# Betting on future physics

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## Abstract

The "Cosmological Constant Problem" (CCP) has historically been understood as describing a conflict between cosmological observations in the framework of general relativity (GR) and theoretical predictions from quantum field theory (QFT), which a future theory of quantum gravity ought to resolve. I argue that this view of the CCP is best understood in terms of a bet about future physics made on the basis of particular interpretational choices in GR and QFT respectively. Crucially, each of these choices must be taken as itself grounded in the success of the respective theory for this bet to be justified.

## 1 Introduction

From the vantage point provided by our current best physical theories, how do we anticipate the details of future theories that we do not yet have? Having not yet developed those future theories, the situation is apparently precarious. Common sense skepticism seems to council against even asking such a question: the world has, time and again, surprised us in dramatic ways and defied our expectations of it; the future should likewise come to surprise us still.

But beliefs regarding the contents of future theories are of a different kind than are beliefs about the world, because we are the ones, generally speaking, who are responsible for bringing those future theories about. It should not be surprising, then, that our beliefs today about some of the details of those future theories may fair better in regards to (future) states of affairs than our beliefs today about the world. As such, we plausibly *can* anticipate details of future theories in advance, in which case it becomes prudent to ask how we might indeed go about doing so. And an answer to this question should be of great interest to philosophers of physics and physicists alike— to the former because the answer explicitly concerns the future stability of our present knowledge about the physical world, and to the latter because it is, in a strict sense, the professional intention of that community to carve out the path that ultimately gets us to those future theories, from where we are at present.

Nonetheless, my goal in what follows is not to provide an answer to this question in the most general case; it is, comparatively, much more modest. I will focus (very narrowly) on the circumstances surrounding what I take to be the historically standard version of the "Cosmological Constant Problem" (CCP), a "crisis" in contemporary theoretical physics that has motivated a large amount of speculative work in the past half century of quantum gravity research. In this setting, I will consider what it takes to justify the belief that such a problem is *worth taking seriously* (in the development of the future theory of quantum gravity). While the emphasis here is on motivating paths of research in theory development, I will argue that this issue is essentially about what justifications are available for anticipating that certain details will feature within that future theory which is eventually to be developed.[1] The details in this case will concern a resolution to the historically standard version of the CCP, which one must first bet is well posed within the context of that future theory. It is in this sense that the present study becomes a special case of the much more general project.

Meanwhile, in the context of the more general project, the virtue of focusing narrowly on the case of the CCP is also clear. As already mentioned, the situation in the general case is precarious. But in the special case of the CCP, that the details of the future theory under scrutiny concern a resolution to an explicit problem gives us traction in developing one answer to the general question, at least in the context of quantum gravity research. In particular, I will argue that a belief along the lines above depends, one way or another, on commitments to particular interpretations in our current theories of gravity and matter, according to which there are *reasons to bet* that the problem will indeed arise. To then say that such a belief is grounded in the successes of our current best theories so far will depend on the extent to which we are willing to view our commitments to those interpretations as themselves grounded in the same.

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[1] The suggestion here, more generally, is that there is sometimes a connection between the pursuitworthiness of paths of research toward a future theory and what we anticipate about the details that will turn out to feature within that future theory. In these cases, arguments in regards to the former can be found in the justifications that are available for beliefs pertaining to the latter. Of course, as was alluded to already, it may turn out that we are ultimately wrong about future theory, perhaps in surprising ways. Since the justifications I will discuss below are only ever anchored in the features of our current theories that we *today* believe are responsible for their empirical successes, it is by no means my intention that everyone within the physics community pool their efforts along a single “most pursuitworthy” path (and I also make no claims as to there being anything like a total order on such paths, defined by the extent to which they are each pursuitworthy). The point, rather, is to better understand how disagreements amongst theoretical physicists about how to develop future physics bottom out in principled disagreements about what we may presently anticipate about the end product of that development.

## 2 The ‘Cosmological Constant Problem’

I have argued elsewhere (Schneider forthcoming) that the CCP is best understood as a collection of mutually exclusive problems, indexed by the mutually exclusive assumptions about future physics that give each of them their force. I do not wish here to take a side for or against the claim argued in that paper. What I will do here is adopt, largely uncritically, the thought that when one speaks of the particulars of the CCP, what one really means is to speak of the particulars of one (or another) *version of the CCP*. Moreover, in doing so, one inherits the baggage of whatever assumptions about future physics are implicated in the precise statement of that version.

In particular, I will focus here on (what I take to be) the *historically standard version* of the CCP, or the version of the CCP that corresponds to historically standard assumptions about future physics, made by appeal to our current theories of general relativity (GR) and quantum field theory (QFT).[2] The statement of that historically standard CCP is as follows:

> How does one account for the (enormous) discrepancy between the observationally constrained value of the cosmological constant that arises in the standard model of cosmology and the currently computed values of the zero-point energies that arise in standard model particle physics?[3]

As a slogan, the version of the CCP stated here is apparently quite compelling, lending itself as decades-long motivation for an impressively vast literature of speculative physical mechanisms that, pending their inclusion in the next generation of physical theory, would either resolve the problem or sidestep it altogether. Philosophers of

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[2] For a physicist’s pedagogical introduction to this version of the problem, see Carroll (2001). Weinberg’s (1989) paper first declared it a crisis, but one finds a much longer history in the article (and thorough philosopher’s primer) on the subject by Rugh and Zinkernagel (2002).

[3] Prior to the late 1990s, the standard model of cosmology was consistent with a vanishing cosmological constant, and so earlier commentaries on the CCP frame the problem as a mystery about the vanishing observational signature of the otherwise enormous zero-point energies (e.g. Weinberg (1989)). Nonetheless, the key insight is that putative cosmological observations of the one quantity are, on the historically standard view, taken to be observations in some sense of the sum total of the values of the other quantities.

physics have not ignored this. Earman (2001), for instance, has emphasized that, despite all of the attention the CCP is given in the theoretical physics community, we should be skeptical of its status as a problem. Much more recently, Koberinski (working paper) has argued that, given such a skepticism, we should be hesitant to continue working on projects done in its name.

Within the physics community, meanwhile, in light of all of this activity, a criticism of a slightly different kind has been echoed by a vocal minority. The criticism is this: what we know already about spacetime, or perhaps about fields on spacetime, or perhaps about defining quantum fields, renders the problem stated above as *simply not worth taking seriously*. On this view, the future theory of quantum gravity is just not the sort of thing that one anticipates will feature, in its details, a resolution to this problem. (And if one even thought that it might, then that is already to have conceded that the problem is well posed.) Meanwhile, believing otherwise requires a dogmatic refusal to accept some or other lessons we have already learned about the physical world, on the basis of our current best theories so far.[4] This is the sort of criticism that I think it will be fruitful to focus on here. In particular, one might rightly ask: by appeal to what is one permitted to argue that physicists ought not to take a problem seriously on the basis of our current best theories so far? Conversely, by appeal to what is one permitted to argue otherwise, such that we might anticipate of future theory that it will wind up built as the sort of thing that includes a resolution to that very same problem?

In what follows, I will develop an argument in defense of taking the historically standard version of the CCP seriously, which is to say an argument in defense of the anticipation that the future theory of quantum gravity will come to feature, in its details, a resolution to it. As has already been mentioned, the argument will turn on particular assumptions about standard interpretational commitments that physicists have in our current theories of gravity and matter.

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[4] By way of examples, I take Carlo Rovelli, George Ellis, William Unruh, and Robert Wald to be four influential physicists who would all agree with this criticism, but each for different reasons and to very different ends. I will return to each of these four figures below.

To forestall the possibility of confusion, I want to stress that in developing such an argument, I do not mean to endorse its conclusion. Indeed, I am sympathetic to the skepticism broadly shared by those whom I have already mentioned. Nonetheless, I think it is productive to trace back the locus of that skepticism to particular disagreements with the standard view about what we may claim to know on the basis of the successes of our current best physics. Moreover, for those who are not swayed by such skepticism, the argument I will develop stands as proof of concept: the belief that quantum gravity will come to feature a resolution to the historically standard version of the CCP can be justified on principled grounds, via commitments to particular interpretations in our current, empirically well-supported theories. (And consequently, per the remarks in footnote 1, those paths of speculative research that aim to resolve the problem are themselves worthy of pursuit.)

### 2.1 The physics that anticipates 'vacuum energy'

There are, upon inspection, two distinct statements contained within the slogan given above. The first is that there is a discrepancy between the value of the cosmological constant, on one hand, and the values of the zero-point energies, on the other. The second is that each of these quantities pick out the same physics, or the same features of the world. Put aside the first of these statements to focus on the second: according to what arguments are we supposed to understand the two quantities as picking out the same features of the world? Call this question "Q".

Q is not so straightforward of a question, because the two quantities implicated in it gain their significance in radically different theoretical frameworks (this is, after all, why they are referred to by different names). The cosmological constant arises in the context of GR, our premier framework for understanding the large-scale dynamics of spacetime qua gravity, whereas zero-point energies arise in the context of QFT (on Minkowski spacetime), our premier framework for understanding the small-scale phenomenology of matter. Reconciling the two competing pictures of the world gotten from GR and QFT is precisely what an adequate theory of quantum gravity is meant to do (Huggett and Callender 2001). Depending on whether we are supposed to understand the two quantities as picking out the same physics or not, different adequacy criteria for a theory of quantum gravity will present themselves.

One answer to this question, perhaps the favorite pedagogical answer (see, e.g., Rugh *et al.* (1999) or Carroll (2001)), is that the two quantities each describe, in their respective theoretical frameworks, an energy level associated with the vacuum, or perhaps ‘empty space’, such as can be expected to dominate in the vast regions of void found within our observable universe. On this view, there is some pre-theoretic feature of the world, ‘vacuum energy’, to which the theoretical terms “cosmological constant” in GR and “zero-point energies” in QFT each correspond.

I would like to caution against taking this view as providing an answer to Q, and rather suggest that it amounts to a restatement of the question. The recent history of philosophy of science has taught us to be distrustful of accounts of physics that depend essentially on there being some language of the world, to which our theoretical terms straightforwardly correspond. That we can postulate a pre-theoretic feature of the world called “vacuum energy” and insist that the theoretical quantities of the cosmological constant in GR and zero-point energies in QFT each correspond to it does not explain why those quantities in each of the theories can, in any case, be expected to pick out the same feature of the world. Particularly in the present case of interest, both ‘vacuum’ and ‘energy’ are incredibly theory-laden concepts whose characteristics differ dramatically depending on which theoretical environment, GR or QFT, one considers. It seems like the choice of label, i.e. “vacuum energy”, is unjustly performing much of the purported explanatory work.

I have said why the favorite pedagogical answer is not, in fact, an answer to Q (or at least not obviously so), but I have not yet said how it is a restatement of the question. This is more subtle. First, recall the more general question at the beginning of this paper: how do we anticipate the details of any future theory, given only the resources provided by our current theories? Suppose now that "vacuum energy", rather than directly referring to a feature of the world, refers instead to a quantity in the future theory of quantum gravity that is meant to bring together the domains of GR and QFT under one framework.[5] Such a future theory ought to explain how it is that the two current theories are separately so successful in their appropriate domains. And fortunately, lacking the details of that future theory— for instance concerning the quantity already picked out as "vacuum energy"— does not preclude us from making various bets about those details (to the contrary, it makes the activity of betting more interesting). Here is one such bet: from that which is appropriately identified as "vacuum energy" within the future theory, we ought to be able to recover, in the appropriate limits, both the cosmological constant and zero-point energies. This is, I claim, the historically popular bet about future physics, in the sense that the slogan given above constitutes the historically popular version of the CCP.

Naturally, given this bet, any (enormous) discrepancies between the values of the two quantities in the current theories presents a problem for which the future theory needs, in its details, some or other resolution: how is it that in the appropriate limiting cases, the same quantity in the future theory corresponds to such dramatically different-valued quantities as are familiar in our current theories? Put slightly differently: how can one or another of the theories that represent limiting cases of the future theory of quantum gravity be so wrong in their descriptions of the quantity of 'vacuum energy' thought to arise in that future theory, in particular when each of those limiting theories is so successfully applied toward other ends? Lacking a resolution to this problem renders empirically inadequate any theory that otherwise satisfies the

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[5] I take this to be more a general assumption than that which was assumed in the favorite pedagogical answer. After all, if one believes (as in that case) that the term refers to a feature of the world, then that feature of the world is presumably, in virtue of the properties we are already want to ascribe to it, something that the future theory is expected to describe. But one may also believe the term to refer to some or other mathematical construction relevant to the future theory (which need not possess definite physical content), which stands in certain relationships to the mathematical constructions that populate our current theories of physics. In this case, the explicit identification of such a construction, which indeed stands in all of those relationships, is just part of the job in writing down the future theory.

terms of the above bet. In this way, the act of committing to that bet today gives rise to the expectation that the future theory will, in its details, resolve this problem.

Consequently, justifications for committing to the bet today are also justifications for such subsequent expectations— i.e. beliefs— today along these lines. In this way, we may anticipate that the future theory will detail a resolution to this problem, so long as the bet itself is (presently) reasonable. Of course, I have said nothing about why such a bet is reasonable in the first place; this is, at its heart, Q restated: how does one defend the bet that the future theory of quantum gravity will include such a quantity as just described? Arguments in favor of this bet are thus tantamount to arguments in favor of certain anticipations about details of the future theory.

Here is the form of one such argument. If one can show that the cosmological constant, understood always in the framework of GR, entails a physical quantity in GR that wants for a description in QFT as zero-point energies, and if one can show that zero-point energies, understood always in the framework of QFT, entail a physical quantity in QFT that wants for a description in GR as the cosmological constant, then one has reason to bet that some single quantity in the future theory will reduce in appropriate contexts to each of the two. The sense in which arguments of this form carry force is hopefully somewhat transparent: exactly all we have to work with in the development of future theory are our empirical observations, as they are understood in the contexts of our best physical theories to date. If, in each of our theories of GR and QFT, specific quantities can be shown to be left wanting for a description in the latter as one another, then our best way of understanding the empirical world today is precisely in such a way as there appears to be a feature of the world that admits each of the quantities from GR and QFT respectively as descriptions in suitable limits. This feature of the world is then exactly the sort of thing that the future theory of physics ought to describe.[6]

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[6] On the other hand, these are, after all, just arguments in favor of bets about the future theory; they are not deductive and we may turn out to be radically wrong. The point, in that case, is to understand what exactly we are wrong about now, when our bets later prove in retrospect to have led us astray.

In the next two sections, I will argue one sense in which the cosmological constant, understood always in the framework of GR, entails a physical quantity in GR that wants for a description in QFT as zero-point energies, and vice versa in the framework of QFT. In doing so, I can make explicit which assumptions about the physics within each of the two current frameworks together motivate the historically standard version of the CCP, or equivalently which assumptions about our current physics warrant the bet just proposed. Such assumptions therefore also warrant, on the basis of alleged facts about our current best theories so far, the anticipation that the future theory of quantum gravity will, in its details, resolve the problem that follows from having committed to that bet. In order of their presentations below, these assumptions are:

1. The cosmological constant is regarded on the "matter view" in GR.
2. The cosmological constant is "minimally coupled to matter" in GR.
3. Zero-point energies characterize semiclassical "zero-point stress-energies" in QFT.
4. Semiclassical stress-energies are "minimally coupled to curvature" in QFT.

As I will suggest, these assumptions are only sensible as premises in the context of particular interpretations regarding the physics within the two theories respectively.[7]

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(This "retrospective" view is taken up again in section 3.)

[7] I also suspect that these various assumptions are where the four physicists mentioned in footnote 4 find cause to depart from taking the historically standard CCP seriously in the development of future theory. See footnotes 9, 10, 11, and 12 in section 3 below for more on this point. As one reviewer points out, what I am not doing here is arguing the necessity of these four assumptions in justifying the historically standard version of the CCP. It is enough for my purposes that such assumptions are sufficient to justify it, and that these assumptions are likely to be those which are held by the relevant communities that do indeed take it seriously. Sufficiency ensures that interpretations in our current theories which entail these assumptions likewise entail (by the above argument) taking the historically standard version of the CCP seriously. That these assumptions are likely endorsed by the relevant communities makes it promising that my analysis has identified the loci of disagreement, in practice, about whether physicists ought indeed to take it seriously. Concerning this latter point, I take the implicit satisfaction of these assumptions in the popular effective field theory approach (see §4) to provide at least some evidence that this is so. That the four physicists named previously each seem to depart from the standard perspective in virtue of disagreeing on each of these four respective assumptions provides further evidence along these lines.

### 2.2 Getting to zero-point energies

GR is, from one perspective, a framework for particle dynamics in the presence of spacetime curvature. One traditionally begins with a relativistic spacetime, the points of which are interpreted as events, whereupon curves through the spacetime describe the possible trajectories of test particles of various kinds. For this reason, GR lends itself to the practice of model building in observational cosmology, where the physical scales of interest are such that the observed, reconstructed trajectories of whole galaxies may be regarded as the trajectories of test particles of a certain kind in some background spacetime.

But GR also provides a dynamical theory of the constitution of four dimensional spacetime, where the specification of suitable initial data along a three dimensional spatial submanifold (where such suitable data exists) uniquely determines the nearby characteristics of the four dimensional spacetime. This local determinism is governed by Einstein's equation, which may be written globally (with respect to a fixed manifold $M$) as

$$R_{ab} - \frac{1}{2}Rg_{ab} - \Lambda g_{ab} = 8\pi T_{ab}$$

where $g_{ab}$ is the metric of the spacetime, $R_{ab}$ and $R$ are functions of that metric and its derivatives, $T_{ab}$ is a symmetric tensor field on the manifold that is divergence-free with respect to $g_{ab}$, and $\Lambda$ is a Real-valued constant.

$T_{ab}$ is taken to encode the total stress-energy of some collection of matter fields defined on $M$. Where those matter fields admit of descriptions as fluids or (other) classical fields (e.g. the electromagnetic field), one may study the solution space of Einstein's equation to identify classical *cosmological models*, understood as spacetimes for which it is the case that the corresponding curvature is sourced by the matter defined on top of it. One commonly studied class of cosmological models is that whose constituents all feature the spatiotemporal structure of Minkowski spacetime, the geodesically complete spacetime whose manifold structure is $\mathbb{R}^4$ and whose metric is flat (so, notably, $R_{ab} = \mathbf{0}$ and $R = 0$).

As it turns out, when one commits in cosmology to modeling the universe at the largest scales as if all of the matter were (perturbed) perfect fluids (and one adopts certain guiding principles about the global structure of the universe), the observed, reconstructed trajectories of galaxies, understood as test particles in that spacetime, can be rendered as measurements of the constant $\Lambda$ in Einstein's equation. This is the cosmological constant. Observe that it is present even in the "vacuum sector" of GR, when $T_{ab} = \mathbf{0}$. In what follows, we will only concern ourselves with that sector of the theory, i.e. situations in which Einstein's equation may be expressed as

$$R_{ab} - \frac{1}{2}Rg_{ab} - \Lambda g_{ab} = \mathbf{0}$$

Note the notion of 'vacuum' being deployed here: it applies whenever $T_{ab}$ vanishes, irrespective of the statuses of whatever other fields one wishes to define on the spacetime. In particular, in cosmological contexts, one is free to entertain the possibility of vacuum models of various matter fields. For instance, any free (i.e. non-interacting) scalar field on a spacetime whose field values are everywhere-vanishing is standardly understood to carry everywhere-vanishing stress-energy. Hence, such a scalar field, understood as a (very boring) classical matter field, when defined on a spacetime for which the vacuum sector of Einstein's equation is satisfied, defines a vacuum model of cosmology.

In the vacuum sector, observe that we may just as well express Einstein's equation as

$$R_{ab} - \frac{1}{2}Rg_{ab} + [0]g_{ab} = \Lambda g_{ab}$$

where we have kept a vanishing multiple of the metric on the left-hand side in brackets. Since $\Lambda$ is a constant and $g_{ab}$ is (as a metric) symmetric and divergence-free with respect to itself, the term $\Lambda g_{ab}$ may just as well be regarded as a stress-energy in its own right, which is present even in the vacuum sector of the theory. Call this the "matter view" of the cosmological constant, because it interprets the (entire) measured cosmological constant as characterizing a quantity of stress-energy, and hence a kind of matter, that is associated with vacuum spacetimes.

On the face of things, all that has happened here in adopting the matter view is an algebraic manipulation. But the organization of Einstein's equation doubles as a helpful bookkeeping device, where the left-hand side defines a tensor with a geometric interpretation— the "Einstein$_{\Lambda_0}$" tensor for fixed $\Lambda_0 \in \mathbb{R}$ (written presently as the quantity in brackets)— which is dynamically constrained by the tensor on the right-hand side, interpreted as the total stress-energy associated with that geometric structure. From this perspective, one may understand the matter view of the cosmological constant to be diametrically opposed to another interpretation, call it the "gravitational view", in which the measurement of $\Lambda$— as a measurement of $\Lambda_0$— is understood as modifying the spacetime geometries that one associates with vacuum spacetimes. Note, though, that there exist a continuum of stances between these two, where the term in brackets in the most recent expression takes on any Real value. Each of these stances amounts to a different view about what GR tells us to conclude about the geometries of vacuum models. In exactly one of these stances, namely the matter view of the cosmological constant, Minkowski spacetime counts as a suitable vacuum geometry, i.e. as characterizing inertial motions in a model where gravitational interactions with matter have been "switched off".

Now, observe that the matter view of the cosmological constant— understood as fixing a standard of inertial motions, absent gravity, that is independent of measurements of $\Lambda$— gives rise to certain expectations about the details of the theories that govern the matter fields within any particular vacuum model. Consider any such vacuum model, where we may simplify matters by assuming that there is only one species of matter in it. The stress-energy characterized by the cosmological constant on the matter view, within the context of such a model, implies that within the theory meant to govern that species of matter, there is a quantity of stress-energy that arises just by virtue of the matter being defined at all. This quantity of stress-energy does not depend on any dynamical features of that matter. Instead, it depends only on the structure of the background spacetime on which the matter is defined, as well as on some constant characteristic scalar that must show up within the theory itself.

What is happening here is that the presence of new terms on the right-hand side of Einstein's equation has created new obligations in the theory that is meant to govern the matter implicated in any particular cosmological model. Given, in particular, a vacuum model and the theory of matter implicated by it, it is clear that the cosmological constant must arise as a characteristic term within that implicated theory in such a way that is irrelevant to the (possibly degenerate) dynamics of the matter. In this way, one assumes that the cosmological constant arises as a term in the matter theory that, according to that matter theory, does not depend on the dynamics ascribed to that matter. That is, one assumes the cosmological constant in that theory to be "minimally coupled" to the matter.

But our best theory of matter to date as would be implicated in the standard model of cosmology is not given in terms of classical field theories; it is rather formulated in the framework of QFT (on Minkowski spacetime). In this way, the cosmological constant, on the matter view, is left wanting for a treatment in QFT, our premier theory of matter, as a characteristic term that may be associated with a quantized field, even when that quantized field is arranged in its degenerate or vacuum state. As we will see along the way in the next section, this is precisely what zero-point energies appear to be.

### 2.3 Getting to the cosmological constant

In broadest strokes, given— for pedagogical purposes— a free (i.e. non-interacting) scalar field on Minkowski spacetime, the quantization of that field consists in replacing field values at points in the spacetime with "smeared field operators" that are passed, as input, test functions taken from the collection of smooth fields on the spacetime that feature compact support. In the limit about a given point (in the sense of distributions on the spacetime), one may understand the smeared field operator in the quantized theory to correspond, semiclassically, to the map that takes that point in the spacetime to the value of the classical field evaluated at that point. That is, just as one may define various other classical observables (besides ‘field value’) by specifying certain pointwise operations on the classical field, one may define various other quantum observables (besides ‘smeared field operator’) in the case of the quantized field by specifying certain operations on those smeared field operators. As is the case for any (free) quantized system, states of the quantized field can be thought of as certain maps (satisfying various technical properties) from a set of observables to some abstract field, for instance the complex numbers. The image of a given observable in such a map is interpreted as the expectation value of the corresponding observable, when the quantized field is arranged in that state.

In this broad setting (and defined with respect to Minkowski spacetime), zero-point energies may be understood as a measure of the expected energy of the quantized field, when it is arranged in its vacuum state. More precisely, zero-point energies are the expectation values of some particular observable, call it energy$_Q$, when the field is arranged in a particular state for which it is the case that (globally) there are no excitations of the field and, moreover, given any two timelike-separated points in the spacetime, the correlation functions between the values of the field peaked over those two points depend only on the geodesic distance between them.[8] The latter of these two conditions witnesses the tight connection between the vacuum state of a quantized field and the inertial structure of the background spacetime; the former condition, meanwhile, picks out a global standard for lowest energy field configuration which is preserved under the global symmetries of that background.

I have not said anything of the construction of the observable energy$_Q$ in the

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[8] See Redhead (1994) for a discussion about the vacuum state of a field as it relates to the physics witnessed by inertial observers.

quantized theory; here, it suffices to say that its construction bears strong analogy to the construction, in the corresponding classical field theory, according to which one assigns an energy density to the field. Unfortunately (and quite famously), constructions such as this in QFT, i.e. those which require taking products of smeared field operators in the coincidence limits about single points, lead to divergences. For this reason, various methods are introduced to regularize those sums, so as to recover finite expectation values. In the context of effective QFT, this is done by introducing a cutoff parameter based on high energy regimes where one takes the theory to no longer be applicable (for independent reasons); in more systematic approaches, this is done according to one or another renormalization prescriptions that are tailored so as to cancel out what may be quarantined as just the singular component of the particular sum. For our purposes, we may remain agnostic on the calculational point and merely assume that the resulting zero-point energies, however they are gotten, are formally well-defined and finite.

It is perhaps worth stressing here that there is no a priori reason for the (classical) energy density associated with a quantized field to agree with the expectation value of any particular observable constructed within the quantized theory. Given the above framing, this is easy to see: the only way we have to understand classical energy density is as a feature, namely an observable, of a particular physical theory that happens to be classical. Observables in a quantized theory are simply a different sort of mathematical object. Any relationship between observables in a quantized theory with observables in a classical theory must be put in by hand; an insistence that *some particular observable* in the quantized theory stand in such a relation is nothing short of an intertheoretic demand on the practice of physics— it is not a demand that any candidate quantized theory automatically satisfies (Feintzeig 2017). Nonetheless, one generally assumes that such an identification can be made. By dint of the analogy between the constructions of various observables in QFT and the constructions of observables in classical field theory, one often assumes, as an interpretive resource in the quantized theory, what might be regarded as a “semiclassical translation dictionary.” According to this dictionary, for instance, the expectation value of energy$_Q$ in the quantized theory is interpreted as an expression (perhaps averaged in some sense) of the classical energy density *associated with* the quantized system.

To sum up what has been said so far: via the availability of a semiclassical dictionary as just described, when a quantized field is arranged in its ground state, zero-point energies are expected energies gotten via measurements of a particular operator that corresponds, in the semiclassical dictionary, to the classical energy density associated with that quantized field in that ground state.

But we know that the appropriate, observer-independent geometric quantity that encodes the classical energy density of a field is a stress-energy tensor, so to be more precise in our semiclassical translation dictionary, we are looking for a “semiclassical” stress-energy tensor that is defined with respect to those zero-point energies. That is, we want a stress-energy tensor that, when acted on by unit four-vectors at any point in the underlying spacetime (that correspond to arbitrary inertial observers at that point), gives a measure of the “semiclassical” energy density associated with the field in that state. As it turns out, the only family of suitable stress-energy tensors that are invariant under the symmetries of Minkowski spacetime (and hence yield the same energy density with respect to arbitrary inertial observers) is the Minkowski metric, up to a constant factor. In other words, on the assumption that zero-point energies so characterize “zero-point stress-energies”, up to a scaling constant there is only one way possible to define a semiclassical stress-energy tensor in those terms. Since that scaling constant amounts to a scaling of units in proper time along an inertial observer’s worldline, we have the following: via the semiclassical dictionary mentality, the constant factor in the semiclassical tensor that encodes those zero-point energies is equal in value to the zero-point energies themselves. Recall now from the previous section that the cosmological constant also appears as a constant factor modifying the spacetime metric. In Minkowski spacetime, these two tensors are syntactically equivalent.

But we have already seen that the cosmological constant appears in Einstein's equation modifying an arbitrary metric, which means it is not enough that we have constructed a semiclassical stress-energy tensor syntactically equivalent to that term in Minkowski spacetime. For zero-point energies to want for a description as the cosmological constant in the relativistic theory, the semiclassical tensor that we have constructed needs to be the sort of thing that is defined in the same way, given any arbitrary metric. This modification has a name: the minimal substitution rule, and it is a familiar tool in classical field theories (see, e.g., Wald (1984, p. 70)). What this rule amounts to is a manipulation of syntax in the expression of a field equation originally defined on Minkowski spacetime: one simply replaces any explicit reference to the Minkowski metric with a reference to an arbitrary metric, and one replaces any explicit reference to the flat derivative operator (native to the Minkowski metric) with the derivative operator that is native to the arbitrary metric just introduced. In this way, one generally says that the resultant theory on the arbitrary spacetime is "minimally coupled to curvature", because it contains no explicit reference to curvature terms that would otherwise have been degenerate in the case of Minkowski spacetime.

Since the minimal substitution rule is a manipulation of syntax, its application to a particular expression therefore requires independent physical arguments: that the field in question is the sort of field for which the application of a minimal substitution rule is warranted. Note that this is a case (perhaps more so than any of the other three assumptions) where it transparently matters how one defends one's choices of interpretations. Why, for instance, should this semiclassical stress-energy tensor be understood as the sort of field that does not explicitly couple to curvature terms? On what grounds, in other words, does one assert that zero-point energies (granted already that they may be understood, semiclassically, as encoding the classical energy density of a quantized field in its vacuum state on Minkowski spacetime), when relocated to curved spacetimes, behave as fields that are minimally coupled to that curvature?

These are difficult questions that I will put aside, except to note that they are exactly the sort that philosophers of physics are already in the habit of asking. This is good! It means that philosophers of physics already engage in the sort of work on the basis of which we may anticipate details of future physics. Consequently, there is a natural way in which philosophers of physics can expect to contribute to the development of future physics: in establishing principled defenses for going about developing that future theory in some ways, rather than other ways, based on how that future theory is supposed to explain the successes of our current best theories so far.

## 3 The epistemology of physical interpretation

We have seen that the cosmological constant in GR and zero-point energies in QFT stand in a certain sort of global handshaking relationship, borne by interpretive moves concerning each of the two quantities respectively, entertained in each of the theories held separately. In particular, I have stressed that the identification of the handshake depends (precisely) on four premises: that the cosmological constant be interpreted on the "matter view" in GR,[9] that the cosmological constant be interpreted as "minimally coupled to matter" in the matter theories implicated within cosmological models in GR,[10] that zero-point energies characterize semiclassical "zero-point stress-energy" on Minkowski spacetime in QFT,[11] and that such a stress-energy tensor is appropriate for the application of the minimal substitution rule in QFT (i.e. it is "minimally coupled to curvature").[12] My central claim from section 2 (cf. section 2.1) is that if we believe

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[9] This is where Carlo Rovelli gets off board the historically standard version of the CCP: "It is especially wrong to talk about a mysterious 'substance' to denote dark energy.... It is like saying that the centrifugal force that pushes out from a merry-go-round is the 'effect of a mysterious substance' " (Bianchi and Rovelli 2010, p. 1).

[10] This is where George Ellis should like to get off board, given his advocacy for unimodular gravity (cf. Ellis *et al.* (2011)), wherein vacuum contributions in the stress-energy associated with one's theory of matter do not couple to spacetime curvature, but meanwhile the stipulation that total stress-energy be a locally conserved quantity gives rise to a cosmological constant of integration.

[11] If we understand this as the claim that zero-point energies are an appropriate quantity to expect to gravitate, this is evidently where William Unruh gets off board, given his recent (2017) co-authored work (clarified further in a (2018) note).

[12] Robert Wald must get off board at this point, as his axiomatic treatment of zero-point energies leads to curvature term ambiguities which, in order to break, he must assume behave in a certain way on

these particular assertions about the physics that arises in the two separate theoretical frameworks, then the cosmological constant and zero-point energies plausibly describe characterizations of the same future physics in two different limits. In other words, such beliefs behave as warrants for the bet proposed earlier, and so render the historically standard version of the CCP as a problem worth taking seriously.

One worry about this account is that such beliefs— made on the basis of interpretations in GR and QFT held separately— are not (contrary to what was assumed in section 2.1) themselves justified by all that we presently have to work with. After all, our empirical observations, as they are understood in the contexts of our best physical theories to date, are empirical observations *as interpreted by mutually conflicting theories*. If we already know that something or other from each of the relevant theories will have to give, one fears placing too much justificatory weight on those parts therein that may just as well soon be discarded.

This worry is reminiscent of a classic discussion by Belot (1998) on interpretations of electromagnetism in light of the Aharonov-Bohm effect. In that discussion, Belot (1998, p. 532) effectively begins with the following moral, or what he calls "the kernel of the common wisdom" about the Aharonov-Bohm effect: "*until the discovery of the Aharonov-Bohm effect, we misunderstood what electromagnetism was telling us about our world*" (emphasis in the original). According to Belot, what this moral says is that, regarding those aspects of our world that we can understand correctly by virtue of the theory of electromagnetism being successful in limited domains, our classically-motivated interpretation of that theory was leading us astray. In this way, it is easy to imagine our worry above as actually realized in that older episode in the history of physics. Conceivably, anticipations about the theory that came to be quantum electrodynamics, whose relevant bets depended on that misunderstanding, would have been misguided.

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Minkowski spacetime that would give rise to other values for zero-point energies in other spacetimes (cf. Wald (1994, pp. 85-97)).

The prima facie puzzle that Belot goes on to discuss is how there can be such aspects of our world, concerning which interpretative work in a known-to-be-false theory could lead us to misunderstandings. In our case, this is to ask: how can such anticipations as just imagined turn out to have been misguided? He spoils at least part of his conclusion within the introduction (p. 533):

> Thus we find that the requirement that our false theories [electromagnetism, non-relativistic quantum mechanics] mesh in an appropriate way—ontologically as well as empirically—places strong constraints upon our interpretative practice.

The key point may be put like this: there is knowledge about the world to be gotten by virtue of the fact that *these two false theories in particular* co-exist, messily, in our contemporary corpus of physical theory. Considerations of only one or the other of these false theories in isolation would necessarily miss the signposts toward that knowledge (and so in our imagined case, we were misguided insofar as we, by hypothesis, missed those signposts). On the other hand, requiring, in our interpretations of each of the false theories, that those false theories mesh well provides a way of generating some of that knowledge.

In present context, Belot's conclusion appears to constitute a challenge to any claim that we warrant bets about future physics via interpretative work in our current theories held separately. Contrary to our initial expectation, there is at least some sense in which those successes of our current physics include *more* than just what is to be interpreted in each of the two theories on its own. As such, the possibility of misunderstanding what either GR or QFT on its own is telling us about the world threatens the integrity of the justificatory chain intended to ground our bet about future physics in facts about the successes of our current best physics so far. We might turn out to be misled, that is, in virtue of our interpreting each of the theories separately and disregarding all of the ways in which our current best physics ultimately includes both.

I agree with much of Belot's original argument, and so this present challenge strikes me as serious. What is at stake here is not only the justification for my committing to such bets (such as would entail my forming beliefs about the details of the future theory as discussed), but also the status of my beliefs subsequently formed. Whether those beliefs of mine constitute my anticipating future physics depends not only on my having committed (for better or worse) to the relevant bets, but on the reasonableness of my having done so.

Nonetheless, I think it is important to recognize that Belot's view is, essentially, retrospective (and, as will become clear, this is sufficient to defuse the challenge). That is to say, his view takes, as its starting point, that the goal at hand is to understand the world, *given, in retrospect, the best theories we have so far managed to articulate*. One way this shows up is in his assessment of what, ultimately, goes into interpretive work, understood as additional structure placed on top of the formalism of a physical theory (cf. p. 551): purely metaphysical views and our beliefs about the structure of our own world. Making no stance in regards to the first of these, the second seems to me to beg the question in many cases of interest, at least in the context of frontier physics research. This is because our beliefs about the structure of our own world are, in a very real sense, precisely that which are being formed as we go about our theorizing. Our trust in any tentative guesses on this front hardly seems to be the sort of thing that would provide sturdy foundations for interpretive work in the current theories we intend to soon discard.

A tidy demonstration of this point can be found incidentally in an article by Teh (2014) on the subject of whether lower-dimensional GR can be regarded as a gauge theory, such as could (perhaps) be quantized in ways similar to other field theories familiar in contemporary physics.[13] I have in mind a small remark therein (p. 510), where Teh points out that different interpretations in GR lead to dramatically different

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[13] Though, see also Fletcher *et al.* (2018) for broader concerns about the status of physical interpretations in lower-dimensional GR.

quantizations, such that "if we mean to interpret the classical theory in light of its quantization, then we should take into account the fact that different actions will in general give rise to different quantizations." On the other hand, Teh then goes on to offer a purely classical argument for regarding two particular actions as distinct interpretations of GR (wherein one of them permits—in the language introduced above—cosmological models that exhibit spinor fields, and the other does not).

In the context of building a theory of quantum gravity in the first place, the former approach— interpreting in light of expecting to quantize down the road— does not provide any leads as to which interpretation might best capture what we know about the physical world. On the other hand, the latter approach— interpreting via classical considerations— does so transparently, in at least one sense: if one has arguments to the effect that the cosmological models of GR should include spinor fields as possibilities, then one of the two interpretations discussed by Teh ought to be picked out in favor of the other. That is, interpretive work in the purely classical regime (at least if our universe admitted one fewer dimensions) is what would ultimately pick out the theory that one feels is worth it to quantize in the first place.[14] Likewise, in the present case of interest, whether the historically standard version of the CCP is worth worrying about in the first place is exactly what is up for grabs.

For this reason, I would like to distinguish between the epistemological context of Belot's project and my own in the following way: whereas his is a "past-looking" project, concerned with an assessment of what we know about the world based on our best theories so far, mine is a "future-looking" one, concerned with an assessment of what we may anticipate about the contours of future theory based on the same.[15] I am

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[14] One might object that spinors are hardly to be understood as "purely classical", because all of the usual motivations for them are born in the wake of quantum theory. Perhaps this is so, in which case the story here is more complicated. But inasmuch as spinors are defined classically on a manifold (and relate, e.g., to familiar classical concepts like the existence of a conformally flat metric), one can nonetheless imagine— in principle— motivations from classical physics for their inclusion.

[15] Following Barrett (2008), there is another distinction that one could draw to help frame what I am doing here: between an understanding of our current theories in terms of their truthlikeness and an understanding of our current theories as snapshots in diachronic inquiry. On one particular reading of Belot (1998), wherein an interpretation in the classical theory is favored *on the basis of it being less*

quite happy, that is, to concede Belot's point that how we interpret known-to-be-false theories ought to be constrained by considerations of our beliefs about where future theory will soon take us.

On the other hand, in the practice of building toward that future theory, I contend that it is the identification of where our current theories are supposed to mesh, via their respective interpretations in isolation, that paints the contours of our frontier research. Belot writes (p. 553) that "…it seems essential to demand for every pair of overlapping theories an assurance that their empirical predictions mesh in the appropriate manner." In other words, what I care about is already assumed in his antecedent: what justifies a belief that such theories indeed overlap any one way, rather than any other?[16] And here, it seems clear that the answer has to be given in the terms specific to each of the relevant theories, which is to say in terms of the physical world *as it is interpreted by the lights of each such theory held separately*.

If, as I have just claimed, one must leverage each of our current theories separately from one another in the context of frontier physics research, what should we make of the initial worry, amplified to the status of a challenge by Belot's work, that we will be misled in virtue of doing so? Here is where, I believe, the past-looking/future-looking distinction is particularly useful. Imagine again the situation wherein there is some anticipation about quantum electrodynamics that follows from a bet made on the basis of a classically-motivated interpretation of electromagnetism. Today, (following Belot)

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*false* (in a world whose particles turn out to behave quantum mechanically), this is perhaps the more valuable distinction to make for the purposes of framing my project. Nonetheless, I prefer the distinction made in the body of this paper, because it seems to remain appropriate under a much broader reading of Belot's argument.

[16] To be clear: I do not take myself to be arguing here for a distinction that Belot would find controversial. Indeed, he as good as states the distinction himself in the middle of his paper (p. 546):

> One's interpretative beliefs can shape one's judgments as to the relevance of certain quantizations or approaches to quantization. Conversely, one must accept that one's interpretative beliefs are open to revision in light of the empirical success of the approaches to quantization which they suggest.

Belot clearly cares foremost about the revision of one's interpretive judgments in light of new beliefs about the world. But he is also quite happy to contend that interpretive beliefs shape one's judgment about how to move forward in the first place.

we would recognize that anticipation as having been misguided, precisely to the extent that it depends on what we now (by hypothesis) recognize as a misunderstanding of what electromagnetism tells us about the world.

But note that it is only *in retrospect* that the anticipation is misguided, as a consequence of the relevant bet taking for granted an interpretation that we have *since found reason* (namely, in the discovery of the Aharonov-Bohm effect) to discard. Prior to that discovery, the bet was, by hypothesis, reasonable. That is to say, *prospectively*, the imagined anticipation about quantum electrodynamics was perfectly apt, for as long of a time as we lacked the additional information provided by the discovery. This imagined example captures the fact that our original worry— that we are placing justificatory weight on something that we may soon be compelled to abandon— is merely a reflection of how it is that, in the business of anticipating future physics, we ought always to be prepared to revise our beliefs in light of new information encountered along the way. The subsequent challenge, meanwhile, is a red herring: there is nothing wrong, epistemologically speaking, with the state of *having been* misled.

As I have said already, it is not my intention in this paper to argue for or against the particular interpretive commitments that I have insisted would justify the historically standard version of the CCP. And so, likewise, it is not my intention to argue what discoveries have (or may) come about that would point to our having been misled by those commitments, in virtue of other commitments being on better footing. But such debates are ones that philosophers of physics would do well to have for the sake of both anticipating details of the future physical theory and working with physicists toward the wholesale development of it. In this context, I have suggested that the way to have these debates is by considering each of our current theories in isolation from each other for as long as possible. At the end of the day, with well-argued interpretations settled in each of the theories independently, conflicts in the "overlapping" areas *revealed in the first place by those interpretations* constitute justified bets about the future theory: that there are particular, articulable problems arising in the context of that future theory, which the future theory will, in its details, resolve.

## 4 The view from high energy physics

In contrast to what I have advocated so far, one finds a very different attitude in the high energy physics/effective field theory community, in which our current frameworks of GR and QFT are never held apart in mutual isolation. (In philosophical circles, the attitude of this community is defended most adamantly in the view put forth by Wallace (2006), but see also Crowther (2013).) For this reason, it is worth remarking briefly on that view in the context of the CCP. Indeed, as will be discussed shortly, from the perspective of this community, the severity of the historically standard version of the CCP appears inescapable.

Space will not permit me to elaborate on the possible virtues or vices of the effective field theory approach, which attempts to bring together all of contemporary physics under one interpretation. Instead, I must content myself with briefly sketching how the resulting interpretation implicitly engages with the four assumptions I described above.[17] To be sure: just as my claim above was neither to argue for nor against the interpretations that support the four assumptions needed to take seriously the historically standard CCP, my claim now is not that this community has been led astray regarding the CCP by virtue of their attitude opposite what I have advocated. Nonetheless, insofar as it is opposite, there is reason down the road to study the arguments in favor of that view, such as would justify (what I argue shortly) is their

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[17] Indeed, for readers not already invested in the effective field theory view (nor in its relationships to other perspectives in frontier physics), this section is supererogatory to the core aims of the paper. The short summary of the section is this: a highly popular view of the success of contemporary physics seems to support an interpretation of contemporary physics that implies each of the four assumptions I discuss above, from which we get the historically standard version of the CCP. Whether the historically standard version of the CCP is worth taking seriously as a consequence of this being so will depend on the arguments offered in favor of the popular view in the first place. That is to say: a justification for the effective field theoretic interpretation of contemporary physics should, by my arguments above, be the sort of thing that would justify taking seriously the historically standard version of the CCP.

running together the threads that I have endeavored to keep separate. On the view I have advocated above, just such a study is what is needed in order to justify taking the historically standard version of the CCP seriously *by virtue of its inescapability on this approach*.

One way of presenting all of the predictive power of contemporary physics is by writing down a single (classical) Lagrangian for all of the matter fields implicated in the standard model of particle physics, a prescription for how to quantize the free and interacting terms within it, a list of cutoff parameters (by which the various divergent sums that would otherwise arise in the aftermaths of those quantization prescriptions are regularized to finite values), and to include, at the end of the long expression, terms familiar from the Einstein-Hilbert action as well (i.e. the action from which one may recover Einstein's equation in the vacuum sector), including the cosmological constant. Just as when one varies the action defined by that Lagrangian with respect to the metric in the classical case, the cosmological constant retains its gravitational significance from GR in the quantum case by providing a zeroth-order approximation to the path-integral determined by that Lagrangian.

But meanwhile, zeroth-order terms in the rest of the action, found in the components of the Lagrangian that correspond to each of the standard model matter fields, also take on gravitational significance in the same way. These values make no difference to the predictions of QFT absent considerations of gravity, but are fixed via the regularization prescription alluded to above (in terms of the chosen cutoff parameters). When one introduces gravity, those fixed values provide an enormous contribution of opposite sign to the very small cosmological constant measured via the standard model of cosmology. Hence, the fundamental cosmological constant at the very end of that long Lagrangian has to nearly exactly compensate the effects of all of the other terms. The demand that the fundamental cosmological constant provides this extraordinarily large and exact compensation is generally regarded by this community as physically unreasonable (at least absent additional mechanisms to explain that compensation).

Consequently, the discrepancy between the total sum of contributions from the matter fields and the measured cosmological constant is considered in obvious need of resolution, which is just to say that this community takes the historically standard version of the CCP very seriously.

In this framing of contemporary physics, one can get the sense that the historically standard version of the CCP is inescapable. This may be so, but it is important to see how that inescapability can be traced back to what has already been assumed of the four premises about current physics that I emphasized earlier. On the GR side, the distinction between the matter view and the gravitational view (and every other view in between) is seemingly disregarded, in favor of an insistence that large and exact compensations by the fundamental cosmological constant are physically unreasonable, absent additional mechanisms. This is the naturalness problem, and is the source of its own philosophical discussion (cf. Williams (2015) in the context of the Higgs sector and references therein). But from the perspective taken in this paper, the argument against the naturalness of the cosmological constant providing large and exact compensations is, in effect, an argument that measurements of the cosmological constant cannot bear on the question of what we take to be the inertial structure of the vacuum, prior to or absent considerations about the interactions between gravity and matter.

Meanwhile, the second premise articulated above— that the cosmological constant from GR characterizes a field "minimally coupled to matter"— is stipulated outright. In taking the Einstein-Hilbert action to be the (leading) contribution to the gravitational portion of the path-integral in light of the success of GR as a large-scale theory of gravity, one has just as well regarded the fundamental cosmological constant as directly analogous to all of the other zeroth-order terms present. But this need not be the case, as is demonstrated by various dark energy proposals in the very same tradition.[18]

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[18] That dark energy proposals which toy with this assumption count as worthwhile projects highlights

On the QFT side, that stress-energies associated with each of those zeroth-order terms from the matter contributions resemble cosmological constant-like terms on Minkowski spacetime, and that these terms each minimally couple to curvature, each come for free with the decision to include curvature invariants in one's derivation of the path integral. The only reason that this practice is well-defined, however, is because one has already insisted on a shift from expressing the matter theory classically as a Lagrangian, whose action is understood as taken with respect to the volume element associated with Minkowski spacetime, to a Lagrangian density, whose action is understood as taken with respect to the volume element associated with the metric that determines those curvature invariants. This decision is, in some sense, an assumption in its own right of minimal coupling to curvature: it supposes that the way to introduce the metric as a new interaction is, from the classical perspective, as a new independent field.

## 5 Concluding remarks

I have argued that we can anticipate details of future physical theories in a principled way. As such, I have also suggested that the pursuit of such future theories in the first place, in particular regarding a theory of quantum gravity, may be approached systematically and on principled grounds. One consequence of the particular analysis I have given is that it is philosophical work in the foundations of our current theories that is well suited for uncovering the particulars of that systematic approach. Namely, work concerning interpretations in our current theories, understood in each of their own rights, can give rise to precise bets, the commitments to which entail particular beliefs about details of future physics. That is to say, it is via interpretations in our current theories that we may locate concrete problems today for which it is reasonable to bet that future theory will, in its details, resolve.

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the difficulty in assessing when purported solutions to the CCP are indeed solutions as such (without having agreed in advance about the nature of the problem to be solved). This is, more or less, my observation in (Schneider forthcoming).

I have also explicitly contrasted the suggestion here with the view developed by Belot (1998), also regarding interpretations at the cross-roads of contemporary physics. With no criticism of his past-looking view, making sense of the structure of our physical knowledge given our best, albeit strictly incompatible, theories so far, I have emphasized that there is, as well, a future-looking view, which provides grounds for developing new theories *from those very present, incompatible theories*. In the future, those new theories will hopefully come to furnish us with even higher-fidelity knowledge of the physical world than that which can be gleaned from recognizing Belot's point (i.e. that there is knowledge to be gotten from the fact that it is our present theories *in particular* that are what co-exist—however messily—in our present corpus of physical theory).

In the particular case of quantum gravity research, the future-looking view articulated here has brought attention to several assumptions about interpretations in our premier theories of gravity and matter respectively, on which the popularity of the historically standard version of the CCP seems to rely. If those assumptions are not themselves well-motivated (because interpretations that do not entail them are favored in accounting for the successes of the respective theories), so be it, and physicists ought perhaps to move on to other versions of the CCP that may arise by virtue of those other interpretations (cf. Schneider (forthcoming)), or other problems altogether (cf. Koberinski (working paper)). If, on the other hand, a physicist should find them to be well-motivated by the successes of the respective theories (perhaps for reasons related to the endorsement of a view like that discussed in section 4), then they better bet that the future theory of quantum gravity will explicitly resolve the historically standard version of the CCP, skeptics be damned.

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