the singularity therein into a setting that features a “classical (non-singular)” bounce. Meanwhile, since those lifted geodesics may be extended in the setting of the bounce, one can ask questions about how pre-bounce physics effects, downstream and post-bounce, familiar observations in standard model cosmology. The diagrammatic tool presented in [1] thus enters the discussion, as a helpful means of bookkeeping in the ensuing general program of research in theoretical cosmology beyond the standard model.

Why discuss techniques to extend already maximal geodesics in singular, Big Bang spacetimes? It may be helpful to recall some basics. Typically, causal geodesic curves in a spacetime are identified with the inertial trajectories of test particles through spacetime (where, then, test particles trace out other predictable trajectories, if forced in particular, expected ways — e.g. by a Lorentz force law, in the case of a charged particle). So, in particular, geodesic curves tell us something about the local communication channels between physical systems that are not spatiotemporally coincident. That is: the geodesic structure of a spacetime describes the viable ideal communication channels linking events therein, as subject to various physical constraints, e.g. whether the courier of the information is massive or massless, charged in the presence of an ambient electromagnetic field, and so on. (Though it may be that, in some cases, the relevant particle limits are poorly motivated as descriptions of the wavefront dynamics of fields in the spacetime, which are to be designated as information couriers [16].) From this perspective, maximal geodesics describe the total lifetimes of such idealized couriers, which may pick up information anywhere along their paths, to be dropped off anywhere else.

Consequent to this perspective, in singular cosmologies, which feature incomplete maximal causal geodesics, one is led to conclude that information is lost “into” the singularity — as carried there in finite parameter time by massive or massless couriers that traverse the (respectively timelike or null) incomplete maximal geodesics. In the specific case of the Big Bang singularity in standard model cosmology, every conceivable courier is swallowed up at a finite time toward the past. As has become common in the literature on semiclassical gravity, e.g. in the vicinity of black holes, it would be satisfying to have an answer about where goes the information carried by those couriers, as one reaches the Big Bang (moving toward the past). If those couriers’ paths could somehow be further extended — that is, extended beyond their finite lifetimes within the singular spacetime — then one might hope to trace back the information that comes to be relevant to structure formation in the early universe, all the way to cosmic epochs preceding the Big Bang.

It is important to recall that this view of geodesic structure, spelled out in terms of information couriers (in singular spacetimes or otherwise), rests on various theorems in general relativity — see e.g. [17], and other previous results cited therein. Broadly speaking, these theorems are what establish an association between geodesic curves and free streaming test particles, capable of communicating information between disjoint neighborhoods in spacetime: our ideal model of couriers. In the case of singular spacetimes, as already stated, some such couriers bring information to or from the relevant singularities, in the sense that they exhaust their given paths in finite time. The foundational point to be emphasized here is that the loss of information into a singularity is ultimately to be understood entirely as a matter of the local wavefront behaviors of fields coupled to the spacetime metric within singular neighborhoods — and this is a wholly classical subject matter.

This raises a question: in the case of bouncing cosmologies, do the techniques to extend incomplete maximal standard model geodesics tell us about viable com-

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6 Since I assume global hyperbolicity in this exposition, all these models witness traditional cosmic censorship. This will become important in the next section, in connection with coarse-graining over microscopic pathologies in the classical spacetime approximation of the quantum cosmos.
munication channels between local physical systems pre- and post-Big Bang? Or, in other words, do the standard model couriers survive the bounce, in any particular given scenario? I understand this to be a non-trivial technical question, and likely model dependent, as concerns the ongoing development of the foundations of bouncing resolutions to the Big Bang singularity in general. But in the context of cosmology done as effective field theory, one in effect assumes a positive answer: for “classical (non-singular) bounces” as considered by [1], the accuracy of the leading-order description of the quantum gravitational state by classical spacetime geometry ensures, by fiat, the couriers’ safe passage.

Or, at least, this would seem a necessary check that a bouncing model proposed belongs within the class. Otherwise, the diagrammatic tool introduced by [1] would be woefully inaccurate. Numerical relativity demonstrations are helpful here [18], to defend the expectation that correlations between the physics pre- and post-bounce are not washed out because of the fates of the information couriers in between. But meanwhile, there is a more profound way to spoil the fates of the couriers in the semiclassical model, which is motivated by considering singular bounces: if, in the vicinity of the bounce, the coarse-graining of the semiclassical approximation of the quantum gravitational state fails to commute with the semiclassical approximation of the coarse-graining (i.e. symmetry reduction) of the quantum gravitational state.

Here is a heuristic for this kind of profound failure: where unexpected geodesic deviation relative to the cosmic metric in the vicinity of the bounce indicates a failure to sequester UV effects of quantum gravity through the bounce, which manifest as a force law on the information couriers. If it can be shown that, classically, information couriers survive through the bounce on geodesic trajectories, it may still be that the geodesic trajectories fail to model the ideal behaviors of those information couriers, because of such effective force laws. A further assumption undergirding the bouncing cosmologies diagrammed in [1] is therefore that there is a global well-behavedness between the coarse-grained lightcone structure of the bouncing cosmology depicted in the diagram and the micro-causal structure of the physics that is relevant locally throughout, and in particular through the bounce. Without such an assumption, those communication channels that are taken to classically permit a courier’s safe passage through the bounce in the effective description need not hug the paths the information couriers are compelled to follow.

Call this assumption ‘local-to-global well-behavedness’: where, to leading order, the local, micro-causal structure of cosmic history is at all times faithfully represented (so far as concerns the IR physics resolved at cosmological scales) by the coarse-grained lightcone structure that is taken to be relevant at the cosmological scales relevant in the diagrams, where local-to-global well-behavedness is imagined to fail (i.e. within some cosmic epoch), there would follow a breakdown there of the kind of scale-decoupling that one is accustomed to, in the context of EFTs. Namely: one would be unable to consider the IR, local physics there as subject to the coarse-grained properties of the spacetime.

It is important to note that, conceivably, certain classical spacetime descriptions taken as correct to leading order with respect to the as-yet unknown theory of quantum gravity may violate local-to-global well-behavedness, in the vicinity of a bounce. (So, it is not the mere demonstration that cosmic history is always at energy scales well below the Planck-scale that renders the bouncing cosmologies considered by [1] satisfying resolutions to the standard model Big Bang.) One can imagine, e.g. in the case of spacetimes that admit multiple, non-unique extensions beyond Cauchy horizons, that coarse-graining procedures might obscure that troublesome fact.

One explicit construction along these lines, in the context of two-dimensional general relativity, is found in a modified extension to the bottom half of Misner spacetime. (For concise definition and pedagogical presentation of Misner spacetime, see [20].) The bottom half of Misner spacetime is a flat spacetime that one may regard as foliated by compact Cauchy surfaces coordinatized by values $x$ taken from a reference metric circle (of some fixed radius of extrinsic curvature), wherein the lightcone structure “tips over” at a rate given as a function of a $t$-coordinate (everywhere normal to the coordinatized leaves of the foliation). If units are chosen so that the lightcone structure would fully “tip over” at a coordinate time $t = 0$, there is a Cauchy horizon there in any maximal extension of the spacetime, with closed timelike curves lying just beyond it.

Consider an extension to the bottom half of Misner spacetime, where the lightcone structure, having fully tipped over at $t = 0$, spontaneously and smoothly begins to right itself from $t = 1$, onward (where I have supposed that units are carefully chosen, for which the $x$-axis coordinate values range over very large values — that is, the radius of the reference metric circle is $>> 1$). Sufficiently coarse-grained, one might overlook that, for an interval of coordinate time, the micro-causal structure of the spacetime is utterly perverse. In such a case, geodesic structure in the coarse-grained setting would seem patently ill suited for considerations about viable communication channels between physical systems at $t << 0$ and $t >> 1$. The couriers that hug those geodesics away from $t = 0$.

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7 Here again is a close connection to traditional considerations of cosmic censorship, in relation to underlying quantum gravity: the existence of non-unique maximal extensions to globally hyperbolic spacetimes in classical general relativity have been taken to signal conceptual problems in the classical theory that cosmic censorship would help alleviate [19].

8 Note that Misner spacetime, and the modification considered shortly, feature incomplete maximal geodesics — hence, they are singular spacetimes. But the underlying manifold structure is entirely well-behaved along the Cauchy horizon [21].
behave wildly differently in its vicinity.

**IV. ONE MORE REMARK**

Cosmology done as effective field theory is a viable approach in theoretical cosmology. But contrary appearances, it does not quite succeed in decoupling early universe cosmology and quantum gravity research. As noted in footnote 4, prior confidences in particular models within the program relative to others can be influenced by conjectures like trans-Planckian censorship within quantum gravity research. Moreover, as alluded in footnote 7, there is a close relationship between the cosmic censorship conjectures and at least some constraints on failures of local-to-global well-behavedness of effective cosmic information couriers.

But more generally, one should wonder as to the virtues of committing, as a matter of principle, to a program in theoretical cosmology beyond the standard model that would *all but* decouple early universe cosmology and quantum gravity research. While there are certain procedural advantages in quarantining regimes of ignorance from our scientific theorizing elsewhere, doing so here does cut off an otherwise exciting intersection in research, which promises increased empirical traction on a regime in which it is famously difficult to get any substantive empirical traction. In the philosophical literature, ‘methodological conservatism’ refers to the position that we hold onto established scientific beliefs until we are compelled by evidence to drop them. But not all beliefs relevant to scientific theorizing are themselves scientific beliefs. In particular, the belief that it suffices to pursue theoretical cosmology by means of studying dynamics of an effective cosmos is not itself a scientific belief. There strikes me little reason to hold onto it as a matter of principle.

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