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A critical analysis of cosmological typicality and the anthropic principle

(Análisis crítico de la tipicidad cosmológica y del principio antrópico)

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Keywords

Anthropic Principle
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Reference class

ABSTRACT: Stephen Weinberg's prediction of the cosmological constant (Λ) represented an influential application of the Anthropic Principle in cosmology. His approach relied on key assumptions including: a multiverse framework, a proportionality between the number of observers and the formation of galaxies, uniform priors for the vacuum energy density within the anthropic range, and the assumption of typicality. While Weinberg's model successfully constrained Λ within observationally reasonable limits, its methodological foundations may raise some concerns. This paper examines three central components of Weinberg's reasoning: the choice of probability measure, the conditionalization scheme linking observer abundance to galaxy formation, and the assumption of typicality. Particular attention is given to the role of self-locating uncertainty in translating observer counts into predictive weight. While Weinberg's framework is internally coherent once its assumptions are granted, I argue that its predictive force depends on substantive commitments concerning prior distributions and the resolution of indexical uncertainty. Recognizing the conditional structure of these assumptions clarifies the epistemic status of anthropic predictions and highlights the need for greater methodological precision in future cosmological applications of observer-based probability.

Palabras clave

Principio Antrópico
Principio de Mediocridad
Tipicidad
Clase de referencia

RESUMEN: La predicción de la constante cosmológica (Λ) realizada por Stephen Weinberg constituyó una influyente aplicación del principio antrópico en cosmología. Su enfoque se basaba en varios supuestos clave, entre ellos: un marco de multiverso, una proporcionalidad entre el número de observadores y la formación de galaxias, «priors» uniformes para la densidad de energía del vacío dentro del rango antrópico, y la suposición de tipicidad. Aunque el modelo de Weinberg logró restringir Λ dentro de límites observacionalmente razonables, sus fundamentos metodológicos pueden suscitar algunas dudas. Este artículo examina tres componentes centrales del razonamiento de Weinberg: la elección de la medida de probabilidad, el esquema de condicionalización que vincula la abundancia de observadores con la formación de galaxias, y la suposición de tipicidad. Se presta especial atención al papel de la incertidumbre auto-localizadora en la traducción del número de observadores en peso predictivo. Aunque el marco de Weinberg es internamente coherente una vez que se conceden sus supuestos, sostengo que su poder predictivo depende de compromisos sustantivos relativos a las distribuciones a priori y a la resolución de la incertidumbre indexical. Reconocer la estructura condicional de estos supuestos permite aclarar el estatus epistémico de las predicciones antrópicas y pone de relieve la necesidad de una mayor precisión metodológica en futuras aplicaciones cosmológicas de probabilidades basadas en observadores.

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Gako-hitzak

Printzipio antropikoa
Mediokritatearen printzipioa
Tipikotasuna
Erreferentzia-klasea

LABURPENA: Stephen Weinberg-ek konstante kosmologikoa (Λ) aurresan izana printzipio antropikoaren aplikazio garrantzitsu bat izan zen kosmologiaren arloan. Haren ikuspegia funtsezko zenbait suposiziotan oinarritzen zen, besteak beste hauetan: esparru multibertsal bat, behatzaile kopuruaren eta galaxien eraketaren arteko proportzionaltasuna, hutsaren energia-dentsitaterako «prior» uniformeak tarte antropikoaren barruan, eta tipikotasunaren suposizioa. Weinberg-en ereduak egokiro lortu zuen Λ zedarritzea behaketan arrazoizkoak diren mugen barruan, baina eredu horren oinarri metodologikoek zenbait zalantza eragin ditzakete. Artikulu honek Weinberg-en arrazoibidearen hiru osagai nagusi aztertzen ditu: probabilitatea zenbatesteko egindako aukeraketa, behatzaileen ugaritasuna galaxien eraketarekin lotzen duen baldintzapen-eskema eta tipikotasunaren suposizioa. Arreta berezia jartzen zaio autolokalizazioaren ziurgabetasunak behatzaileen kopurua aurresan-pisu bihurtzean betetzen duen rolari. Nahiz eta Weinberg-en markoak, haren suposizioak ontzat hartuz gero, barne-koherentzia osoa duen, argudiatzen dut haren aurresan-ahalmena *a priori*ko banaketei eta ziurgabetasun indexikalaren ebazpenari buruzko funtsezko konpromisoen mende dagoela. Behin suposizio horiek baldintzazko egitura dutela aitortutakoan, argi gelditzen da aurresan antropikoek estatus epistemikoa dutela, eta agerian uzten da zehaztasun metodologiko handiagoa behar dela behatzaileetan oinarritutako probabilitatea etorkizuneko aplikazio kosmologikoetan erabiltzeko.

1. Introduction

The philosophy of cosmology explores fundamental questions about the universe, such as its origin, evolution, but also the implications of our existence as observers. And every time a cosmological theory is developed, a major challenge is faced: the scarcity of direct observational data. This forces reliance on theoretical principles and probabilistic reasoning to establish a conceptual framework within which well-founded hypotheses can be formulated.

One common strategy to address this type of reasoning is the application of the Anthropic Principle (AP), a topic of extensive discourse (Barrow & Tipler, 1986; Bostrom, 2002a; Carter, 1974). This principle attempts to explain the universe we observe by examining the prerequisites for our existence and how they influence our interpretations. The AP is a self-referential constraint that acknowledges the inherent bias introduced by our mere existence, as it determines observable physical laws and cosmological parameters. Accordingly, our knowledge of the universe is inevitably filtered through the lens of our own existence because every alternative scenario that do not permit observers like us remains unobservable.

Stephen Weinberg (1987, 1989, 1996, 2000) proposed an influential application of the AP to address the long-standing cosmological constant (Λ) problem, which was the following. Although the exact value of Λ was unknown in the mid-1980s, a discrepancy with the calculated magnitude had been partially identified and an explanation was demanded. Weinberg theorized that Λ had to be constrained by the conditions necessary for the existence of galaxies — thus the potential to host observers. Since a sufficiently large Λ would prevent the formation of gravitationally bound structures, Weinberg argued that anthropic selection effects could provide a natural explanation for the observation of a relatively small —but nonzero— cosmological constant.

The problem was indeed severe. Once Λ was measured, it revealed a dramatic discrepancy of approximately 120 orders of magnitude between the predicted value by the standard quantum field theory and the observed values (10^{112} erg/cm^3 vs 10^{-8} erg/cm^3) (Carroll, 2004). However, in contrast to this failure of conventional physics, Weinberg's anthropic calculations had successfully predicted a value of Λ in reasonable agreement with observations. This remarkable achievement demonstrated the potential of anthropic reasoning to constrain fundamental physical parameters, even in the absence of a complete theoretical mechanism to determine Λ from first principles (Polchinski, 2005).

Actually, Weinberg did not aim to uncover the mechanism that determined the cosmological constant, nor its probability within the distribution of possible values. Instead, he demonstrated the likelihood that a given value would be observable, using the formation of galaxies as the only major restriction to establish an upper limit to the universe's vacuum energy, from which Λ was derived. He also assumed the following assumptions:

— The existence of a multiverse (H1): different regions of the multiverse display particular values of Λ, and our observable universe is just one realization of these possibilities.

— Observer dependence on galaxy formation (H2): the number of observers is proportional to the number of galaxies, because gravitational condensation of matter is the primary factor in the emergence of life.

— Uniform priors on the anthropic range (H3): a uniform distribution of the values of Λ characterizes the narrow anthropic range where life-permitting conditions hold.

— The assumption of typicality (H4): we should consider ourselves typical among all possible observers in the multiverse.

Weinberg's assumptions were elegant in their simplicity but relied on methodological choices that called into question certain aspects of their validity. As Azhar (2014, 2015, 2016, 2017) has pointed out, three major challenges emerge when attempting to formalize any cosmological theory: the measurement problem, the framework for conditionalization, and the typicality assumption. And each of Azhar's challenges offers a basis to examine Weinberg's assumptions and evaluate their coherence and justification.

The first issue concerns the definition of a probability measure to count universes, a crucial step in justifying why certain Λ values should be deemed more likely than others. In general, resolving the measurement problem in cosmology is far from trivial because in a vast and potentially infinite universe, where every possible observable event could occur countless times, the calculation of a certain proportion may be impossible if infinities appear in the quotients. Even though different tactics have been described to overcome this issue (Freivogel, 2011; Page, 2008; Vilenkin & Yamada, 2020), choosing the right measurement is generally a controversial aspect. Both the definition of the sample space and the calculation of the probabilities of the different elements that compose it are difficult.

In an effort to resolve the measurement problem for Λ, Weinberg assumed that the distribution of values across the multiverse followed a well-defined probability distribution, at least within the observable range —the only region of interest. Assumptions H1 & H3 enabled him to make a statistical prediction about what observers should expect to find. But Weinberg's choice of a uniform prior over the anthropic range of Λ seemed to introduce an additional layer of arbitrariness. The assumption that all life-permitting values were equally probable may lack a clear physical or epistemic justification, and alternative priors could lead to quite different conclusions. This raises the first important question: to what extent did Weinberg's result depend on an unjustified assumption about prior probabilities, rather than a genuine anthropic necessity?

Once one accepts that a probability measure can be meaningfully defined, the next challenge deals with how probabilities should be updated in light of the observer selection effects. Weinberg's H2 assumption relied on conditioning the probability distribution of Λ on the fact that we observe a life-permitting universe. Thus, our prior knowledge had to be refined by including only those universes capable of supporting observers, and Weinberg chose the formation of galaxies as the way to account for it. In essence, the number of observers in any universe was assumed to scale with the quantity of matter that condensed into galaxies, which was itself determined by mass conservation and Friedman equations. Then, by imposing constraints on the early universe density perturbations and the vacuum energy density, the same equations allowed him to derive an upper threshold for the cosmological constant. However, this conditionalization step was far from trivial. The methodological question of whether observer selection effects genuinely constrain physical parameters, like Λ, remains contentious, as different prior probability distributions could lead to vastly different posteriors. If the anthropic range of Λ was itself an artifact due to how the priors were defined, then the problem of conditionalization may reduce to an issue of priors dependence rather than an independent validation of the argument. Being so, did Weinberg's approach truly reveal why our universe has the observed value of Λ, or did it simply restate an assumption in a way that appeared explanatory?

A final and more subtle difficulty emerges in how Weinberg defined a typical observer in the multiverse. On the one hand, assumption H2 established that the number of observers was proportional to the number of galaxies, implying that universes with more galaxies should have greater weight. Consequently, this assumption played a crucial role in establishing the expectation value of Λ, as it dictated how universes had to be counted in anthropic reasoning. However, his approach also presupposed that galaxy formation was an adequate proxy for intelligent life, an assumption that may not hold. If the likelihood of the emergence of observers varied significantly by other factors, then weighing universes uniquely by their galaxy count would introduce a potentially misleading bias. Moreover, if the weight of each universe was exclusively determined by the number of observers it hosted —without considering any additional property that governed the probability of the universe appearing in the first place— then the outcome becomes trivial: we should always expect to find ourselves in the universe that contains the most observers. Under this assumption, anthropic selection simply directed us to the most populated universe, where it was assumed we were typical, without providing any deeper insight into the fundamental distribution of Λ. And this raises another concern: did such a distribution even impose a meaningful threshold for applying anthropic reasoning?

A deeper issue also arises from assumption H4, concerning our declared typicality. Weinberg implicitly assumed the existence of a well-defined reference class of observers (sufficiently similar to us), but this was nontrivial because the probability distribution of universes was itself weighted by the number of observers they contained. So, if the number of observers defined the distribution, then the very act of constructing a probability measure depended on how the reference class was chosen in the first place. This may introduce a self-referential element: we indeed may assume that we are typical among a group of observers, but the definition of that group in itself shapes the probability distribution that we seek to derive. What would happen to the statistical weighting if the reference class was broader or narrower than expected? Did Weinberg's assumption subtly impose constraints on the distribution of observer that were not physically justified? If the reference class was indeterminate, then the statistical reasoning used to derive Λ may not be as robust as it initially appeared.

The goal of this paper is to critically examine the assumptions of a case study where the Anthropic Principle was successfully applied to develop a cosmological model. Weinberg's prediction of the cosmological constant will be analysed through the lens of Azhar's framework, with particular attention to whether assumptions such as typicality and observer selection introduce elements of arbitrariness. Section 2.1 will examine the measurement problem, focusing on the assumption of equiprobability within the anthropic observational range. Section 2.2 will address the conditionalization schema, which relies on the proportionality between the number of observers and the number of galaxies. Section 2.3 will investigate the implications of considering humanity as typical. After this analysis, Section 3 will propose an alternative approach that may provide a new foundation for future studies.

2. *Critical examination of the framework*

Weinberg's approach to predicting the cosmological constant through anthropic reasoning represented a very influential inference under uncertainty in cosmology studies. His framework, grounded in the idea that our observed Λ is neither arbitrary nor unnatural but constrained by observer selection effects, provided a compelling alternative to fine-tuning arguments. However, as with any theoretical model incorporating anthropic principles, its success depended not only on its numerical predictions but also on the soundness of its methodological assumptions. Notably, Bousso and collaborators (2007) later demonstrated, using a method that relied on less speculative assumptions, that Weinberg's prediction fell short three orders of magnitude. This deviation suggests that reconsidering the original hypotheses may provide a more accurate framework.

A careful examination reveals that Weinberg's approach, while pragmatic and successful, relied on simplifying assumptions that may have introduced an arbitrariness that affected its epistemic robustness. The upcoming sections will analyse Weinberg's reasoning through the lens of the three major conceptual challenges identified by Azhar: the problems of measurement, conditionalization, and typicality. These challenges do not merely expose technical difficulties but rather fundamental issues regarding how probabilities were assigned, updated, and interpreted in a multiverse scenario.

They call into question whether Weinberg's predictions were the result of a genuine anthropic necessity or if they came closer to an artifact of model-dependent choices.

2.1. Confronting H1 & H3: issues on the measurement

By employing a probability updating scheme grounded in the anthropic observational bias, Weinberg achieved a remarkable approximation. The anthropic constraint offered an explanation on the scale of 20σ if the whole sample space of the vacuum energy density (*pv*)—from which Λ could be derived—was considered. Indeed, his remarkable success clarified what was 'observable' versus what was 'possible'. Yet, if the values of *pv* were uniquely evaluated within the anthropic observable range, then Weinberg's accuracy remained in a much lower percentile. The success of his prediction is moderate when it is referred only to what we could actually measure.

The Anthropic Principle was effectively used as a starting point to impose certain limits on the possible values of *pv*. Nonetheless, once the principle was embraced, the distribution of the remaining values was considered equiprobable, thus the idea of further observer selection effects was implicitly abandoned. With regards to this possibility, it is important to acknowledge that models grounded in theoretical frameworks can only be accurately constructed in the absence of inherent biases (think of the Malmquist bias in astronomy).[1] As it has been affirmed, cosmological theories can be highly speculative, and they may risk overlooking unnoticed biases (Ellis, 2007) and this may be one example of it.

Before addressing the issue of assuming an equiprobable distribution of *pv*, it is important to note that Weinberg incorporated an additional stipulation: the range of anthropically allowed values of the vacuum energy density was so narrow, that all other fundamental constants of the universes could be considered as fixed. However, as demonstrated elsewhere (Tegmark *et al.*, 2006), severe variations in these constants can result in universes that appear identical to our own despite having different values of *pv*. As it was shown, assuming uniform priors for *pv* in predictive models to obtain universes similar to ours did not necessarily correspond to uniform priors for derived expressions of *pv* with other fundamental constants.[2] Also, universes like ours could be largely obtained with lower values of *pv* if other fundamental parameters were allowed to vary (even by several orders of magnitude), so a simpler model with fixed parameters and uniform priors may tend to overestimate *pv* towards higher values. But even though Weinberg's model may not fully capture the complexity of the universe's dynamics, particularly given the challenge of incorporating other fundamental constants whose distributions are even less understood than that of *pv*, it is worth acknowledging his audacity of developing a simplified model that brought the theoretical prediction closer to observation.

Weinberg co-formulated the probability distribution that a random observer in any subuniverse could measure values of *pv* in a given range (Martel *et al.*, 1998, p. 4, eq. 1). According to Bayesian statistics, $P_{obs}(pv)$ corresponded to the mean number of observers in universes with a specific *pv* divided by the total observations made in the full set of observable universes, that is,

$$P_{obs}(\mathrm{pv}) = \frac{N(pv)\times P(pv)}{\int_0^{\infty} N(pv)\times P(pv)\partial pv} \qquad \text{eq. 1}$$

1 This effect occurs when observing cosmological entities (galaxies, quasars, stars, etc.) and an increase in the average luminosity with distance is detected. This simply occurs because fainter sources are no longer detected as distance increases.

2 i.e. $pv/\xi^4 Q^3$, which relates the vacuum energy density with the matter per photon and the scalar fluctuation amplitude. If a predictive model to obtain universes like ours is based on this expression, the value of *pv* loses power relative to other fundamental parameters with selection effects against galaxy-forming dense halos. This could mean that other fundamental constants may have greater significance and should not be dismissed too quickly.

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Since one did not know the distribution of observers in each universe with a specific *pv*, nor the distribution of *pv* itself, eq. 1 seemed irresolvable. In order to find a solution, Weinberg stated that "the range of anthropically allowed values of *pv* is so much smaller than the energy densities typical of elementary particle physics that, within this narrow range, we can take the *a priori* probability distribution P(*pv*) to be constant" (Martel *et al.*, 1998, p. 5, eq. 2). As P(*pv*) was equalized, the term could be eliminated from both the numerator and the denominator. At the same time, as N(*pv*) had been previously related to galaxy-forming matter thanks to assumption H2 (see section 2.2 for further details), it could then be expressed as a function of known physics equations that described how matter condensed to form galaxies, and $P_{obs}(pv)$ could be finally calculated.

However, there is a problem with removing P(*pv*) from eq. 1 and leaving the weight of observing a certain *pv* to be exclusively determined by N, the number of observers. This simplification, though effective as it obtained a successful prediction, relied on an implicit assumption that was not entirely justified. By eliminating an initially unknown distribution of *pv* only by presuming it to be uniform, the model converted an epistemic limitation into a tractable predictive structure. One could ask whether the method genuinely constrained *pv* or merely concealed the lack of prior knowledge behind a *post hoc* statistical justification. Specifically, there appears to be a problematic shift where neutrality about a distribution (ignorance) was misinterpreted as an argument for low probability (knowledge), an unjustified inference that has been critiqued in other contexts (Benétreau-Dupin, 2015; Norton, 2010). This plausible fallacy will be further discussed in Section 2.3.

The premise of equiprobability, as stated in H2, emerges as fundamentally problematic when scrutinized. First, from a mathematical perspective, assuming a uniform distribution for *pv* may be misleading, as multiple studies suggest that the underlying probability distribution is not flat at all (Garriga & Vilenkin, 2000). In the inflationary framework employed by Weinberg, the values of *pv* were contingent upon the scalar field potential, meaning that the natural variation of *pv* across the multiverse followed a distribution that could deviate significantly from uniformity. Then, if the probability density of *pv* was inherently skewed, Weinberg's assumption of equiprobability within the anthropic range was not derived from fundamental physics but rather imposed for simplicity. Again, this technique proved to be useful, but at the same time it also casts doubt on whether the predicted value of *pv* was explained by anthropic selection or if it was merely an outcome of an arbitrary prior assumption.

Second, from a formal perspective, the appearance of uniformity in the probability of *pv* may be an artifact of scale-dependent comparisons between the anthropic and non-anthropic domains (see fig. 1). When the full multiverse is considered —including regions where *pv* is so large that no galaxies form— the anthropic range appears compressed within this much broader distribution. This can create the illusion of constancy, much like the size differences between microscopic and macroscopic living organisms would seem negligible when plotted against the vast scale of galaxies.[3] However, once selection effects come into play and our attention is restricted only to the anthropically viable range, its probability density is no longer seen in the context of the full distribution. In this restricted domain, significant variability may emerge, and the probability function may display extreme differences that were previously masked by scale effects. Thus, Weinberg's conjecture only holds if the entire range of possible values is considered in his probability assignments. But, if one removes the broader set and retains only the anthropic subset, it is no longer methodologically sound to assume that properties derived from the full range, such as uniformity, still apply.

[3] Consider a hypothetical plot displaying the sizes of various entities in the universe, ranging from subatomic particles to entire galaxies. Within such a scale, the region representing living organisms would appear highly compressed. One might then claim that "all living creatures are roughly the same size", as their variations seem negligible compared to astronomical scales. If this observation were used to define a universal measuring scale, and attention were later restricted to biological sizes using that same ruler, the result would be misleading: subtle variations would be obscured, and extreme cases —such as microscopic life— might go entirely unnoticed.

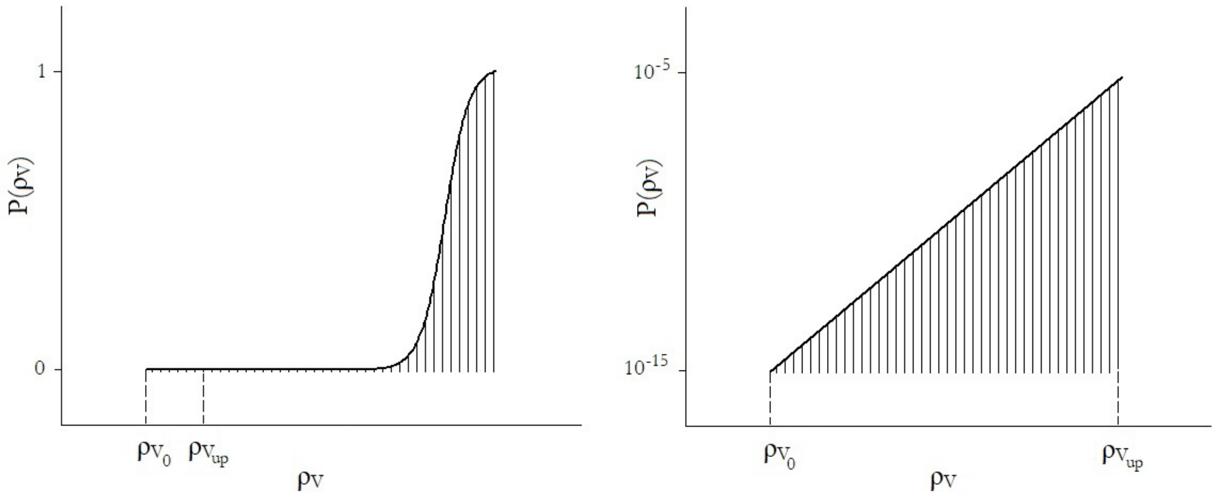

Figure 1

Hypothetical cumulative probability distribution of pv, showing an apparently constant range within observable limits (pv_0, pv_{up}) (left). The same observable range is zoomed in to show a variation of several orders of magnitude previously unnoticed due to scale comparisons (right)

Another key issue derived from the removal of P(*pv*) from eq. 1 is that it effectively became proportional to the number of observers in each universe. This introduced a subtle but crucial shift in how probabilities were assigned. Once observer abundance is given dominant weight in the posterior, the predictive distribution becomes primarily sensitive to multiplicity rather than to independently motivated variations in the prior occurrence probabilities. The methodological question, therefore, concerns how strongly posterior predictions should depend on observer abundance when prior structure remains weakly constrained.

This issue can be better understood by distinguishing between the two different components involved in anthropic probabilistic reasoning: the prior occurrence probabilities of possible universes and the way observer-related information is incorporated into predictive calculations. In a multiverse framework, one element of the prediction concerns how frequently universes with particular values of *pv* are expected to occur according to the underlying physical theory. A second element concerns how the presence and distribution of observers within those universes should influence the probability of what is ultimately observed.

Depending on how these two components are combined, predictive weight may be driven primarily by the prior likelihood of different universes or, alternatively, by the relative abundance of observers associated with each cosmological scenario. When observer abundance is given independent multiplicative weight, universes containing larger numbers of observers contribute more strongly to the posterior prediction, whereas approaches that rely primarily on prior occurrence probabilities place greater emphasis on the physical distribution of cosmological parameters themselves. The methodological question, therefore, is not whether observer information should be included —such conditioning is unavoidable in anthropic reasoning, as it is inherently *de se* in character— but how strongly predictive outcomes should depend on assumptions concerning the multiplicity of observers across possible universes.

In Weinberg's formulation, once the prior distribution P(*pv*) is assumed to be approximately uniform within the anthropically allowed range, it effectively cancels from the predictive expression. Then, the resulting probability distribution becomes proportional to the expected number of observers associated with each value of *pv*,

$$P_{obs}(pv) \propto N(pv)$$

Under these conditions, the posterior predictive distribution is driven primarily by observer abundance rather than on independently motivated differences in the prior occurrence probabilities of the corresponding universes. Structurally, this produces a weighting scheme closely related to those observer-count updating rules discussed in the literature on self-locating beliefs (Bostrom, 2003), in which scenarios with a greater number of observers receive a proportionally greater posterior weight. As a result, predictive outcomes become highly sensitive to assumptions concerning observer multiplicity when prior world-occurrence probabilities remain weakly constrained. From a cosmological perspective, this dependence raises the question of whether the apparent predictive success reflects genuine physical constraints on *pv* or, instead, actually expresses modelling assumptions about how observer populations are distributed across possible universes.

Weinberg's formulation implies that, under the assumption of a uniform prior distribution over possible values of *pv*, the posterior probability becomes proportional to the observer abundance. In this setting, we should expect to find ourselves in universes where observers are more frequent. However, this proportionality depends crucially on the simplification that prior occurrence probabilities do not differentially weight cosmological constant values. If the underlying distribution of universes were non-uniform, retaining the factor P(*pv*) in eq. 1 would play a substantive role in shaping the prediction. The appropriate treatment of this prior term remains a matter of ongoing debate, and arguments developed in related contexts (Bostrom, 2002b; Bradley, 2012) suggest that considering prior structure may strengthen the robustness of anthropic predictions concerning the cosmological constant.

To illustrate the role of observer-weighting more clearly, consider an adaptation of Leslie's emerald thought experiment (Leslie, 1996, p. 20). Suppose that, at an early stage in the experiment, three individuals are each given an emerald. Several centuries later, in a second stage, five thousand individuals are each given an emerald. Imagine that you find yourself holding an emerald but lack information about which stage of the experiment you belong to. If both stages are assumed equally likely a priori, self-locating reasoning suggests that you should assign a higher probability to belonging to the stage containing the larger number of participants, since there are more possible observer-locations compatible with your current evidence.

Since there are vastly more participants in the second century, a rational observer should conclude that it is overwhelmingly likely to belong to the later century. This probability is $P_{late} = 5000/5003 = 0.9994$, indicating that you are far more likely to be in the era of five thousand emerald recipients simply because it contains more observers.

Importantly, this inference does not imply that observers determine the underlying structure of the experiment. Rather, it reflects a probabilistic updating rule that conditions on indexical information —namely, the fact that one is an observer participating in the experiment. The resulting posterior probability depends both on the prior likelihood of each stage occurring and on the number of observer-locations associated with each stage.

This probabilistic reasoning reveals a structural parallel with Weinberg's prediction for *pv*. As eq. 1 shows, once P(*pv*) is treated as uniform, the posterior probability becomes proportional to the abundance of observers, so that self-location is effectively modelled as sampling from the largest population of observers. In this simplified setting, multiplicity alone drives the update. The analogy helps clarify this structural feature, but cosmological applications involve additional physical considerations. Unlike the *Emeralds* thought experiment, which abstracts from the conditions under which observers arise, cosmological modelling must also account for the underlying physical mechanisms that permit observer emergence. In this sense, the analogy is instructive but incomplete, since the predictive weight assigned to observer number ultimately depends on how those physical conditions are incorporated into the probabilistic framework.

To see this more clearly, suppose the thought experiment is modified: in addition to receiving an emerald, you also receive an undated astronomical report stating that there is a 50% chance that a catastrophic asteroid will strike Earth before that future distribution. If the asteroid hits, 90% of the future population will perish, and only five hundred survivors will remain to receive the emeralds. If you trust this report, then the probability of belonging to the second century must be revised downward to reflect that possibility. The probability of being in the second century should not be simply proportional to the number of observers but should also incorporate the probability of the catastrophic event occurring. So, the new calculation should be $P_{late} = (0.50\times5000+0.50\times500)/ (3+0.50\times5000+0.50\times500) = 0.9989$.

This simple example highlights the importance of relying on the frequency of world-observer pairs rather than uniquely on observer-relative frequencies[4]. By assuming uniform priors, Weinberg's approach becomes more dependent on observers multiplicity than on independently motivated variations in prior occurrence probabilities. Just as the asteroid impact affects the number of emerald holders in the second century, cosmological factors should also influence the probability of different universes existing —not just the number of observers within them. Thus, incorporating, and maintaining, this perspective should provide more robustness to the results.

2.2. Confronting H2: issues on conditionalization

A key aspect of Weinberg's anthropic argument is the conditionalization scheme he employed to predict the observed value of Λ. In this context, conditionalization refers to the process of weighting probabilities based on the presence of observers, ensuring that only habitable universes contribute to the final probability distribution of the measured Λ. Weinberg's assumption H2 stated that the number of observers, N, was proportional to the amount of baryonic matter that ended up in galaxies. This means that universes containing more galaxies should host more observers and, therefore, should be assigned a greater probability to obtain the prediction of *pv*.

This assumption appears *prima facie* reasonable: the formation of gravitationally bound structures, such as galaxies, is a necessary condition for life as we know it. However, a closer analysis reveals that this weighting scheme becomes problematic because no threshold for the formation of galaxies was well-defined. If any arbitrarily small number of galaxies could be considered sufficient for life, then Weinberg's conditionalization process may no longer constrain *pv* in a meaningful way.

The lack of a well-defined threshold for the formation of galaxies weakens the fine-tuning argument by allowing it to dissolve into a vague and imprecise selection effect, rather than a robust constraint on *pv*. In a stronger argument, the observed value of *pv* should be explained as falling within a narrowly constrained range that is necessary for the existence of observers. However, if the anthropic selection criterion is too flexible —allowing for an arbitrarily small number of galaxies to be considered viable for life— then the distinction between fine-tuned and non-fine-tuned universes becomes ambiguous. Instead of defining a clear boundary that separated universes where life could exist from those where it could not, the selection effect may have been applied too broadly, accommodating an indefinite range of *pv* values without offering a precise explanation for why we observe one particular value over another, other than being where the majority of observers are. Under such conditions, the argument risks losing the predictive framework that dictates the observed value of *pv*; instead, it becomes a *post hoc* rationalization that merely confirms that our universe must have a habitable *pv* because we exist to observe it.

To maintain the strength of the argument, it should be crucial to establish well-defined limits on the conditions necessary for observers to emerge. So, one of the major challenges in Weinberg's approach should have been to specify a minimum threshold for the formation of galaxies that would have meaningfully constrained *pv*. Consider the following scenario: as *pv* increases, the universe expands more rapidly, reducing the time available for matter to collapse into galaxies. But at some critical value of *pv*, only one galaxy forms; at a slightly lower value, two galaxies form; at an even lower value, three galaxies form, and so on. However, the number of observers does not necessarily scale linearly with these numbers of galaxies. If an undetermined number of galaxies are required before the first observer appears, then those universes on the higher end of the anthropic range may still be devoid of observers but still be factored into the calculations, potentially distorting the predicted distribution of *pv*.

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[4] Or, equivalently, assuming uniform prior probabilities over world occurrence, such that the world-weighting factor cancels out in the probabilistic model and the posterior becomes effectively driven by observer abundance alone.

This introduces a fundamental inconsistency in Weinberg's conditionalization scheme: if some values of *pv* allowed the formation of galaxies but still resulted in uninhabited universes, then the assumption that more galaxies necessarily led to more observers becomes unreliable. In that case, the model would not account for scenarios where galaxies formed yet no observers emerged despite the presence of large-scale structures. This issue may not be purely theoretical, because when the predicted value using Weinberg's model was compared with the measured value of Λ, a discrepancy of three orders of magnitude was found (Bousso *et al.*, 2007). One possible explanation for this deviation may be the artificial inflation of the predicted peak of *pv* towards higher values, as explained above.

Building on the previous explanation, the anthropic range of *pv* could be better defined by adopting a more sophisticated model. A key enhancement could be the addition of thresholds for the emergence of life, as this process can be viewed as inherently probabilistic (observers ultimately arise from abiotic processes, and the transition from inert matter to organic molecules is highly stochastic in nature). An example that illustrates this point comes from RNA, a molecule thought to play a crucial role in the origin of life due to its ability to store information and self-replication. RNA is a chain of nucleotides that, given a specific sequence, can reproduce itself. Although the exact minimum length required for RNA to exhibit self-replicating properties remains uncertain, current estimates place it between 40 and 100 nucleotides (Totani, 2020). Based on these estimates, the probability of forming a self-replicating RNA sequence through random combinations can be calculated —and it is extraordinarily low. For instance, if we assumed a probability of such polymerization event of 1 in 10^{23} per billion years per star, then, considering that our universe contains roughly 10^{22} stars, the expected number of successful events that may eventually lead to the emergence of observers might be as low as one.

This calculation suggests that, in universes with fewer galaxies than our own, the expected number of observers may decrease far more sharply than a simple proportionality with baryonic collapse would imply. In Weinberg's framework, the number of observers is effectively treated as proportional to the fraction of matter that condenses into galaxies, so that

$$E[N(pv)] \propto F(pv)$$

where F(*pv*) denotes the fraction of matter forming gravitationally bound structures.

However, this assumption smooths over the stochastic structure of observer emergence. The transition from galaxy formation to the appearance of intelligent observers involves highly contingent biochemical and astrophysical processes that may introduce strong non-linearities into E[N(*pv*)]. If the probability of life emerging within a given galaxy is extremely small, then universes with modest galaxy formation could experience a disproportionately large decline in the expected number of observers.

Under such conditions, the relationship between cosmological parameters and observer abundance would not be well approximated by a linear scaling with galaxy mass. Instead, E[N(*pv*)] could exhibit threshold-like behaviour in expectation, even without imposing a discrete cutoff. In that case, the predictive distribution for *pv* may differ significantly from the one obtained under Weinberg's proportionality assumption.

The methodological concern, therefore, is not the need for an explicit threshold excluding universes with N=0, but whether the proxy used to estimate observer abundance captures the probabilistic structure of observer emergence with sufficient fidelity. If the emergence of observers is governed by rare and highly stochastic processes, then modelling E[N(*pv*)] as a smooth function of galaxy formation may artificially broaden the anthropic range and shift the predicted peak of *pv*.

This way, although the original model was functional to a certain extent, it should be reconsidered in favour of a more complex one. As it has been described (Bousso *et al.*, 2007), a star-based metric —expressed by the total stellar entropy— seems to be a more reliable predictor for the likelihood of observers than Weinberg's matter-forming galaxies. In addition, this approach may incorporate a more physically meaningful correlation between cosmic structure and the emergence of complex life.

2.3. Confronting H_4: issues on typicality

In cosmology, the typicality assumption plays a fundamental role in reasoning about observer-based probabilities. The Mediocrity Principle (MP), widely used in scientific literature, declares that our position in the universe should be considered representative rather than exceptional (Vilenkin, 1995). However, in a multiverse framework, typicality is not merely a philosophical stance, as it becomes a structural component of probabilistic inference.

Weinberg explicitly framed his anthropic reasoning in a way that preserved typicality once observer selection effects were taken into account. As he wrote:

> … the measured effective cosmological constant would be much smaller than the value expected on dimensional grounds in elementary particle physics, not because there is any physical principle that makes it small in all subuniverses, but because it is only in the subuniverses where it is sufficiently small that there would be anyone to measure it. (Weinberg, 1996, p. 3-4)

Immediately after, he reinforced the role of typical observers:

> In previous work I calculated the anthropic upper bound on the cosmological constant, which arises from the condition that *ρv* should not be so large as to prevent the formation of gravitational condensations on which life could evolve. This bound is naturally larger than the average value of the cosmological constant that would be measured by typical observers, which obviously gives a better estimate of what we might find in our subuniverse. (Weinberg, 1996, p. 4)

Weinberg's prediction of Λ relied on the assumption that the number of observers scaled proportionally with the fraction of baryonic matter that condensed into galaxies (H2). Once this proportionality was adopted, an additional assumption was required in order to translate the abundance of observers into a probabilistic prediction. For this purpose, assumption H4 postulated that we are typical observers within a reference class that contains all such observers. In this way, the probability of observing a given value of *ρv* becomes proportional to the total number of observers associated with that value.

This inferential step performs the precise function of specifying how self-locating uncertainty is resolved. Formally, it amounts to adopting a distribution over all observer-instances, such that

$$P(\rho v|\text{we observe}) \propto P(\rho v)N(\rho v) \qquad \text{eq. 2}$$

Typicality is therefore not merely a heuristic appeal to mediocrity, but a structural component of the probabilistic model. Without this assumption, the multiplicative weighting by N(*ρv*) would not follow. If typicality were rejected or replaced by a non-uniform self-locating rule, the proportionality to N(*ρv*) would not arise, and observer multiplicity would lose its direct predictive role in the posterior distribution.

However, the justification of the relevant reference class remains non-trivial. As Hartle and Srednicki (2007) emphasize, typicality should not be assumed by default but assigned only once a well-defined ensemble has been established. In cosmology, we lack empirical access to other intelligent observers, and thus the extension of the reference class beyond our own observational standpoint is necessarily theoretical. The MP licenses treating ourselves as typical within some ensemble, but it does not distinctly define how that ensemble ought to be characterized.

The essential question is not whether anthropic conditionalization is valid —it is inescapable— but rather how to address self-locating uncertainty within a *de se* framework. One common approach to resolving this issue involves considering ourselves as randomly selected from the entire collection of observer-instances, which means that universes with a higher number of observers are given proportionally more significance. Under an alternative resolution, the relevant self-locating fact is not which observer-instance we are among many, but simply that we inhabit a universe capable of supporting at least one observer. In that case, the predictive structure would instead resemble

$$P(pv \mid \text{we observe}) \propto P(pv)P(N(pv) \geq 1),$$

so that abundance beyond the minimal condition of observability would not automatically increase posterior probability. In the limiting case of extreme observer scarcity —where at most a single observer emerges in each viable universe— sampling over observer-instances would become substantially insignificant, since there would be no multiplicity over which probability weight could be distributed.

This reveals that Weinberg's conclusion depends on a specific resolution of self-locating uncertainty. The predictive force of $N(pv)$ is conditional on adopting a uniform distribution over observer-instances. Alternative resolutions of *de se* uncertainty —such as conditioning only on the existence of observers rather than on our random selection among them— would not automatically generate proportional weighting by total observer number. Since anthropic reasoning itself does not uniquely determine how self-locating probabilities should be assigned, the choice requires independent justification.

These concerns connect with broader debates on self-locating beliefs. For example, weighting by the total number of observers, as in the Self-Indicating Assumption (SIA), tends to favour scenarios with larger populations and such reasoning may yield counterintuitive consequences when empirical constraints are weak (Bostrom, 2002a; Ćirković, 2004). The so-called Presumptuous Philosopher problem illustrates how probabilistic reasoning may grant overwhelming credence to theories that posit vastly larger numbers of observers, even in the absence of additional empirical support.

More generally, as Benétreau-Dupin (2015) observes in his analysis of cosmic probabilistic puzzles, the combination of neutrality assumptions —such as uniform priors— and appeals to typicality can yield surprisingly sharp predictions from limited informational input. The concern is that strong predictive conclusions may emerge from assumptions that were intended to express epistemic neutrality.

A further methodological refinement is suggested by Lacki (2021), who emphasizes that probabilistic outcomes associated with observer multiplicity depend crucially on how finely physical theories are decomposed into distinct micro-hypotheses. If observer-instances are treated as interchangeable without specifying the underlying physical microstates that differentiate them, the move from physical theory to probabilistic weighting remains underdetermined. In that case, multiplying by the total number of observers does not track a count of physically distinct realizations of the relevant observational situation, but instead reflects a coarse-grained representation in which qualitatively identical observer-instances are simply enumerated.

Similarly, Dorr & Arntzenius (2017) argue that the transition from qualitative priors over physical theories to self-locating beliefs requires substantive bridging principles that link physical hypotheses to indexical probability assignments. This reinforces the point that anthropic prediction depends not only on cosmological assumptions but also on how self-locating uncertainty is formally resolved.

In classical probability problems —such as drawing coloured balls from an urn— we reason as external agents with full knowledge of the sample space. The elements are discrete, empirically identifiable, and countable. Cosmology, by contrast, provides no external vantage point from which the total number and distribution of observers can be independently verified. While typicality arguments are highly effective in statistical mechanics, where macrostates are defined over well-characterized ensembles (McCoy, 2018), the cosmological application relies on theoretical postulates about observer abundance that remain empirically inaccessible.

Weinberg's framework is internally coherent once these assumptions are granted. Yet its predictive success depends not only on anthropic selection effects, but also on the adoption of a particular resolution of self-locating uncertainty and a particular level of theoretical coarse-graining. Since alternative, equally coherent resolutions remain available, the robustness of the prediction for *pv* should be understood as conditional rather than unconditional.

A central issue in Weinberg's framework concerns how self-locating uncertainty enters into the probabilistic reasoning. Once observer abundance is incorporated into the predictive expression, the resulting update depends on how indexical information should affect posterior probabilities. This structural feature finds an analogue in the Sleeping Beauty problem (Elga, 2000), which examines how an agent should revise her credence in a hypothesis upon receiving purely self-locating information. In that thought experiment, the disagreement does not concern the underlying physical setup, but the rule governing how multiplicity of observer-moments bears on rational belief revision. The debate is commonly divided into two principal positions:

— Thirders, who argue that the probability of heads should be 1/3, on the grounds that it leads to a single awakening (unlike tails, which results in two awakenings).

— Halfers, who maintain that the probability of heads remains 1/2, since the experiment does not change the initial chances, and the number of awakenings is irrelevant to the credence.

The philosophical significance of this debate extends beyond the thought experiment itself and bears on broader questions about self-locating probability in cosmology. The contrast between thirder and halfer positions illustrates how different resolutions of indexical uncertainty can yield different posterior weightings, even when the underlying physical hypotheses remain unchanged. In particular, thirders treat multiplicity of observer-moments as directly relevant to posterior probability, whereas halfers maintain that purely indexical information does not automatically warrant such proportional updating.

This structural contrast reflects the issue raised earlier. The role of multiple observers in probabilistic prediction depends on how observer instances are individualized and weighted. If observers cannot be meaningfully distinguished as distinct probabilistic units with respect to the data under consideration, their collective number may function as a modelling parameter, but its epistemic strength should require further justification.

From an epistemic standpoint, an additional concern arises regarding how ignorance about the total number of observers is represented. In the absence of empirical access to the distribution of observers across possible universes, our background information B appears compatible with a wide range of possibilities, that is, from a universe containing a single observer to one containing arbitrarily many. Formally, our state of knowledge in a background B does not privilege any specific disjunction of the form

$$N_1, N_1 \vee N_2, N_1 \vee N_2 \vee N_3, \ldots$$

where N_i denotes the hypothesis that exactly *i* observers exist. Mere ignorance about observer abundance does not, by itself, determine a probability distribution over these alternatives.

Once the Principle of Mediocrity is introduced, however, observer multiplicity becomes epistemically relevant. The probabilistic framework now includes weighting by observer count, thereby assigning greater posterior weight to hypotheses that contain larger numbers of observers. This shift does not follow from ignorance alone, but from the adoption of a substantive principle connecting observer abundance to self-location probability.

Norton (2010) has argued, in a related context, that certain forms of probabilistic reasoning can generate strong inferential shifts from evidentially neutral starting points. The present concern is not that Weinberg's reasoning is formally invalid, but that the transition from neutrality about observer number to multiplicity-sensitive updating requires an additional justificatory step. In this respect, anthropic predictions depend crucially on how ignorance about observer distribution is formalized within the probabilistic model. Since alternative resolutions of self-locating uncertainty remain available, the epistemic force of observer multiplicity should be understood as conditional on the adopted updating principle rather than as a direct consequence of empirical data alone.

3. Conclusions

This paper has presented a critical examination of the premises underlying Weinberg's probabilistic prediction of the observable cosmological constant. Within the framework of anthropic selection, Weinberg's reasoning is internally coherent and yielded an impressively accurate order-of-magnitude estimate when evaluated against the full theoretical range of possible values. His work remains a significant illustration of how selection effects may constrain otherwise weakly constrained cosmological parameters.

The analysis developed has highlighted that the predictive force of Weinberg's result depends not only on cosmological modelling, but also on how self-locating uncertainty is resolved within the probabilistic framework. Once observer abundance is incorporated into the predictive expression, additional epistemic commitments enter the model —specifically, principles governing how observer multiplicity bears on posterior probability assignments.

Therefore, the central issue is methodological. Certainly, anthropic conditionalization is unavoidable in any scenario where our existence functions as evidence. However, the transition from qualitative physical assumptions to quantitative beliefs about self-location requires transition principles that are not solely fixed by physical theory itself. In any case, different internally consistent resolutions of indexical uncertainty remain available, which can lead to varying degrees of multiplicity sensitivity in the resulting probability distribution.

This dependence indicates that the robustness of anthropic predictions depends largely on how the lack of knowledge about the observer distribution is formally represented and how observer instances are individualized within the model. Thus, the introduction of the number of observers as a weighting factor reflects substantial assumptions about self-location, rather than direct empirical constraints.

A more comprehensive treatment of these issues would therefore require further investigation into the principles linking cosmological hypotheses to indexical probability assignments, as well as clearer articulation of the level of theoretical granularity at which observer multiplicity is evaluated. Such refinements would clarify the epistemic status of the assumptions on which it depends.

In this sense, Weinberg's prediction should be understood not as a definitive confirmation of anthropic selection, but as a powerful illustration of how cosmological inference can hinge on subtle questions about self-locating probability. Recognizing the conditional structure of these assumptions allows for a more cautious yet conceptually transparent assessment of anthropic arguments in contemporary cosmology.

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