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ARTICLE

Rethinking the Anthropic Principle

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Abstract

The anthropic principle (AP) states that "what we can expect to observe must be restricted by the conditions necessary for our presence as observers". But the phrase "our presence as observers" cannot be uniquely interpreted in the context of the theories within which AP is meant to be understood and applied: namely, for *effective* theories. We thus describe and defend a reformulation of AP, which we dub the *effective observation principle* (EOP). EOP describes what we can expect to observe in physical settings by considering our 'observational situation' (and not, specifically, 'observers')—understood solely in terms of effective theories.

1. Introduction

The 'anthropic principle', coined by Brandon Carter almost 50 years ago, continues to be a source of controversy. The principle in its original form was developed in cosmological settings and states that: "what we can expect to observe must be restricted by the conditions necessary for our presence as observers" (Carter, 1974, p. 291). It has been variously described as "unscientific" (Pagels, 1985, p. 37) and yet a "remarkable device" (Greenstein, 1988, p. 47). Weaker versions of the principle have been deemed "virtually trivial" (McMullin, 1993, p. 372), displaying the "trivial validity of tautologies" (Mosterín, 2004, p. 9), and "a corollary of a truism of confirmation theory" (Earman, 1987, p. 309). Stronger versions and applications are "logically risky" (McMullin 1993, p. 372) and based on "irrational mysticism" (Wilczek, 2007, p. 43). Yet the principle has proven useful, as for when Carter's original arguments precluded the need for the relatively speculative physical theories of Dirac; and more recently it has been thought to furnish a "real rationale" (Freivogel et al., 2014, p. 2) for certain cosmological outcomes (linked to the 'landscape' of string theory). [See Bostrom (2002, ch. 3) for further discussion.]

There are two (interrelated) reasons for why the anthropic principle has been maligned and misapplied. First, it is unclear, in physical settings, to what certain

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terms in the principle should *refer*. Secondly, it is unclear (even assuming that the first reason has been addressed) to what ends the principle should be *applied*. We'll outline (and then set aside) in (1), below, our methodologically conservative position on this second issue.

Misunderstandings due to the first reason have arisen because the phrase "our presence as observers" cannot be uniquely interpreted in the context of the theories within which the principle is meant to be understood and applied. These theories are our current best physical theories, which are generally thought to be *effective* theories (to be described further, below). However, what can be characterized by such theories is (some account of) our 'observational situation'. In this paper, we thus propose a reformulation of the anthropic principle, which we dub the *effective observation principle* (EOP), wherein our 'observational situation'—as understood in the context of our effective theories—is placed front and center. EOP makes clear that what is important for understanding and applying the intended content of the anthropic principle is an 'observational situation', within which we arise as contingencies. What we can "expect to observe" relates to this *observational situation* and not specifically to us as *observers*. Note that we grant that perhaps some practitioners have had in mind such a formulation of the anthropic principle all along: in this paper, we motivate, make explicit, and analyze that formulation.

This yields a question that we address as part of our analysis. Insofar as we may wish to reason using anthropic-style principles, how should we characterize our observational situation? We philosophically unpack this question and endorse a response that focuses on the context-dependent nature of our observational situation. Furthermore, we analyze cases in which the anthropic principle has putatively been successfully applied, showing that what has in fact been (successfully) applied in each case is EOP. This analysis highlights and exemplifies further features of our response to how we ought to characterize our 'observational situation' for EOP.

We will construe the concept of an effective theory in broad terms, as one that has a limited regime of applicability—a regime that is typically delineated by a range of energy (or length) scales. The standard model of particle physics can be thought of as an effective theory, as can the standard ΛCDM model of cosmology ('Λ' refers to a cosmological constant and 'CDM' refers to Cold Dark Matter). Descriptions in terms of effective theories comprise one of the more important shifts in physical theorizing in the last half a century. [See Hartmann (2001) and Williams (2015) for philosophical discussion.]

At the outset, note the following two points, related to the scope and context of our project.

(1) We are not advocating for an entirely new type of anthropic-style reasoning. Our goal is to present and defend a conceptually precise formulation of the anthropic principle. We thus set aside detailed discussion of the second reason, above, for why the anthropic principle is controversial. Indeed, we endorse a methodologically conservative position on the ends to which the principle should be applied (irrespective of how one might address the first reason, above): that is, the principle tells us to *beware of selection effects*. That is, for EOP, *we* can arise only in certain observational situations, as these situations are

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described by our current best physical theories: these situations then delimit what we can "expect to observe".

(2) When it is used to successfully predict (or postdict) the value of some observable, EOP isn't *explanatory* in the sense in which physical theories traditionally 'explain'. But, co-opting the description by Earman (1987) (of what is perhaps achieved by a particular application of a weak version of the anthropic principle), it *explains away our surprise* about the value obtained. There may be (unbeknownst to us) a more standard story to be told (such as a causal story) for why the value is obtained; where this story is somehow deemed better (or more explanatorily powerful) than the account provided by EOP. Putting this another way, EOP-style reasoning proceeds in a particular manner—wherein physical states or conditions that are 'downstream' theoretically (such as characterizations of observational situations, 10 billion years into the evolution of our universe) *explain away our surprise* about states or conditions that are 'upstream' theoretically (such as the value of a particular cosmological parameter). This mode of reasoning should not be understood as replacing a more standard direction of explanation—wherein a cosmological parameter in the context of a theory might help to explain a subsequent observational situation.[1] Our position is consistent with suspicions about the anthropic principle—expressed by a number of practitioners—arising from its seeming departure from the usual explanatory goals of science. Yet we concede it may still play a non-trivial role in our theorizing about physical settings—as we will see later in this paper. [See Koberinski et al. (2023) for a stance on the anthropic principle that is complementary to the one discussed here, and in (1).]

Here is our plan. In Sec. 2, we develop and analyze EOP—via a re-analysis of various versions of the anthropic principle—making clear its connection to our current best physical theories and to theoretical settings more generally. In Sec. 3, we apply EOP in some relevant settings—showing that in cases where the anthropic principle is thought to have been successfully applied what has in fact been (successfully) applied is EOP. Our applications involve cosmological settings in Sec. 3.1, as well as a more local physical setting in Sec. 3.2. A summary of our remarks appears in Sec. 4.

2. Formulating EOP

We begin by introducing and analyzing salient aspects of Carter's version of the anthropic principle.

2.1. Carter's Anthropic Principle

To provide explanations for certain large-number coincidences in cosmology, in 1974, Brandon Carter introduced the 'anthropic principle'. Applications of this principle

[1] Even if one is not committed to the claim that standard explanations in physics are 'causal explanations', anthropic explanations involve a direction of explanation that is opposite to that of standard explanations in physics.

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allowed Carter to avoid explanations of these coincidences that used certain "exotic theories … involving departures from normally accepted physical conservation laws" (Carter, 1974, p. 291). Carter's original statement of the principle (which we'll denote by AP) is

> AP: what we can expect to observe must be restricted by the conditions necessary for our presence as observers (Carter, 1974, p. 291).

Carter goes on to say parenthetically (on p. 291) that "our situation … is inevitably privileged to some extent". And this highlights a key aspect of its content as understood by Carter: that is, our (observational) situation must be somewhat special, to the extent that it must allow for observers. It isn't necessarily clear what is meant by an observer—and this is one source of imprecision in AP (and other versions of it), which motivates EOP. But before we press this issue (in the following subsection), we'll set the stage by briefly analyzing relevant aspects of AP.

AP can be illustrated by considering a scenario in which we will be performing an experiment (of a certain type)—where we are interested in what we can expect to observe for the outcome of that experiment. The conditions that are necessary for observers, according to AP, will delimit the possible *observed* outcomes of the experiment. Carter distinguishes two different types of anthropic principle. His 'weak anthropic principle' (WAP) is primarily about our spatiotemporal location within our universe, where the fundamental parameters and relevant initial conditions of our physical theories are held fixed. We will formulate it as follows.

> WAP: what we can expect to observe about our spatiotemporal location within our universe must be restricted by the conditions necessary for our presence as observers.

So, if the observation of interest is the distance of our planet from our sun, that distance cannot be so small so as to preclude, on account of how hot it would be, the possibility of life (insofar as we understand it). And that distance cannot be so large so as to preclude, on account of how cold it would be, the possibility of life. His 'strong anthropic principle' (SAP) is primarily about the fundamental parameters and/or initial conditions of our physical theories. We will formulate it as follows.

> SAP: what we can expect to observe about the values of fundamental parameters and/or initial conditions must be restricted by the conditions necessary for our presence as observers.

So, if the observation of interest is the value of the cosmological constant, that value cannot be so large and positive so as to preclude the possibility of life, on account of it effecting so rapid an expansion of the universe that stars cannot form. And that value cannot be so large and negative so as to preclude the possibility of life, on account of it leading to a recollapse of the universe after an initial big bang such that stars do not have time to form. In this way, the nature of the 'experiment' to which AP is being applied may be thought of as involving either WAP or SAP or perhaps even a

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combination of the two.[2] What is common between these principles is that they both warn that only a proper subset of a set of (physical) possibilities is to be expected to be observed: they both warn of selection effects. This common message will allow us to proceed by treating them in parallel.

Note also the following points about any formulation of the anthropic principle (such as AP, WAP, or SAP). (1) The principle ought to be understood in the context of a physical theory. In what follows, such theory-dependence will be assumed (and will be further analyzed later in this section). (2) The principle is typically stated in terms of an 'expectation' regarding observations (via "what we can expect to observe"). How to understand such an expectation (does it involve probabilities, for example) is not crucial for understanding the intended content of the principle and so we will set this issue aside.

It will help, in what follows, to write AP in slightly more formal terms. (We will switch between various ways of referring to the principle as is appropriate.) So, denote 'observers' by $\mathcal{O}$ and let $\{p\}$ denote a set of possible values for the outcome of an experiment of interest. Then AP may be written as

$$\mathrm{AP}_1 : \left(\mathcal{O} \text{ can expect to observe } p_0 \in \{p\}\right) \Rightarrow \left(\{p\} \text{ allows for } \mathcal{O} \text{ to arise}\right). \qquad (1)$$

Here, p_0 is a possible value for the outcome of the experiment and the implication sign is to be understood within the context of an underlying physical theory. This principle certainly sounds reasonable: if the consequent is denied (so that no outcome in $\{p\}$ allows for $\mathcal{O}$ to arise), then, given the theory, there will simply be no observers to observe an outcome in $\{p\}$.

In the more formal version [in Eq. (1)], note that the consequent contains the phrase "allows for". And one might wonder whether a stronger phrase is permissible, one that indicates that, say, each element of $\{p\}$ provides sufficient conditions for the existence of $\mathcal{O}$. But this is to ignore important theoretical content that is built-in to AP_1. Any such anthropic principle ought to be understood in the context of our current best physical theories. And in such theories, the notion of an 'observer' cannot be made precise. What one can plausibly describe are broadly interpreted conditions that would (likely) preclude observers—as we might *qualitatively* understand them. So, as described earlier, a planet that is too close to its sun or a cosmological constant that is too large and positive would each most likely preclude observers as we qualitatively understand them. Thus, we can (only) plausibly specify outcomes $\{p\}$ that would not preclude (that is, would "allow for") observers—in a way that is not sensitive to precisely how one defines an observer.

2.2. *An* effective *interpretation*

Assuming, then, that our current best physical theories cannot unambiguously describe observers, we will argue that one ought to think of the 'observer' referred to in the consequent of AP_1 in a very different way to the 'observer' in its antecedent.

[2] There have been various interpretations of WAP and SAP that differ from Carter's intended meaning: with metaphysical, teleological, or theological emphases. Such interpretations lie outside the scope of our analysis. [That Carter's SAP has been misinterpreted is widely agreed upon. See, for example: Earman (1987), Leslie (1989), and Friederich (2021).]

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Developing this argument will be the task of this subsection and will lead us to EOP, which better captures what is meaningful in AP_1.

Insofar as anthropic-style principles refer to what 'we'—as beings carrying out and analyzing the results of experiments—should expect to observe, the notion of the observer in the antecedent of AP_1 should be clear. This notion refers to 'us' understood as such beings and no further elaboration (theoretical or otherwise) is needed. (After all, this is a principle that we will be using in our theorizing about the world in which we find ourselves.)

But the notion of the observer in the consequent of AP_1 is ill-defined. Our current best physical theories are only able to account for background physical conditions out of which observers (as we qualitatively understand them) *might* arise. In such a theoretical context, observers as we qualitatively understand them are contingencies (or, more prosaically, 'accidents'). And were such observers to arise, a sensible principle specifying what these observers can expect to observe ought to point to these background physical conditions and not, specifically, to conditions that relate to some ill-defined notion of an *observer*. Thus the 'observer' referred to in the consequent of AP_1 ought not to be an observer at all, but ought to be some physical entity with respect to which observers (like us) might arise. Such a principle would be consistent with the theoretical content and scope of our physical theories.

To further motivate such a principle, it might help to consider a *misinterpretation* of AP in which "our presence as observers" is assumed to (mistakenly) refer to a very specific observer: say, Joe, a 24-year old Cantabrigian. Then AP would read:

> what we can expect to observe must be restricted by the conditions necessary for the presence of Joe, a 24-year old Cantabrigian.

This, of course, is absurd (by design). For "what we can expect to observe" in performing, say, some cosmological experiment, ought to have little to do with Joe's presence. But consider the conditions that are necessary for Joe's presence. Joe cannot arise if Joe's parents never meet. Nor can Joe arise if Joe's grandparents never meet. Indeed, there is a very long list of conditions—such that were these conditions to not obtain, Joe would not arise. Some of these conditions (such as the meeting of Joe's parents) ought not to have a hand in a sensible (theory-relative) anthropic-style principle—one that describes "what we can expect to observe". If we exclude such irrelevant conditions, what conditions remain and precisely what do they pick out?

The remaining conditions won't ostensibly refer to Joe or, more to the point, to anything like an observer. Take, for instance, the condition that *energy-density perturbations (about the mean density) on spatial slices are small, very early on in the history of the universe.* (This condition needs to hold for observers to arise but it ostensibly has very little to do with observers.) Such conditions, unlike "our presence as observers", are indeed expressible in terms of our current best physical theories and are those upon which we believe we need to focus to extract a sensible (theory-relative) anthropic-style principle. The conditions are constrained in some way (for example, by physical considerations even earlier on in the history of the universe) but they aren't constrained, in an essential manner, by considerations about 'observers'—the ones referred to in the consequent of AP_1.

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Thus we are led to a reformulation of AP. This reformulation crucially makes use of our effective physical theories (which are our current best physical theories) and includes a term that we denote by δ, which (inter alia) serves to replace the notion of an 'observer' in the consequent of AP_1. Here, δ is an entity that can be expressed within the context of an effective theory (or possibly multiple such theories): that is, there are rules that secure a correspondence between that entity and physical states and/or physical conditions of the theory. Given that δ is instantiated, observers (as we *qualitatively* understand them) may arise (as a cosmic accident). We dub this principle the *effective observation principle* (EOP).

> EOP: what we can expect to observe must be restricted by conditions that are necessary for the presence of δ.

The underlying effective theory might be an effective cosmological theory such as the ΛCDM model, coupled to the standard model of particle physics; but in more general applications of EOP, it might also involve, for example, nuclear theories or biophysical theories. As for generating δ in a given observational situation, we doubt that this can be achieved algorithmically. The issue is not that of finding a δ that *constrains* an observable, but that of finding more relevant δs that yield *suitably precise constraints*. At the end of Sec. 3.1.1, we'll exemplify considerations that may arise in selecting more relevant δs. Nonetheless, we can characterize general features of δ—as detailed in the following subsection. For now, an example of a δ relevant to a cosmological setting could be *energy-density perturbations on spatial slices, very early on in the history of the universe, which are drawn from a specific statistical distribution* (such as perturbations that satisfy a gaussian distribution). Note 'gaussian energy-density perturbations' can indeed be interpreted (unambiguously) in the context of an effective theory such as that of ΛCDM—and that out of such perturbations, *observers* as we qualitatively understand them *might* arise (as we believe they may have).[3]

It will be helpful to rewrite this principle along the lines of a more general version of Eq. (1). There we introduced $\{p\}$—a set of possible outcomes for some experiment (for a single cosmological parameter, for example). But we can think of this set more generally as a set of possible values for a vector $\vec{p}$ where each element of this vector denotes a parameter and/or a condition (such as an initial condition) required for the theory to yield predictions. Then we may consider a more formal version of EOP, denoted by EOP_δ.

$$\mathrm{EOP}_\delta : \left(\mathcal{O} \text{ can expect to observe } \vec{p}_0 \in \{\vec{p}\}\right) \Rightarrow \left(\{\vec{p}\} \text{ allows for } \delta \text{ to arise}\right). \quad (2)$$

So, although the set $\{\vec{p}\}$ encodes necessary conditions for δ, and this set can also be thought to encode, via a consideration of δ, necessary conditions for 'observers' (as we qualitatively understand them), no further refinement of the conditions for δ as they relate to observers is stipulated. That is, observers as we might qualitatively understand them may or may not arise given (conditions for) δ. Indeed, our effective theories are such that we cannot further specify what we may expect to see.

[3] Insofar as generating a suitable δ is about describing an appropriate proxy for 'observers', our reformulation of AP is consistent with the proposal by Stein (1995) (in general physical settings) for the need to 'schematize the observer'. [See also: Curiel (2019), Smeenk (2020), and Cuffaro (2023).]

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2.3. Characterizing the entity δ

So, what are the key features of δ and how ought we to understand it?

δ is expressible in terms of the theory.

The entity δ is to be understood as expressible in terms of the effective theory of interest. (This is indeed one of its virtues compared to the use of the notion of an 'observer' in the consequent of AP_1.) To understand what we mean by this, note that any effective theory has limited resources to describe the physical world. For instance: the ΛCDM model of cosmology contains no terms and/or variables that directly encode specific facts about individual observers, such as your date of birth or the brand of car you may drive. Nor can one compute such facts from the theory. Compare this with the case of some specific statistical distribution of energy-density perturbations in the early universe. The ΛCDM model does contain variables that directly encode energy-density perturbations on spatial slices consistent with a given distribution. (The variables are simply the energy density as a function of space and time; the encoding occurs together with suitable conditions on those variables, which can indeed be expressed in terms of the model.) Candidate δs for EOP have precisely this feature: there are terms and/or variables that appear in the effective theory of interest (together with suitable conditions that are expressible in terms of the theory) that directly encode δ.

δ can be multiply realized.

Assumptions and results in cosmology (and astrophysics) are often expressed in terms of aggregate properties (such as statistical properties), which can be realized by multiple combinations of parameter values and/or values of initial conditions. So, for example, a δ that corresponds to energy-density perturbations that satisfy a specific statistical distribution at a time t, such as a gaussian distribution, is consistent with various possible point-by-point specifications of conditions at a time earlier than t. Or, for an example that is non-statistical in character, a δ that corresponds to energetic degrees of freedom in spacetime that satisfy certain 'energy conditions'—where (inter alia) the energy density is non-negative—is consistent with various possible values of parameters and/or initial conditions. Thinking in terms of EOP_δ, this type of multiple realizability of δ amounts to the claim that there are multiple different vectors $\vec{p}$ that can all realize the same δ.

There are multiple candidate δs for a given theory.

If we fix our theory of interest, there are multiple different entities δ that could reasonably complete our statement of EOP. Here is a sample:

(i) a low-entropy 'initial' state;
(ii) a gaussian distribution of energy-density perturbations in the early universe;
(iii) a precondition (that is, a necessary condition) for *complexity*—as understood in the context of a specific account of complexity that we will denote by $\mathbb{C}$;
(iv) the account of complexity $\mathbb{C}$, itself.

How are we to select from amongst such candidates—taking into account that there may be relationships between them? The response we endorse is that one ought to select that entity that is as specific as possible about our observational situation (and

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is indeed expressible in terms of the theory). This is primarily for the descriptive and predictive power that one might expect from such a choice.[4]

For example, compare option (iii) (a precondition for $\mathbb{C}$) with (iv) ($\mathbb{C}$ itself). Our position favors the choice of (iv) over (iii) (assuming we have $\mathbb{C}$ in hand): option (iv) is more specific and therefore more useful as regards our observational situation. To see this, assume the following five preconditions for complexity to emerge, as described by Livio and Rees (2018), are preconditions for $\mathbb{C}$. The preconditions relate to: (a) constraints on the strength of gravity; (b) charge-parity violation (so that the resulting universe contains more matter than antimatter); (c) energy-density perturbations of the right type; (d) non-trivial chemistry (effected by a particular balance between the strong nuclear force and the electromagnetic force); (e) constraints on the expansion rate of the universe. The choice of just one of these preconditions as a candidate for δ seems underspecified, compared to $\mathbb{C}$ itself. For instance, compare the following two ways of completing EOP_δ:

$$\left(\mathcal{O} \text{ can expect to observe } \overrightarrow{p}_0 \in \{\vec{p}\}\right) \Rightarrow \left(\{\vec{p}\} \text{ allows for complexity to arise}\right); \quad (3)$$

$$\left(\mathcal{O} \text{ can expect to observe } \vec{q}_0 \in \{\vec{q}\}\right) \Rightarrow$$

$$\left(\{\vec{q}\} \text{ allows for matter} - \text{antimatter asymmetry to arise}\right). \quad (4)$$

The first of these two options seems a lot more useful—at least insofar as we might expect to observe $\vec{p}_0$ rather than $\vec{q}_0$. For $\{\vec{p}\}$ is reasonably a proper subset of $\{\vec{q}\}$, as matter-antimatter asymmetry seems consistent with possibilities that aren't as constrained as those by complexity. Even the conjunction of the five preconditions (a)–(e) seems underspecified compared to $\mathbb{C}$ itself. For the latter will include information beyond the preconditions, which could arguably be useful for understanding our observational situation.

If we don't have an account of complexity in hand, taking the conjunction of the five preconditions as a single candidate *seems* more preferable than taking δ to be just a single precondition. This selection, of the conjunction of the five preconditions over a single precondition, assumes that the relationship between the five preconditions and the δ of interest (in this case, complexity) is unambiguous. However, note that according to our current best physical theories, the relationship between such preconditions and the occurrence of complexity isn't unambiguous. There are uncertainties about what may arise when we simultaneously vary multiple parameters of our current best physical theories. That (a)–(e) are all preconditions for complexity is made plausible by considering scenarios in which we vary the values of parameters one at a time, holding the others fixed. [Livio and Rees (2018) also consider scenarios in which two parameters are varied simultaneously.] If an unambiguous relationship can't be ensured, then a δ that is less restrictive ought to be

[4] Note that from the example related to Joe, above, one might (mistakenly) get the impression that specifics about observational situations such as facts about Joe's grandparents should not matter *simpliciter*. But this is not our position. Our position is that specifics such as facts about Joe's grandparents cannot matter *unless* they can be understood in the context of the physical theories of interest. This follows from the observation that how specifically an observational situation may be characterized is determined by the descriptive capacities of relevant physical theories.

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selected. Such considerations form part of the challenge, in applying EOP, of selecting appropriate *theory-dependent* δs.

The candidates (i)–(iv) are 'nested', in that according to our current best theories of physics (perhaps supplemented by our understanding of biology), (i) can be thought of as necessary for (ii). Similarly, (ii) can be thought of as necessary for (iv). In this way, the response endorsed above—that we ought to choose the candidate for δ that is expressible in terms of the theory and is as specific as possible about our observational situation—recommends a choice amongst such options that is as far down the chain of implications as possible [namely, as far as possible to the right of the chain $(i) \Leftarrow (ii) \Leftarrow (iv) \Leftarrow \ldots$], but where one can unambiguously express the choice in terms of the theory. Thus (iv) would be preferable to (i), for it is unclear that the resulting version of EOP would appropriately constrain "what we can expect to observe": it would be too permissive regarding such expectations.

Our remarks reveal that the entity that δ represents naturally arises in cosmic history before the relevant observers (those in the antecedent of EOP_δ). It may persist during the act of observation (if δ was *complexity*, say) or it may not (if δ was, say, *a low-entropy initial cosmological state*). And the entity need not reach back to the beginning of the universe: it may emerge at some later point.

2.4. Addressing anthropocentrism in EOP

Our remarks in this section suggest a line on the question: to what extent should we consider EOP_δ to be 'anthropic'? There is a sense in which EOP_δ is clearly not about humans as observers—it is not about humans at all: humans (and indeed observers more generally) aren't unambiguously expressible in terms of our effective physical theories and so they can't be central to the nature of the inference contained in EOP_δ.

Nonetheless, it is still via considerations of the conditions that are causally relevant for humans (and observers more generally) that we would go about choosing a suitable δ. Thus we take EOP_δ to be observer-class relative (in a mild sense)—a class that contains humans but also observers who are at least somewhat qualitatively like us. If we demand that EOP can account for totally different types of observers, different to anything we've experienced, then EOP may be rendered vacuous. If δ represented, say, slight inhomogeneities in the very early universe (conditions that are presumably amenable to very different types of observers) then the power of EOP as a principle is significantly compromised. Thus, while EOP_δ is not an anthropic principle as such, it rests on an inference from the observational situation (represented by δ) in which we (as observers of a type with which we're at least qualitatively familiar) find ourselves, to necessary conditions (represented by $\{\vec{p}\}$) for such an observational situation.

Note that it has been remarked that the specific reference in AP to human observers is not needed to appropriately interpret the principle (McMullin, 1993; Wilson, 1991). Wilson (1991, p. 169) says that the "problem is how to specify the required degree of anthropocentrism, that is, how to define the class of beings whose necessary conditions are singled out". In our view the problem is instead about how to identify an entity (a δ) that usefully relates to the observational situation of interest. We thus agree with Wilson that there's a problem for anthropic-style reasoning, but that it shouldn't be framed in the way he describes. Furthermore, it should be clear

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that some features upon which anthropic-style considerations might be based—and which, according to Wilson (1991, p. 170), have been mentioned by others—such as "intelligence, morality, [and] consciousness", are irrelevant. Such features are not plausibly within reach of our physical theories and so cannot practically be part of the story.

Indeed, as we will now show, human observers and observers more generally aren't part of what is taken into consideration when AP is putatively applied in physical settings.

3. Applying EOP

Despite the lack of clarity about the anthropic principle's referents, it has putatively been successfully applied in a variety of physical settings. We'll now work through some of these applications—covering cosmological settings (in Sec. 3.1) and more 'local' settings (in Sec. 3.2). We show that in each case, what has in fact been successfully applied is an instance of EOP—with a specific, context-dependent choice for δ in hand.

3.1. Cosmological settings

We address cosmological applications via two analyses. First, in Sec. 3.1.1, we present a non-probabilistic analysis of a putative application of AP as developed by Carter (1974). Secondly, in Sec. 3.1.2, we present a probabilistic analysis of an application as developed by Earman (1987).

3.1.1. A non-probabilistic analysis

Carter (1974) provides two examples of anthropic reasoning, one based on WAP and the other on SAP, that account for two separate large-number coincidences using standard physical theories. These accounts of the two coincidences get around the need to invoke non-standard physics. The inferential pattern underlying both examples is identical. (1) Identify proxies for the presence of observers. (2) Explicate the theoretical link between those proxies and our spatiotemporal location (in the case of WAP), or on fundamental parameters of the physical theory (in the case of SAP). (3) Derive a constraint on our spatiotemporal location (in the case of WAP), or on fundamental parameters of the physical theory (in the case of SAP). If the constraints—assuming further (standard) theoretical input—allow one to account for the coincidence, then the need for non-standard physics is avoided and the application succeeds. In what follows we focus on Carter's example that relates to WAP (but a similar account can be given for the example that relates to SAP).

Carter is primarily interested in a large-number coincidence that can be straightforwardly derived from considerations of the current age of the universe, t_0. The coincidence is that (for a specific choice of units in which all physical quantities are dimensionless) the present (Hubble) expansion rate of the universe, denoted by H_0, is of the order of magnitude of the cube of the mass of the proton, m_p:

$$H_0 \sim m_p^3. \tag{5}$$

(It is the inverse of each term in this relation that is large—of the order of 10^{60}.) It is well known that for certain simplified cosmological scenarios, one may estimate H_0 by

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the inverse of the current age of the universe, $H_0 \sim t_0^{-1}$, and so if one can show that $t_0 \sim m_p^{-3}$, one secures the coincidence. For our purposes, the coincidence is less important than how it is that Carter determines t_0.

He estimates that t_0 is of the order of magnitude of the typical amount of time a star (somewhat more massive than our sun) spends on the 'main sequence': that is, undergoes hydrogen-burning to produce helium in its core (we'll denote this time by t_*). If, as Carter reasons, the current age of the universe was significantly shorter than this time ($t_0 \ll t_*$), then the heavier elements would not have formed; if the current age of the universe were significantly longer than this time ($t_0 \gg t_*$), then our galaxy would not have very many stars left in it and the stars it would contain wouldn't have sufficient energy output to sustain observers. What is serving as a proxy for the presence of observers thus generally relates to processes that arise within stars of a certain type. A rough (conceptual) lower-bound on t_0 comes from considering heavy elements as necessary for observers while a rough upper-bound on t_0 comes from considering sufficiently energetic stars as necessary for observers. Carter indeed goes on to derive that $t_* \sim m_p^{-3}$: assuming that $t_0 \sim t_*$ one obtains $t_0 \sim m_p^{-3}$, thereby securing the coincidence. (This corresponds to an age that is on the order of 10^{10} years—indeed consistent with our observations.) Note that this is a single constraint on the current age of the universe—so that the lower and upper bounds are distinguished only conceptually—yielding a single order-of-magnitude estimate. This suits Carter's purposes for he is interested in a large-number coincidence where order-of-magnitude precision is sufficient.

The key point for our analysis is that nothing like an observer has been uniquely singled out in Carter's argument. Neither of the proxies that are assumed in Carter's calculation are proxies for just an observer, let alone for (as stated in WAP) "our presence as observers"—and so it is not clear that WAP has been applied (even if one could uniquely interpret it). All sorts of physical states could be substituted for the notion of an observer and one would obtain the same estimate for t_0 via Carter's reasoning. What has been identified in this example are two entities $\delta_1 \equiv$ 'heavy elements' and $\delta_2 \equiv$ 'heavy elements and sufficiently energetic stars', which are expressible in terms of our theories of cosmology and astrophysics. Given constraints associated with these entities, observers who arise as contingencies in this 'observational situation' would indeed obtain the estimate $t_0 \sim m_p^{-3}$. In this way, a version of EOP such as the one that follows has been identified and applied:

> what we can expect to infer about the present age of the universe must be restricted by conditions, related to such a timescale, which are necessary for δ.

Can Carter's estimate be improved upon by selecting more relevant δs? Presumably, this involves accounting for more details of our observational situation. Although the presence of heavy elements and a sufficiently luminous star is important for our observational situation, so is the presence, on our planet, of certain chemical elements. Hogan (2000, p. 1151) describes how radioactive nuclei and iron help to create the Earth's magnetic field: one that is strong enough to protect the atmosphere against erosion by the solar wind—creating planetary conditions conducive to life. So, perhaps including (via new δs) conditions for sufficient amounts of these nuclei to form would help to improve Carter's estimate. However, one also needs to account for significant decreases in star-formation rates in galaxies—as

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estimated over the timescale of the present age of our solar system (Hogan, 2000, p. 1151)—which yield corresponding decreases in formation rates of salient radioactive nuclei. Some of these considerations may hinge on theoretical details that are less well established than for heavy-element production, so as to not improve Carter's estimate. We'll leave further analysis for future work. But it's plausible that such considerations can address the same question (that of the present age of the universe) by potentially employing more relevant δs (consistent with Carter's δ_1 and δ_2).

3.1.2 A probabilistic analysis

We turn now to a probabilistic analysis of a putative application of AP, developed along Bayesian lines. We'll focus on an anthropic account of the large-number coincidence in Eq. (5), as developed by Earman (1987). The core idea is that a low posterior probability for a standard cosmological theory given the coincidence is raised by virtue of (Bayesian) conditionalization on 'life'. The new posterior probability for the standard theory given the coincidence *and* life is then approximately that for the non-standard (exotic) theory. In this way, one avoids the need for the non-standard theory.

We can explicate this core idea in the following way. That Dirac's non-standard physical theory T_{D} is able to account for the large-number coincidence (which we'll denote by $\mathcal{C}$) in Eq. (5) may be expressed probabilistically as $P(\mathcal{C}|T_{\mathrm{D}}) \sim 1$. That the standard big-bang model of cosmology T_{B} cannot so account for the coincidence may be expressed as $P(\mathcal{C}|T_{\mathrm{B}}) \ll 1$. Thus, using Bayes' theorem, we have [assuming equal priors, $P(T_{\mathrm{D}}) = P(T_{\mathrm{B}})$] that

$$\frac{P(T_{\mathrm{D}}|\mathcal{C})}{P(T_{\mathrm{B}}|\mathcal{C})} = \frac{P(\mathcal{C}|T_{\mathrm{D}})}{P(\mathcal{C}|T_{\mathrm{B}})} \gg 1, \tag{6}$$

so that Dirac's theory is overwhelmingly favored. If, however, we conditionalize (as Earman does) on the proposition $\mathcal{L} \equiv$ 'Life such as ours now exists', then this conclusion is modified. So, instead of using just the coincidence $\mathcal{C}$ as our total evidence, we now include $\mathcal{L}$—so that our total evidence is $\mathcal{C} \wedge \mathcal{L}$. In which case, using Bayes' theorem [again assuming equal priors, $P(T_{\mathrm{D}}) = P(T_{\mathrm{B}})$],

$$\frac{P(T_{\mathrm{D}}|\mathcal{C}\wedge\mathcal{L})}{P(T_{\mathrm{B}}|\mathcal{C}\wedge\mathcal{L})} = \frac{P(\mathcal{C}\wedge\mathcal{L}|T_{\mathrm{D}})}{P(\mathcal{C}\wedge\mathcal{L}|T_{\mathrm{B}})} = \frac{P(\mathcal{C}|\mathcal{L}\wedge T_{\mathrm{D}})}{P(\mathcal{C}|\mathcal{L}\wedge T_{\mathrm{B}})}\frac{P(\mathcal{L}|T_{\mathrm{D}})}{P(\mathcal{L}|T_{\mathrm{B}})}. \tag{7}$$

If we assume that the probability of life isn't very different for the two theories, $P(\mathcal{L}|T_{\mathrm{D}}) \simeq P(\mathcal{L}|T_{\mathrm{B}})$, then the ratio of the posterior distributions [on the far left-hand side of Eq. (7)]—also known as the posterior odds of T_{D}—depends just on the ratio $P(\mathcal{C}|\mathcal{L}\wedge T_{\mathrm{D}})/P(\mathcal{C}|\mathcal{L}\wedge T_{\mathrm{B}})$. Given Carter's argument (related to WAP) in the previous subsection, it is reasonable to assume that the two probabilities $P(\mathcal{C}|\mathcal{L}\wedge T_{\mathrm{D}})$ and $P(\mathcal{C}|\mathcal{L}\wedge T_{\mathrm{B}})$ are roughly the same (and each is also high) so that their ratio is roughly unity. This means that the posterior odds of T_{D} is roughly unity. Dirac's theory is thus no longer favored and we have evaded the need for the non-standard physical theory.

But how well-defined is this line of reasoning? There are two key considerations. First, note that the key distributions that influence the conclusion (that we need not invoke non-standard physical theories), $P(\mathcal{C}|\mathcal{L}\wedge T)$ and $P(\mathcal{L}|T)$ (for particular theories T), are least subjective when the proposition $\mathcal{L}$ is expressible in terms of the theory T. In which case it is appropriate to think of this proposition as a function

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(of sorts) of the theory $\mathcal{L}(T)$. When $\mathcal{L}$ cannot be described in this way, an important question arises as to how one might actually compute such probabilities. That is, if $\mathcal{L}$ is not expressible in terms of the theory, what does it mean to assign a sharp number to the quantity $P(\mathcal{L}|T)$ (for example)? Secondly, the comparison of such probabilities that is implicit in Eq. (7), is arguably well-defined if and only if the notion of 'life' is basically the same for each theory. That is, we require that either $\mathcal{L}(T_\mathrm{D})$ should *mean the same thing* as $\mathcal{L}(T_\mathrm{B})$ or, at the very least, any differences in how we interpret $\mathcal{L}(T_\mathrm{D})$ and $\mathcal{L}(T_\mathrm{B})$ should not be relevant. If there is a relevant difference, then it is not clear that it makes sense to compare a number such as $P(\mathcal{L}(T_\mathrm{D})|T_\mathrm{D})$ with $P(\mathcal{L}(T_\mathrm{B})|T_\mathrm{B})$ (a comparison indeed employed above).

Arguably, reasonable interpretations of $\mathcal{L}$ for each theory will be sufficiently similar. Life, as it is understood in the context of a theory in which the gravitational constant G scales as t^{-1} (as for Dirac's theory T_D) is not obviously different to life understood in the context of a theory in which G is a constant (as for the standard big-bang model, T_B). Thus, the second consideration above does not present an issue. The problem, however, is with the first consideration. For neither theory is it the case that the notion of life is expressible purely in terms of the cosmological theory. The dependence of the concept of life on each theory is thus unclear and this threatens how objective and thus well-defined may be probabilities such as $P(\mathcal{L}|T)$.

In a probabilistic setting, there are two ways forward. (1) Interpret probabilities such as $P(\mathcal{L}|T)$ subjectively—perhaps as credences of agents who are assessing a cosmological theory T. (2) Make the connection between such a theory and the notion of life more manifest. Assuming we are interested in objective comparisons, and thus focusing on (2), one would need to append theories to the cosmological theory T so as to secure a characterization of life that accords with how it is (at least) qualitatively understood. For example, one may need to append theories of astrophysics, astrobiology, and biology. In which case the resulting characterization of life may more closely resemble our qualitative understanding, but only if we can 'match' these other theories in regimes where they may overlap. Such matching presents a hurdle because theories that relate more closely to life are relatively underdeveloped.

To summarize the above discussion: issues faced by probabilistic applications of AP are very closely related to concerns raised in our non-probabilistic analysis. AP makes reference to an entity (as in the consequent of AP_1—namely, 'observers' or 'life') that cannot be uniquely interpreted in the context of the theories within which AP is meant to be understood and applied. In probabilistic cases, this ambiguity in what could be meant by 'observers' undermines the objectivity and thus the well-definedness of probabilities that are assigned—thus undermining arguments that rest on comparisons of such probabilities.

These worries are obviated if we reconceptualize the reasoning involved in terms of EOP. Then we are compelled to restrict attention to entities (namely, δs) that are expressible in terms of the theory, T. Indeed, the recommendation (as discussed in Sec. 2.3) is to choose that candidate that is expressible in terms of the theory *and* is also as specific as possible about our observational situation. This choice renders the underlying reasoning well-defined—whether it be non-probabilistic or probabilistic. Of course, in probabilistic situations, the issue remains as to how we ought to compute something like $P(\delta|T)$ for some cosmological theory T—but, crucially, the question itself is well-defined. And, just as we discussed in the non-probabilistic situation,

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when estimates are made for probabilities of life—putatively based on AP (such as in Earman's analysis)—what is actually being employed is some proxy for life (or observers). What has been identified (along with theoretical input related to cosmological modeling) is an entity (and conditions for such an entity) such that were it to obtain, observers might arise as an accident, but where that entity doesn't refer to observers in an essential way. That is, a version of EOP has been identified and applied.

Note that we are not suggesting that EOP evades the hurdle (faced by AP), wherein the matching of theories is required to more closely connect δ—understood at the level of a cosmological theory—to the concept of an 'observer'. For such a concept indeed seems better 'schematized' by the inclusion of (say) biological and chemical considerations. But this hurdle is made *manifest* in applying EOP—as a consequence of our general recommendation for selecting δ. This recommendation emphasizes two tasks: that of (i) unambiguously expressing δ in terms of the theory; and (ii) selecting δ such that it is as specific as possible about our observational situation. Accomplishing (ii) more closely connects δ to 'observers'—so that EOP can presumably be more *usefully applied*, via considerations of a richer account of our observational situation.

In this way, we believe EOP provides conceptual clarity—over and above that provided by AP—that helps to highlight a further benefit of our reformulation of AP. That is, EOP describes explicit, specific (though non-algorithmic) tasks [(i) and (ii)] that may help to facilitate appropriate applications of anthropic-style reasoning in scientific practice. In particular, such tasks may help to yield better estimates for "what we can expect to observe", whilst revealing (significant) limits to the precision of such estimates. (Towards the end of Secs. 3.1.1 and 3.2, we provide some thoughts on this front; we leave a more thorough analysis for future work.) Furthermore, considerations of EOP can make *failures* of anthropic-style reasoning more conceptually transparent—as for when one of the two tasks, (i) and/or (ii), is not adequately completed. In which case, for instance, uninformative constraints (such as very broad constraints) on observables may arise.

3.2 Beyond cosmology

Thus far we have analyzed EOP and its precursors, AP, WAP, and SAP, in expressly cosmological (and astrophysical) contexts. This is natural given that the first papers to use anthropic-style reasoning were focused on cosmological considerations (Dicke, 1961; Carter, 1974). However, it has since become clear that anthropic-style reasoning can be applied in very different contexts, such as in particle physics and astrobiology.[5] We shall now apply EOP to an example that goes 'beyond cosmology'. In particular, we will see how an example—presented by Barrow and Tipler (1986, Sec. 5.5) as an application of WAP to nuclear physics—is best reconstructed as an application of EOP, indeed in a local physical setting.

Prior to developing the example, note that EOP can be applied in a more 'local' sense whenever observers are part of a subsystem that is effectively isolated from its 'environment'. What "we can expect to observe" corresponds to observables in that subsystem. The 'effective isolation' should be understood, theoretically, as a

[5] See Barrow and Tipler (1986) for an accessible, comprehensive survey; in particular chapters 5 and 8.

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'decoupling' between the system and its environment: so that one can capture any effects the environment may have on the subsystem in terms of degrees of freedom of the subsystem. Regarding the role of theory in such a setting, the particular variables or parameters we are looking to constrain when we apply EOP largely determine the relevant theory. If we are interested in a cosmological parameter, then T will correspond to a cosmological theory, possibly coupled to an astrophysical theory. But any theories further 'downstream'—such as astrobiological or biological theories will be irrelevant—for there is an effective decoupling of such theories from cosmological theories (and possibly also from classes of astrophysical theories). But if the parameter or observation of interest is more 'local' in nature—such as one that relates to a terrestrial phenomenon, then the relevant theory will be more geophysical in character; in which case cosmological theories (and perhaps astrophysical theories) will be irrelevant. In this way, the observation by Carter (2006, p. 2), that AP is "not intrinsically cosmological, but just as relevant on small local scales as at a global level" applies to EOP as well.

Turning to the example, Barrow and Tipler (1986, Sec. 5.5) ultimately derive a constraint on two parameters of physics, employing anthropic-style reasoning (putatively applying WAP). These two parameters are: the fine-structure constant of electromagnetism, $\alpha_0 \approx 1/137$, which mediates the strength of the electromagnetic force between charged particles; and an analogous constant for the strong nuclear force, $\alpha_{s,0} \approx 1/10$, which mediates the strength of the strong force between nucleons (protons and neutrons). (In this subsection, a subscript '0' will denote a value as measured in our universe.) There are two steps to this derivation. We'll only touch upon the first (for it is standard) and will focus on the second (for this is where 'anthropic' considerations enter).

Thus, first, Barrow and Tipler (1986) rehearse a standard calculation wherein the nucleus, with a total of Z protons and N neutrons (and thus $A = N + Z$ nucleons), is described via a simplified phenomenological model (known as the 'liquid drop model'). Their calculation yields the result that a nucleus is stable (that is, it won't undergo fission) if the *fissionability parameter* Z^2/A satisfies

$$\frac{Z^2}{A} < \frac{2a_s}{a_c} \approx 49. \tag{8}$$

Here, a_s and a_c are constants associated with the model, proportional to α_s^2 and α respectively. The approximation in Eq. (8) uses measured values: $a_{s,0} \approx 17.23$ and $a_{c,0} \approx 0.7$ [as in Segrè (1977)]. Carbon-12, for instance, with $Z = 6$ protons and $N = 6$ neutrons (so that $A = 12$) has a fissionability parameter of $Z^2/A = 3$ and so is expected, according to this model, to be stable.

In the second step, where considerations putatively related to observers enter, Barrow and Tipler consider a scenario in which α and α_s can deviate from their measured values (in our universe). Such considerations yield an approximate upper bound for the fissionability parameter, wherein a nucleus is stable if[6]

[6] To derive Eq. (9), assume $a_c \propto \alpha$ and $a_s \propto \alpha_s^2$ so that one may consider $a_c \equiv a_{c,0}\,\alpha/\alpha_0$ and $a_s \equiv a_{s,0}(\alpha_s/\alpha_{s,0})^2$. Substituting these definitions into Eq. (8) yields Eq. (9).

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$$\frac{Z^2}{A} \lesssim 49 \left(\frac{\alpha_s}{\alpha_{s,0}} \right)^2 \frac{\alpha_0}{\alpha}. \tag{9}$$

Interestingly, one can turn this relationship around and think of it as providing constraints on possible values of α and α_s, assuming that nuclei with a given value of the fissionability parameter are stable. (In this case, A and Z effectively correspond to two physical degrees of freedom.) Equation (9) immediately yields

$$\frac{\alpha}{\alpha_0} \lesssim \frac{49A}{Z^2} \left(\frac{\alpha_s}{\alpha_{s,0}} \right)^2. \tag{10}$$

If we now assume that Carbon-12, *which is presumably necessary for life*, is stable, we obtain (where, recall, $Z^2/A = 3$ for Carbon-12)

$$\frac{\alpha}{\alpha_0} \lesssim 16 \left(\frac{\alpha_s}{\alpha_{s,0}} \right)^2. \tag{11}$$

So goes the argument, according to Barrow and Tipler (1986), which putatively applies WAP and leads to a constraint [in Eq. (11)] on possible values of α and α_s. But note that this constraint has not been derived via a consideration of observers. Rather, the application identifies an entity—here, stable Carbon-12 atoms (which might at best be thought of as a proxy for observers)—such that were this entity to arise, "we" might arise. What has in fact been applied, therefore, in obtaining Eq. (11), is an instance of EOP—where δ corresponds to *stable carbon atoms*. This instance of EOP might read as follows:

> what we can expect to observe about the relationship between values of α and α_s, must be restricted by conditions on α and α_s that are necessary for stable carbon atoms.

The theory with respect to which this principle ought to be understood is, of course, the liquid-drop model. What it means for δ (as *stable carbon atoms*) to be 'expressible in terms of the theory', is that Carbon-12 atoms can be represented in the model by specifying values for numbers of nucleons (A) and protons (Z); and where the balance of the forces that appear in the model secures stability.

Now, the chances that we might arise presumably increase if one assumes conditions for an observational situation that better accords with our own. One might achieve this by demanding the stability of nuclei with larger fissionability parameters (smaller values of the factor $49A/Z^2$)—which generally involves nuclei with more protons than Carbon-12. Indeed, one can straightforwardly show [from Eq. (10)] that sequentially demanding the stability of nuclei such as Nitrogen-14, Oxygen-16, and Sulfur-32—nuclei that are also generally thought to be important for life—has the effect of driving the least upper bound on the ratio α/α_s^2 closer to the observed ratio $\alpha_0/\alpha_{s,0}^2$. This suggests that it is possible to obtain better estimates for "what we can expect to observe" by including more detailed theoretical considerations (albeit with presumably diminishing utility).

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4. Conclusion

We have described and defended a reformulation of the anthropic principle, which we have dubbed the *effective observation principle* (EOP) (see Sec. 2.2). Unlike Carter's versions of the anthropic principle—AP, WAP, and SAP (described in Sec. 2.1)—EOP is a selection principle that (i) makes explicit the focus of such principles on observational situations (but not on 'observers') and (ii) does so relative to an explicitly acknowledged 'effective' theoretical context.

The observational situation is characterized by an entity, denoted by δ, that is instantiated by a set of conditions that are theory-dependent. This focus on an observational situation is important, for the phrase "our presence as observers", included in AP, WAP, and SAP alike, cannot be unambiguously understood in the context of our current best physical theories. Such theories are generally thought to be *effective* (hence the 'E' in 'EOP')—that is, theories with a limited range of applicability, typically delineated by a range of energy (or length) scales. EOP is consistent with our understanding of the scope of these theories. Furthermore, EOP can be broadly applied. For, as we explored in Sec. 3, the traditional pattern of anthropic-style reasoning as it has been employed in canonical cosmological settings, as well as in more 'local' settings, is only precisely described as an application of EOP.

Finally, while we can characterize general features of δ (see Sec. 2.3), we doubt that there is an algorithm that generates an 'optimal' δ in a given observational situation. Nonetheless, our applications of EOP (in Sec. 3) provide examples of how to isolate useful δs. We leave it to future work as to whether there are heuristics for determining 'more relevant' δs in general observational situations.

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