THE CONCEPT OF THE UNIVERSE IN PHYSICAL COSMOLOGY

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Abstract: The concept of the universe is used in physical cosmology differently from the usual meaning of the term, naively considered as the entire reality. Traditionally, thinking about the whole led to logical contradictions. Taking as reference the Kantian antecedent, different contemporary philosophical notions of the universe are analysed in the first part of this paper, including realist and constructivist approaches, as well as a notion of the universe as a physical object. In the second part, the specific notion from the standard physical cosmology is discussed. Although modelling the universe as a physical system provides a specific way to define some global properties, the universe as a whole remains empirically inaccessible. Hence, the discussion about the under-determined global properties depends ultimately on philosophical preferences. Under these circumstances, it is argued that the realist interpretation of such properties becomes problematic because it leads to unstable conclusions. Finally, it is argued that the notion of the universe as conceived in standard cosmology is not necessarily consistent with an approach that considers it to be a physical object.

Keywords: Philosophy of cosmology, universe, Kant, cosmological models, under-determination.

1. Introduction

Physical cosmology has experienced an important boost in recent decades. The development of vast observational programs has allowed data of substantial cosmological relevance to be collected, such as large-coverage galaxy surveys or the all-sky characterisation of the cosmic microwave background (CMB) fluctuations. Additionally, theoretical and technological advances have fostered access to new observational windows; for instance, weak gravitational lensing, baryonic acoustic oscillations or gravitational waves. As a result, cosmologists have had the opportunity to determine the

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value of the cosmological parameters defined in the context of the standard model with unprecedented accuracy (Planck Collaboration, 2018, VI). In the present state of the discipline, this trend is expected to be maintained at least in the near- and medium-term future because new observables such as CMB spectral distortions, 21-centimetre line observations from the so-called dark ages, dark energy proofs or a primordial background of gravitational waves might be intended to be measured (e.g., Kogut et al., 2019; Silk, 2018; Kamionkowski and Kovetz, 2016).

Although different definitions of physical cosmology have been provided depending on the assumed optimism level about the scope of the discipline (e.g., Goenner, 2010: 390), this discipline is typically presented as the scientific study of the universe as a whole. In particular, it is distinguished as dealing with the origins, evolution and components of the universe. But, what is that universe exactly? From a general standpoint, it is common to assume that this term is synonymous with 'reality'. In a more specific version, it provides a way of referring to the application domain in which scientific laws can be established, that part of the world susceptible to modelling. Be that as it may, although based on general assumptions about the world[3], the specific domain of cosmology is substantially more modest in practice. On the one hand, according to general relativity, its empirical base is epistemologically restricted to the space-time volume causally connected with Earth. On the other hand, the very nature of modelling consists of selecting certain aspects of reality to the detriment of others (see Section 2.2). In addition, because the way in which some global features are conceived depends on counterfactuals (i.e., physical links theoretically established involving observational consequences), the specific notions of the universe drawn by different models are assessed *a posteriori* in the light of the success in consistently explaining the large-scale observations. Therefore, the model is unable to determine *everything*. As a matter of fact, most global features remain ultimately under-determined by the data. Thus, future theoretical changes induced by new observations might also imply changes to the entire view.

Access to new observational windows bolsters the empirical shift that made possible cosmology to be consolidated as a scientific discipline. Not only have relevant

[3] For instance, the standard scientific approach assumes that local laws are universally valid and can be reasonably extrapolated to large scales. Far from perceiving these requirements as necessary, they are premises within the current model. On the contrary, local effects are caused by global physics in some Machian approaches. An epistemological inversion is given under these frameworks, in the sense that global features of the universe could be inferred from local observations.

technological advances been necessary to achieve this, but theoretical developments providing a useful conceptualisation have also proven to play a critical role. Traditionally, dealing with the idea of the world as a whole led to logical contradictions. Greek sceptics were already suspicious of this notion:

> [I]f anything is a whole, it is either something different apart from its parts or else is its parts themselves. Now a whole appears to be nothing different from its parts; at any rate, if the parts are destroyed nothing is left behind which would encourage us to reckon the whole to be something different apart from them. But, if the whole is the parts themselves, then a whole will be merely a name and an empty noun, and it will have no subsistence of its own – just as a separation is not anything apart from the things separated, or a timbering apart from the timbers. Therefore there are no wholes (Sextus Empiricus, 2007: 170).

It is widely known that Kant extensively analysed this idea in his 'Critique of Pure Reason', concluding that thinking about the whole world gives rise to antinomies. Although the sceptical purpose was showing that no option could be asserted with greater certainty than its complementary alternatives, Kant argued that both premises (thesis and antithesis) should be rejected on the basis that the world as a whole is not an empirical object (e.g., Stevenson, 2012: 137). Taking Kant's account as reference, the first part of this paper is devoted to examining different contemporary ways of conceiving the universe as a whole. As will be shown, even within the realist approach typically assumed by scientists, some conceptual difficulties persist when thinking about the entire reality as a totality. Essentially, two different strategies have been followed in order not to face the mentioned problems. The first obviously consists of denying the existence of an actual whole. Although for different reasons, this is not only the option chosen by Kant but also the course other contemporary philosophical analyses have taken under views such as materialistic realism or constructivism. The second strategy is simply to avoid the problem. Possible options include considering the universe not to be the whole but a part of a greater reality; or relegate the role of the notion of the universe to a heuristic plane; for instance, assuming that the scope of cosmology is exclusively limited to the observed structures at the largest scales.

In the second part of this paper, how the notion of the whole is articulated within relativistic models of the universe is analysed. Current standard cosmology is mainly based on an application of general relativity that defines a physical system in which different statistically homogeneous and isotropic energy components are considered to be perfect fluids subjected to their corresponding equations of state. That symmetry is also attributed to the space-time manifold itself assuming the cosmological principle, requiring in consequence the use of a perturbed version of a Friedmann-Lemaître-Robinson-Walker (FLRW) metric. Under these assumptions, the system dynamics are described in terms of the scale factor. Although this factor vanishes at a finite past time in many FLRW models, the presence of a singularity is not a necessary condition of the framework. In principle, relativistic models with a cosmological-constant term can be built in such a way that the scale factor tends to a positive value when $t \to -\infty$. As a matter of fact, such a term is also present in current standard cosmology accounting for a dark-energy component, but it is only dominant at recent times and, therefore, does not prevent the initial singularity.

Because the speed of light is finite, the past of expansion determines what space-time volumes are accessible to the present observation, so that a particle horizon appears (e.g., Ellis and Rothman, 1993). Whereas the model's parameters are defined in global terms, the empirical basis is restricted within the theoretical framework to the observable universe. Therefore, it seems natural to consider the largest accessible scales as the correct application domain of cosmology because it is there where the cosmological principle has been demonstrated to be valid. Moreover, it is also evident that cosmologists, encouraged by the interpretation of data in terms of the standard model, typically make claims, the predicate of which is the universe as a whole. However, because a relativistic cosmological model could eventually provide a necessary but insufficient explanation for the observations, this reading requires auxiliary assumptions to be considered that are not empirically justified.

Summarising, this paper is structured as follows. Section 2 deals with different philosophical approaches concerning the universe as a whole. First, the Kantian view is developed in order to lay certain foundations for subsequent discussion. Second is the usual realist approach assumed by scientists when applying their models to certain empirical domains. Third, a notion of the universe as a physical object is described. This view sparks a discussion about the status of cosmological laws. Finally, another analysis is offered from a constructivist point of view. Moreover, the specific conception from standard cosmology, along with its realist interpretation, is analysed in Section 3. Finally, conclusions are drawn in Section 4.

2. The universe as a whole

The notion of the universe is often used in fuzzy terms. Assuming a materialistic point of view, it may be conceived as the totality of what is real. However, this naïve meaning hinders its characterisation because it does not provide a specific way to delimit the concept. In particular, even assuming the relativistic approach, its interpretation depends on the specific philosophical notion of reality that is handled. For instance, authors for whom reality is merely an epistemological notion may argue that the relativistic concept of the universe expands the ontological boundaries to a realm, the existence of which, despite not having a causal impact on our cosmological environment, seems to be necessary in order to yield a consistent mathematical model. Conversely, for authors who claim the existence of an external reality, there seems to be no *a priori* reason to assume a limit on the largest scales, in such a way that it is the fact that light has had a finite time to reach us from everywhere in the universe that acts as the ultimate reason for not having empirical access to the entire reality. This is undoubtedly the philosophical approach that most cosmologists implicitly assume.

In essence, a correct characterisation of the concept of the universe as used in cosmology would help to settle some controversies around the discipline and delimit the scope of this science. This section revisits different approaches concerning the universe as a whole. As a major antecedent, the Kantian idea of the whole is included in order to be contrasted with contemporary scientific attitudes when dealing with current cosmological models.

2.1 The Kantian account

It is widely accepted that Kant's cosmological approach from his early works constitutes an antecedent of the so-called nebular hypothesis (see, e.g., Whitrow, 1967). In 1755, Kant seemed to believe that, at least some aspects of the largest scales could be analysed using a scientific approach. In fact, he suggested that, far from being independent of each other, the different nebular stars, considered as other Milky Ways, could comprise a much larger system (Kant, 2008: 38). Previously, Kant had provided in 'Thoughts on the True Estimation of Living Forces' (1747) an explanation for the three spatial dimensions based on a necessary connection between the number of dimensions and the inverse square law (Kant, 2012: 27-28). At that time, he admitted the contingency nature of some aspects of space, insofar as they depend on certain laws rather than others.

He was willing to consider the possibility of other worlds with a different number of spatial dimensions in a similar way that contemporary cosmologists confront different universes.

In spite of that, Kant's views changed significantly in later works (see, e.g., Hatfield, 2006). In 'Critique of Pure Reason', the author is known to claim space and time not to be empirical concepts but, rather, pure forms of intuition. Similarly, according to Kant's transcendental idealism, the unity of nature, as well as the empirical laws we obtain, are conceived to be a necessary consequence from *a priori* notions from our mind:

> The understanding (…) is not merely a faculty for making rules through the comparison of the appearances; it is itself the legislation for nature, i.e., without understanding there would not be any nature at all, i.e., synthetic unity of the manifold of appearances in accordance with rules; for appearances, as such, cannot occur outside us, but exist only in our sensibility (Kant, 2000: 242).

Without these rules of understanding, no representation is possible[4]. However, empirical knowledge is not only based on categories, but the corresponding intuition is also necessary to cognise an object. Although pure intuition can provide *a priori* cognition through mathematics, the resulting notions are still potential:

> «[A]ll mathematical concepts are not themselves cognitions, except insofar as one presupposes that there are things that can be presented to us in accordance with the form of that pure sensible intuition. Things in space and time, however, are only given insofar as they are perceptions (representations accompanied with sensation), hence though empirical representation» (Kant, 2000: 254).

As a result of this view, the idea of a material whole is merely shaped as a synthesis of all material objects. That is to say, in Kantian terms, the complete series of conditioned objects along with its condition as given (i.e., the conditioned along with the unconditioned) is supposed to be implicit within the concept of the universe as a whole (Kant, 2000: 515). As far as possible, one can empirically regress along the conditioned series (phenomena) up to a certain condition, but the inclusion of the unconditioned is not

[4] As a matter of fact, Kant claimed Euclidean geometry to be an *a priori* notion preceding all possible representation. From this point of view, the three dimensions of space are now seen as apodictic (Kant, 2000: 176).

empirical. This synthesis is nothing but a transcendental illusion. It represents the use of a pure category in which no temporal order is considered, whereas the empirical synthesis implies an actual succession of phenomena in time, being therefore necessarily incomplete.

According to Kant, support for this conjecture can be seen in the fact that the consideration of the whole seems to give rise to logical contradictions. Traditionally, the line some critics adopt focuses on refuting logical arguments supporting either the thesis or the antithesis of the first antimony (see, for instance, Craig, 1979; and references therein). Nevertheless, what is interesting for our purpose is to emphasise that Kant himself based his position on the belief that cosmological questions are beyond any empirical verification. On the contrary, because the world is an object accessible to experience, the antimony might be solved using an empirical approach (Mion, 2014: 377).

2.2 Modelling the universe

Kant could not anticipate the role of non-Euclidean geometries in the future conception of space-time. Within general relativity, Euclidean geometry is no longer a necessary requirement for physical space. As a result of the theory's interpretation, the function of Kantian pure intuition is relegated to be effective in relation to another natural order, which is independent (but constituent) of our mind[5]. Whereas scientific activity is acknowledged as resulting from human capacities, a nature domain is implicitly assumed to be a premise of the realist approach. From the very beginning, the assumptions that make possible cosmological applications of general relativity imply beforehand the existence of a totality. Moreover, relativistic models provide a specific framework for dealing with global properties in relation to some empirical observations. Because, as far as known, the validity of general relativity is perceived as contingent, these models constitute causal schemes to construct counterfactuals, such as those used by pre-critical Kant for explaining the dimensionality of space. Insofar as the theory has been shown to be the most useful alternative for explaining and predicting cosmological observations in a consistent manner with other local gravitational effects, it constrains the terms in which the cosmological discussion takes place. As Munitz wrote, «[i]n place of a concept of

[5] In Munitz's words: «[T]he problem of determining spatial metrics of any continuum is independent of the successive acts of apprehension of some mind» (1951: 332). According to this author, the Kantian discussion about the antimonies is completely subordinated to his distinctive transcendental idealism, as well as the Newtonian framework. In consequence, once foregone those, his arguments are not useful to the current scientific debate.

totality as based on the form of a *series* one finds the introduction of a *theory* that deals with the universe as a *physical system*» (1951: 333–334).

In a sense, after assuming its existence, following this approach entails giving up 'the entire reality'. Because the domain of phenomena that can be included in a model is always limited, it cannot be correctly claimed that there could be a unique scientific approach that accounts for the entire empirical spectrum. Assuming the access to an external reality in which all research domains should ideally converge in a coherent manner, physicists might one day be able to span both domains of quantum physics and gravity with a single theory. However, even if such a theory were assumed to be a hypothetical theory of everything, which explained all the fundamental interactions within a single framework, it would not yet be a suitable tool for dealing with all phenomena[6].

In general, as Goenner (2010: 390) points out, scientists always work with idealised systems that select certain aspects of reality. A mathematical model aspires to capture isolated properties of a particular kind of phenomena. In practice, the variables deemed relevant to each problem establish which is the application domain of a model. As a result, inasmuch as many other involved factors are not considered, it is often said that no phenomenon occurs exactly as the model predicts (e.g., Torretti, 2000: 173). According to Pauri (1991: 300), this approach implies an artificial division of the world into three different components, namely the object of study, the observer and the rest of the world. Because the rest of the world is considered to be irrelevant to the ultimate causes of the phenomenon to be studied, a part of this factor is encoded as initial or boundary conditions, whereas the other part is encapsulated inside a general *ceteris paribus* clause.

As mentioned, although physical cosmology arose from the possibility of building models of the universe using general relativity, its scientific credibility does not rest on a mere rational idealisation of the whole, but rather on its ability to provide a consistent explanation for a wide range of phenomena, as long as it does not conflict with other well-established scientific knowledge. In particular, the standard cosmological model defines an effective physical system, the dynamics of which constitute the basis for a causal

[6] Furthermore, Stevenson (2012: 139–140) points out that such a theory would not be an actual theory of everything because it would presumably require in turn a set of initial conditions to be specified. Additionally, the theory could not explain itself (i.e. why the ultimate laws are those instead of others).

explanation for the statistical properties of the present largest scales[7]. Hence, the properties that standard cosmology deals with must be seen through special glasses, which blur any detail below a certain scale (i.e., the one from which the cosmological principle is considered to be valid)[8]. In spite of this, big-bang cosmology is not exclusively built from an application of general relativity mainly because of two different reasons. On the one hand, because the model implies a past in which matter is subjected to a high-energy regime, it is necessary to extrapolate laws from other branches of physics, such as quantum mechanics or nuclear physics, to unexplored energy domains. On the other hand, cosmology aspires to reconcile its predictions with that which is observed at smaller scales. This is particularly evidenced by the theoretical efforts to produce, in its proper measure, statistical fluctuations from an FLRW background. Such an approach reflects the attempts to smooth the transition between different application domains.

Ultimately, the entire standard cosmological approach depends on the assumption that local laws can be universally applied to a wide range of scales. However, it should be noted that not all realist approaches are compatible with this view. In particular, for authors who subscribe to the theory of categorical closure, reality is not a finished entity (Madrid Casado, 2018: 251). On the contrary, scientific activity produces new *hyperrealities*, a term that refers to phenomena that do not occur spontaneously in nature at a human scale but can be characterised in controlled laboratory conditions. According to their view, our knowledge about material properties entirely depends on particular actions. On the one hand, hyperrealities such as quasars, X-rays or electrons, are constrained by material properties and considered real insofar as they offer a consistent picture from independent observations. On the other hand, they do not represent any reality with regardless of their detection context. Although, as scientific concepts, they have been used to construct more general explanatory mechanisms, their previous existence as real phenomena waiting to be discovered cannot be rigorously claimed. As a result, the product from different sciences cannot be considered to be explorations of distinct domains of the same reality. On the contrary, they are part of hermetic domains,

[7] As Ellis (2007: 1247) warns, the model is not reality. For instance, as is discussed in Section 3, it includes several elements, such as dark energy or cosmic inflation, without specifying their underlying physical mechanisms, just because they provide necessary effects for explaining the data.

[8] That is certainly not to argue that all potentially viable cosmological models should be limited in this way. For instance, cosmological frameworks built from MOND approaches are expected to be able to make predictions about some aspects of individual galaxies (Merritt, 2020: 40-41).

constituting what is referred to as a discontinuous pluralism (ibid., p. 368). Nevertheless, assuming scientific models and experiments to capture some complementary features of an objective reality, rather than different aspects of incompatible domains, seems to be still the best option for explaining the consistency of our experience, even though scientific models (and theories) are acknowledged to operate in specific domains. In fact, from a realist approach, there is no reason to impose an artificial division depending on contingent features of our detectors or senses, which are in turn materially realised. Whereas the so-called hyperrealities are thought to be materially constrained in some way, restricting their epistemological scope implies not only denying the possibility of extrapolating laws but also alluding to a supposed elusive metaphysics.

As a physical system providing a causal explanation for the observed statistical large-scale features, the universe reflected in the standard cosmological model seems to play a mere heuristic role. The implicit notion of this concept includes all physical ingredients that are necessary in such an explanation[9]. However, there are two aspects of modern cosmology that inevitably relive Kantian concerns. First, some properties within the standard model are interpreted in global terms (i.e., they concern the entire space-time manifold). As will be discussed in Section 3, these properties cannot, in general, be unequivocally determined by empirical observations. Second, every cosmological model requires a set of initial or boundary conditions to be specified. Because their choice lies beyond the explanatory power of the model, they represent what Kant termed the unconditioned. In a way, within models with a Big Bang, this discussion concerns the question (if it makes sense) about the origins of the universe. Some attempts to avoid such a boundary rest on considering a set of laws living on a metaphysical plane that gives rise to the specific initial conditions of our universe. In practice, as will be shown under the following header, this option not only does not ultimately evade the problem but also entails unsolvable difficulties due to epistemological limitations.

2.3 The universe as a physical object and the status of cosmological laws

According to Soler Gil (2016: 177), three basic features can be attributed to a physical object. In the first place, an object makes up a unit, either as a single entity or as a system comprising linked parts. Second, a physical object can be characterised in terms

[9] In this sense, although it does not aspire to account for the entire reality, a cosmological model is not epistemologically bounded. Because past stages of the system concern all states of matter, any future physical discovery will fall within its domain.

of some intrinsic or dynamic features. Finally, it shows a relative independence from the rest of the world at least for a short period of time. Under this view, the author claims that the universe, as considered in cosmology, is an object. Certainly, as just shown, the physical system defined by the standard model trivially conforms to this definition. However, insofar as its referent is ideally conceived as the entire causal chain responsible for the actual large-scale behaviour, there would be no room to establish the notion of independence in a significant way except under the assumption that the explanatory constraint of the model can be literally interpreted (i.e., assuming that the universe ends where the explanatory power of the model does; for instance, conceiving a causal mechanism for explaining the actual set of initial conditions *from outside* the universe). Within such an approach, there could exist a set of pre-existing fundamental laws that governs the universe's behaviour as a whole (e.g., Ellis, 2014: 18). In this sense, cosmology could aim to discover laws within that metaphysical domain. They would stipulate how a universe is generated, how it evolves and what is made of.

Moreover, the rejection of this point of view is invoked by Munitz (1962) to claim that cosmology is not able to generate genuine laws as, for instance, other branches of physics do. This author takes scientific laws to be the result of observing some empirical regularities in a set of instances belonging to the equivalence class associated with a certain phenomenon[10]. Because the universe is assumed to be unique, he claims that cosmological laws cannot be established. This uniqueness constraint is worth analysing in the light of the various possible approaches. On the one hand, under the notion of the universe as a whole, there does seem to be a logical contradiction between this conception of law and the possibility of establishing a set of *genuine* cosmological laws. On the other hand, under some views from inflationary cosmology (as well as other non-standard frameworks that provide the possibility of generating different universes[11]), the problem pointed out by Munitz is displaced to another entity—the multiverse. That is to say, even if a theory were found capable of explaining regularities between universes, it would still not be possible to establish genuine laws of the multiverse. But even so, such a theory

[10] Smeenk (2008: 20) is critical of this conception of scientific laws on the basis that a specific phenomenon is never a pure instance of a law. On the contrary, the laws are applied to particular phenomena in specific ways, taking into account the involved particularities.

[11] In this context, a universe is seen as a space-time region in which a specific set of physical laws governs.

about different universes, considered as physical objects, would have no direct empirical support at all[12].

Summarising, we return to Kant acknowledging that in no case is the universe, even conceived in terms of the cosmological model, an empirical phenomenon. In consequence, all the scientific laws that cosmologists can formulate necessarily refer to constituents of the universe. However, cosmological laws can be alternatively vindicated insofar as their explanatory domain emanates from a cosmological view. For instance, Munitz (1962: 39–40) argues that the Hubble-Lemaître law should be considered at most as an astrophysical law because it is inferred from observations of single galaxies. To be conceived as a cosmological statement, it must be interpreted from the perspective of a model that postulates a larger system that is unique and not empirically accessible. Under these circumstances, it is not possible to make the required empirical comparison in order to establish a genuine law on Munitz's terms. However, that should be sufficient to establish the cosmological nature of this law insofar as the model is considered to be the best explanation for the data[13].

Munitz's critique reveals some of the specific limitations of cosmology, mainly due to the uniqueness of the universe. As Butterfield (2014: 57) alleges, whereas the development of other sciences typically contributes to validate some established theories in different ranges of application, cosmology takes for granted those theories to be applied within domains that are not directly accessible to experience[14]. In other words, cosmology applies an approach from within, avoiding the need for a set of laws in a metaphysical domain (e.g. Ellis, 2007: 1217–1218). Following the Kantian notion of successive syntheses, even if genuine cosmological laws were considered to only apply to the whole, it would seem reasonable to assume that provisional laws demonstrated to be valid to

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[12] In fact, within the standard approach, there would be empirical consequences of a multiverse if two bubbles collided within our observable universe. However, such a collision would only occur in very specific circumstances. In addition, if the universe were sufficiently small, some observational pieces of evidence might rule out the multiverse hypothesis. Unfortunately, none of those seem to be the case (see Ellis, 2014: 14–15).

[13] As a matter of fact, the possibility of providing an alternative explanation based on some intrinsic properties of individual galaxies was considered, for instance, under the interpretation of the redshift pattern as a kinematic effect. The usual explanation based on cosmic expansion is preferred in terms of consistency and unifying power.

[14] Nevertheless, it should not be forgotten that new physics is proposed within the standard model (for instance, dark energy). Of course, this is also the case within many non-standard cosmological approaches, such as the Milgromian models, in order to avoid some widely-assumed auxiliary hypotheses. Eventually, such proposals might enrich our understanding of the world. In addition, new physics might imply epistemological changes, such as within those approaches aspiring to include the Mach's principle allowing cosmologists to infer global properties from local observations.

relatively isolated subsystems constitute a reasonable approximation for an asymptotic theory (e.g., Smeenk & Benétreau-Dupin, 2017: 359–362). In the end, the application domain of cosmology must include particular instances of physical phenomena, although they may be explained invoking past stages of single and theoretically configured dynamics.

Finally, it should be noted that the notion of the universe as a physical object is a preferable characterisation for theological approaches (e.g., Soler Gil, 2016: 178). Not only can an object be created, but it may also be conceived for a specific purpose. In his review of the origins of the idea of the universe in modern science, Ekeberg (2019: 67) claims that both Cartesian and Galilean/Newtonian conceptions rest ultimately on the relationship between God and its creation. That is to say, this contrast with God originally enables natural philosophers to objectify Nature or the universe[15]. However, the author seems to take this argument further assuming that the articulation of the notion of God is the last reason under which an objective reality ready to be discovered is sustained. In his own words:

> The universe in its modern scientific sense is a symmetrical proposition that becomes axiomatic to scientific practice, because henceforth, modern scientist can substitute or complement their belief in God with the belief in mathematical universality—a belief which in turn legitimates the universality of the enterprise as such (Ekeberg, 2019: 77).

As mentioned above, physical cosmology did not garner its scientific credibility until its framework was contrasted with actual observations (e.g., Torretti, 2000: 180). Ultimately, both the cosmological approach and the assumption that there is an external reality and can be known to some extend have been demonstrated to be useful in the light of subsequent results, regardless of what their first incentives were.

2.4 Views from constructivist approaches

Generally, the premise that scientific outcomes are necessarily somehow connected to specific features shown by an objective reality is underestimated by constructivist approaches. For instance, following Ekeberg (2019: 37), modern scientific activity is seen

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[15] «[B]oth accounts [of universality] rely on the constitutive circumscription of the world as given. Whereas Galileo excludes mediation in physics through the void, Descartes excludes it in metaphysics through the *cogito*» (Ekeberg, 2019: 67).

as a sort of solipsism, the major purpose of which is to generate the need for more experiments[16]. Insofar as theory guides research, the observational evidence is selected in such a way that it can be consistent with models. When the expected results are not obtained from the experiment, physicists either adjust the parameters of the model or transform reality to fit, at least locally, the theoretical framework. The outcome of this game ultimately depends on the ability of scientists to gather support from their peers. Ekeberg particularly illustrates this perspective in the context of the controversy between the steady-state and the big-bang models:

> In my reading, the big bang hypothesis did not win out because it is true in any positive, verifiable, and empirical sense but rather because it most effectively gathered and mobilized interest in the scientific community for its explication of a few fundamental constraints. Like the invention of the particle, (…) the hypothesis was so instrumental to further research that it soon became reality (Ekeberg, 2019: 125).

However, although the empirical evidence was certainly not the only relevant factor, the observational tests played a determining role in the refutation of the steady-state alternative (see, for instance, Kragh, 1999: 269). Constructivist approaches typically seem to overlook that confidence in a theory can be diminished when it fails to predict the outcome of certain experiments. Nevertheless, it is a matter of fact that the steady-state model was unable to explain within a unifying framework some of the observations that were being recorded.

It is fair to admit that the usual self-evident presentation of science omits that the specific way in which scientific questions are formulated is heir to a whole cultural tradition. Acknowledging that our present scientific view is only one of all that would have been possible to handle directly implies neither that changes in science have nothing to do with an objective reality nor that different potential views would be necessarily incommensurable. On the contrary, it would be difficult to understand some of the most impressive predictions or the obvious impact of applied science. In the context of the notorious cosmological controversy, the detection of isotropic microwave radiation definitely tipped the balance in favour of big-bang cosmology, not because the CMB interpretation from the big-bang alternative was the only one possible, but because the

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[16] «In the age of 'Big Science', the primary purpose of research is to produce more research» (Ekeberg, 2019: 122).

steady-state framework did not provide any natural explanation of this phenomenon (Kragh, 1999: 355–358). Within current cosmology, the detailed theoretical study of past stages of the universe leads to new observational windows, highly specific effects that are supposed to be measured out there in the real world. In practice, the outcomes of experiments, although theoretically laden, may or may not be consistent with what is expected.

Moreover, following Ekeberg's conception, the worldview from modern science is built in terms of a set of metaphysical entities, belonging to a metalogical domain[17], the empirical reality of which is unable to be directly demonstrated, such as subatomic particles. Their appeal lies exclusively in the fact that they are «theoretically and experimentally operational» (Ekeberg, 2019: 116). In fact, the metaphysical entities in Ekeberg's view constitute what are commonly referred to as theoretical entities[18]. Their consideration does indeed respond to a pragmatic dimension, in the sense that they allow to conceive explanatory mechanisms. Moreover, because their properties can only be derived indirectly, both the experiment designs and their outcomes are highly theoretically laden. In other words, a complex interface, which depends, in turn, on the validity of some scientific statements, is required between the corresponding phenomenon and the observer. However, this does not mean that the entire process depends on a circular logic, but rather on many auxiliary assumptions. As a consequence, the empirical support for a theory should no longer depend on a single kind of experiment, but as far as possible on a set of independent observations that allows consistency to be tested.

Naturally, this is also the case in cosmology, with the aggravating factor that the global space-time manifold of the model is one of these theoretical entities. In Ekeberg's view, insofar as mathematics involved in cosmology are built on metalogical structures, they, in turn, configurate a *hypologic* level of reasoning:

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[17] Following Eckeberg, something is thought in autological terms if it is conceived as «actually existing, which we may not be able to know but for which there is necessarily a reason» (2019: 49). For instance, it is the status of force in Newtonian physics. In contrast, the metalogical is what is postulated beyond the autological regime. It is present in the statistical reasoning, and it is the inherent logic of statistical physics and quantum mechanics, in the sense that «is acausal (…) 'nonlocal', not linked to a specifiable, localizable causal trajectory» (2019: 87). Within this logic, for instance, irreversibility is no longer attributed to the passage of time, which becomes illusory, but to a statistical conception of possible state configurations.

[18] As Neves (2019: 862) points out, a predicted phenomenon within modern science may become cognition (in a Kantian sense) only after particularly complex data interpretations. Cognition is no longer exclusively based on pure and empirical intuition; theoretical entities also play an important role in the interpretation of experiments. In a similar sense, Munitz (1951: 334) claimed that, given a cosmological theory, empirical experience of the universe as a whole is no longer required, as long as its validity can be empirically tested.

> Today, the universe in the scope of scientific cosmology appears as a hollow hypological construction, a name for something constituted by a multitude of metalogical parameters that may in and of themselves make sense of concrete and delimited phenomena but which never add up to a totality: a hypological universe that provides the semblance of unity from a reality too messy for mathematics as well as metaphysics. A simulacrum of unity, to what end? (Ekeberg, 2019: 161).

In particular, the author defines the hypological reasoning as «positing something as under itself, in the manner of a framework, established through the retroactive unfolding of a transformation that makes its terms appear self-evident» (ibid., p. 126). According to this view, the universe of the model is a metaphysical construction focused on the sustainability of research itself. In fact, conducting cosmological observations typically entails substantial costs that are only available to large scientific collaborations, which, in turn, undoubtedly act as an economic engine for the industry and serve as an umbrella for research groups to attract funding. However, the research proposals are subject to a highly competitive selection process in which not only economic and strategic but also scientific factors prevail.

3. The universe in relativistic cosmology

Within relativistic cosmology, the Newtonian picture of space as a passive container of real entities is no longer supported. The product of each model is a theoretical entity, the global space-time manifold, with highly specific features. As Earman and Norton (1987: 519) point out, although it is not included in the energy-momentum tensor, the metric acts as a physical field to which energy can be associated. As a result, the space-time manifold is not considered a mere auxiliary framework because some physical aspects are encoded in its very notion. Two points can be made from a Kantian point of view. On the one hand, considering a particular set of initial conditions, the energy components and the entire cosmic evolution, some aspects of space-time are given at once. In such a manner, the scientific approach breaks down with the Kantian time asymmetry between (given) past and (potentially) future events[19]. On the other hand, in a sense, the model still treats cosmic evolution as a phenomenon because it depends on

[19] Starting from this view, Boyce (1972: 68–69) rejects Kantian arguments because an infinite synthesis could only be potentially realised.

initial conditions (i.e., it is conditioned). In turn, these conditions can be seen either as given (no possible explanation is available for these aspects; things are as they are) or as a result of unrevealed physical mechanisms. In this latter case, new mechanisms operating in the very early universe would always regress to another (possibly perceived as more likely) initial condition. As shown, some approaches deal with this problem conceiving the initial conditions as a consequence of laws operating in a multiverse and, therefore, granting the quality of a physical object described in Section 2.3 to the universe. Some implications from this approach are discussed in Section 3.3.

In any case, it is a matter of fact that the relativistic formalism makes it possible to define global properties of the universe in a highly specific manner, moving away from previous fuzzy rationalist discussions. Those properties depend not only on theoretical assumptions guarantying physical and mathematical viability but also on the different energy components considered, the choice of which is motivated by what is observed. A perturbed FLRW model uniquely establishes the statistical properties to be observed at large scales from anywhere in the universe as a function of the cosmological parameters to be measured. However, it is not yet possible to consider the universe as an empirical object. The situation is even more critical than in Kant's time. Regardless of whether some characteristics can be attributed to the whole or not, the empirical domain within general relativity is necessarily constrained to the observable universe.

The process is analogous to what happens in other branches of physics. The theoretical framework enables cosmologists to develop scientific explanations of a range of phenomena in terms of physical mechanisms[20]. The observational evidence, in turn, fixes some aspects of the model that are parameterised. In practice, although the usual cosmological extrapolation of scientific laws being locally tested increases the degree of uncertainty of the framework, a detailed theoretical study of different stages of the universe results in new observational windows (i.e., new opportunities to refine and test the model's validity). In addition, these dynamics act as a research guide because they might change the direction of future technological and theoretical developments. Insofar as the framework itself is used to recover distances that are then used in the interpretation of data, all cosmological claims become model dependent. The fact that different observations are consistent with what is expected is interpreted as evidence that the

[20] However, whereas the observational consequences from models in other disciplines can be tested in countless instances, the standard cosmology has to deal with only one realisation. In principle, other universes only exist potentially, for instance, as the set of mathematically consistent models.

argumentative chain comprising the theoretical framework is correct and that it serves to predict and explain certain aspects of reality. As mentioned, in spite of the fact that they are modelled by the theoretical structure, it is still possible that the results from specific tests are in disagreement with expectations. Additionally, the fact that the model is designed to explain observations in a highly specific domain does not imply that all its observational consequences are restricted to it. For instance, the age of a single galaxy may raise questions about the framework, although identifying what is wrong would probably be a difficult task, given the complexity of the reasoning involved. In other words, the model can be challenged at any time by observations that do not fit the theoretical interpretation once other systematically effects are ruled out.

Nonetheless, some authors are concerned that the model may be able to fit any data. According to Ekeberg (2019: 149), «it is perhaps not surprising that cosmologists will prefer to tweak individual parameters rather than question the structure of the edifice itself»[21]. But actually, cosmologists are aware that the present cosmological model is far from offering a complete version of what is understood as the universe even under its own view (as shown, such an aspiration is necessarily asymptotical). On the contrary, they agree that the framework is nothing more than an effective approach, not only due to the fact that it operates in a specific application domain with statistically homogeneous and isotropic components but also because this approximate character could likely be the very nature of most of the cosmological parameters. Some elements of the model, such as the inflationary phase or dark energy, clearly account for certain effects without specifying any underlying physical cause[22]. In addition, the uniqueness of the universe prevents a clear differentiation between necessary and contingent elements (e.g., Ellis, 2014: 12). For instance, a theoretical approach that would deal with current initial conditions, such as the cosmological principle or the specific spectrum of quantum fluctuations, as a necessary consequence from new physical mechanisms could result in a substantially different conception of the entire universe. Finally, the initial singularity is also perceived as another hint of the limited scope of the model (e.g., Stevenson, 2012: 140).

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[21] For instance, Ijjias, Steinhardt and Loeb (2017: 39) have even stated that cosmic inflation is not a scientific theory on the basis that, in their opinion, it is always possible to adjust their parameters in order to fit the observations.

[22] The way in which ‘effectiveness’ is taken here is similar to Merritt’s application of conventionalism (Merritt, 2017).

According to Ellis (2014: 15), three requisites seem reasonable for a theoretical entity to be taken as real. First, it should play a fundamental role in a chain of a solidly based argument. Second, its consideration must have empirical consequences, which should be consistent with observations. Third, no alternative explanation without resorting to unseen entities should be available to account for the same phenomena. In light of these criteria, some theoretical entities of the model, such as the metric tensor[23] or dark energy, could be considered as real. Taken together, the system dynamics are interpreted in realist terms. In spite of that, an alternative model that involves a different notion of the universe might replace the current one in order to overcome some of the questions mentioned in the previous paragraph. Such changes would foreseeably affect to the so-called very early universe because the causal chain from the moments after the big bang until the present epoch is assumed to be better established. However, an unexpected discovery or the development of a new theory could still turn the picture around. For instance, according to McGaugh (2014), the present evidence of mass discrepancies is capable of being explained within the standard model in terms of dark matter, but alternatively of being interpreted as the need of considering a more general theory of gravity accounting for MOND-like behaviours. Therefore, in light of Ellis' criteria and without further evidence, the existence of dark matter (and hence, the explanatory power of the standard model) could be questioned in the case that a cosmological model based on Milgromian principles proves to be at least as useful as the former in consistently explaining the whole set of observations. Hence, the specific conception of the universe from the standard model should not be taken without some caution.

The problem is that this warning is not often made explicit to laymen. Pauri (1991: 293) distinguishes two different interpretations of the scientific universe, namely weak and strong approaches. Following the strong view, the universe is a sort of physical object to which some properties such as a topology, size or age can be attributed. In contrast,

[23] Using what is known as the 'hole argument', Earman and Norton (1987) ruled out an ingenuous substantivalist approach for space-time, in which a realist notion of space-time events leads to a local indeterminism. However, according to Rynasiewicz (1996: 304), this approach does not take into account the physical qualities attributed to space-time. In fact, it is common that cosmologists show a realist attitude towards the space-time manifold. As Rynasiewicz (1996: 295–299) showed, Einstein himself conceived of space-time in terms of an ether. Another example is Friedman (1983: 259–261), who, in a similar vein as Ellis, advocates in favour of a realist interpretation of the space-time manifold on the basis of its unifying power. However, it should be noted that cosmological models would provide just an effective characterisation of this entity; in particular, its appearance at large scales. According to many authors, space-time could be an emerging concept from a more fundamental notion (e.g., Musser, 2018), although there is still no well-established framework providing such an explanation.

according to the weak approach, the concept of the universe is used in a heuristic way to refer to the explanatory structure of a data set collected from the largest accessible scales. In practice, the attitudes of cosmologists sweep across the spectrum. But typically, they publicly disclose their findings in a way that leaves little doubt as to their penchant for the strong approach, although in many cases it may have to do ultimately with a question of economy of language. As a consequence, most people imagine the universe to be a physical object with the specific objective features widely broadcast in the media, such as a flat geometry, an age or an energy density, the values of which can be measured from observations. But actually, what they are really being told is that, according to standard cosmology, some of the cosmological parameters to be fitted to observations are interpreted as the local geometry favoured by the data, the time elapsed since the initial singularity that appears in the model or the value of an effective parameter referring to the energy density within the homogeneous and isotropic framework that has been demonstrated to be operational in the large-scale domain. Although all scientific conclusions are inevitably embedded in a framework, global properties of the cosmological case are out of the ordinary because they have no direct empirical counterpart. As will be shown below, without losing sight of the actual implications of some cosmological statements, they may deserve different levels of trust by virtue of their interpretation.

3.1 Cosmological statements

As argued in Section 2.2, cosmological laws can be identified in terms of the domain from which their explanatory power emanates. Under this characterisation, there would be no major problem in granting cosmological status to those statements that refer to magnitudes defined in a coarse-grain grid of large volumes. No other science apart from cosmology includes such large scales within its application domain. An example could be any general statement about the large-scale distribution of galaxies. In spite of that, because such distribution is only observable from a particular point, statements about global statistical isotropy are not rigorously supported, but they are assumed on the basis of consistency. In a similar sense, other cosmological statements refer to global features of the space-time manifold. In practice, they are extracted from the values of the cosmological parameters, which are not properties directly measured from an empirical object. Instead, those quantities are derived, in turn, from large-scale observables, and such a link is exclusively created by the theoretical structure. In particular, the cosmological principle enables researchers to extrapolate local observations to the global space-time. Insofar as the empirical consequences implied by the model are independently and consistently verified, cosmologists are typically willing to accept the validity of the entire framework and, therefore, to interpret its parameters in global terms. Claims such as 'matter makes up about 31% of the current energy density of the universe' are empirically supported, but they only make sense in terms of the model because their referent is not an empirical object.

However, as Manchack (2009) showed, the empirical evidence under-determines the global structure of relativistic cosmological models, so that the choice of a model belonging to the FLRW family is only justified if the cosmological principle is valid. Following Beisbart (2009), although this principle seems to be verified within the observable universe, global statistical homogeneity and isotropy are not epistemologically guaranteed. In spite of that, cosmologists discuss different theoretical alternatives in compliance with the use of certain rational criteria also in force in any other scientific branch, such as the economy or the unifying power offered by the different explanations in dispute. Judging by such criteria, the use of the cosmological principle seems to be the most natural option. Nonetheless, the absence of an empirical referent makes the consequences of this ultimately aesthetic negotiation much less reliable than analogous ones within other sciences. As mentioned, future unexpected discoveries could lead to significant changes in theoretical cosmology that may affect the way in which the universe is conceived. In such a scenario, although the observational consequences were almost the same, global cosmological statements might be significantly different from the current ones.

Although the above cosmological claims are usually not formulated in an appropriate language for an instrumentalist view, they still allow such an interpretation. On the contrary, there is another type of cosmological statement that requires a strong correspondence between reality and the model. Although referring to some observational evidence, they ultimately depend on the most interpretable elements of the framework. This is illustrated with the following common example, which resumes the topic of the Kantian first antimony: 'if the curvature parameter is null or negative, then the universe is spatially infinite'. In fact, there is nothing in the empirical consequences from the model that forces the global manifold to be simply connected (e.g., Ellis, 2007: 1215). Additionally, the presence of infinities in the model does not allow a unique interpretation. For instance, it seems to be natural to use the infinity in local models of general relativity to impose boundary conditions. On the contrary, under the global interpretation of cosmological models, it is common to conceive this spatial infinite in a literal way, consistent with the inherent cosmological premise about the existence of the whole. Another example is: 'there exists a huge number of bubbles in which cosmic inflation has ended'. Cosmological inflation is one of those effective elements of the model, considered insofar as it is a mechanism producing the accelerated expansion in the very early universe that seems to be necessary to explain the observations. The latter example is a consequence of the literal interpretation of a particular set of inflationary models. As discussed in Section 3.3, although it may be a promising approach, it is still far from being sufficiently justified.

3.2 Incommensurable universes

Insofar as each cosmological model generates a particular version of universe, selecting, in turn, what should be considered as relevant data, Pauri (1991: 316) claims that different approaches could yield incommensurable universes. In this sense, he argues that «instead of having a model (i.e. a provisional and pragmatic subsidiary scheme) for a theory, we have here a *theory for a model*». According to this view, it is as if, in the absence of an actual empirical referent, the model itself became the cosmological referent. However, although this is what some conclusions from cosmological research, expressed in prosopopoeic terms, seem to suggest, it should not be forgotten that the ultimate goal of cosmology is not to construct another cosmogonic myth but, rather, to provide reliable knowledge about the world.

As a matter of fact, all sciences make use of different frameworks in order to model some aspects of reality, and yet they are not supposed to study an object defined in self-referential terms. Cosmological models are indeed pragmatic schemes used for predicting statistical properties from specific observations and explaining the large-scale observed features of the world. In practice, cosmologists confront the real data to alternative frameworks assessing each fitting by virtue of standard statistical criteria. As mentioned before, different elements of the *best* model could be taken as real, for instance, by virtue of Ellis' criteria. Ultimately, as in other sciences, the epistemological constraints from Humean scepticism make the realist interpretation a philosophical decision, although the usual problems may be aggravated by the so-called endemic under-determination of relativistic cosmological models (Butterfield, 2012: 59).

Two different circumstances seem to make a difference in the cosmological case. On the one hand, testing the theory is a difficult task due to specific uncertainties associated with epistemological constraints (the presence of cosmological horizons) and theoretical extrapolations of local laws to inaccessible energy domains. On the other hand, its explanatory mechanism implies global consequences that cannot be directly associated with any empirical referent. Although some global aspects of the model could produce empirical consequences in highly specific configurations, as is the case for small universes (Ellis, 2014: 14–15), global properties of the actual universe remain under-determined by empirical evidence. Under these circumstances, the discussion about the universe as a whole cannot be settled without invoking rational arguments concerning the model selection[24].

3.3 The stochastic universe

All those aspects not included in the deterministic structure of the model are considered to be the result of chance. Hence, the actual universe is conceived within the standard model as a particular realisation of a total ensemble of potential perturbed FLRW universes. Given the set of measured values for cosmological parameters, an intrinsic uncertainty is attributed to the expected results from the model as part of the nature of the initial conditions, the so-called cosmic variance (e.g., Ellis, 2014: 12). Statistical arguments are also invoked in combination with anthropic necessities to avoid the issues raised by the apparent improbability of initial conditions that give rise to a universe compatible with observations (e.g., Collins & Hawking, 1973). In this case, the ensemble of universes is required to be ontologically realised for the argument to work as an explanation. On the model-selection level, the epistemological constraints to obtain global conclusions encourage cosmologists to discuss, for instance, the statistical significance of a FLRW model compared with other non-isotropic configurations. In these contexts, a Bayesian approach has been used to determine whether applying the Copernican principle is sufficiently justified (e.g., Beisbart, 2009: 188), although such an approach is not ultimately operational because there is no unique procedure to assign a probability to each physical configuration.

[24] Even from an exclusively theoretical point of view, the global nature of the universe is not completely determined. For instance, FLRW models have nothing to say about topology (e.g., Ellis, 2014: 9).

Moreover, some inflationary models pose a scenario in which our universe is only a bubble in a larger whole where different physical configurations could be realised. In this context, not only the initial conditions but also the physical laws are allowed to vary from one universe to another. However, more importantly, within this mechanism, universes would no longer be considered as potential but rather as ontological entities. In spite of that, because epistemological constraints would remain the same, nothing could be said about those configurations that are not realised within the observable universe. Consequently, the most natural option seems to consider a sort of equiprobability criterion, although this approach is not univocal either (e.g., Norton, 2010: 506). According to Ellis (2014: 15), the universes assumed within the multiverse hypothesis do not satisfy any of the requirements mentioned at the beginning of this section to be considered as real. On the one hand, *a priori* assumptions are required in order to define a probability measure in the multiverse, which would compromise the entire predictive power of the model. On the other hand, except in particularly exceptional circumstances, the existence of such a multiverse seems to be untestable. Additionally, this kind of multiverse does not seem to be the unique possible explanation for the current observations.

4. Conclusions

Similar to frameworks in other sciences, cosmological models are assessed in terms of pragmatic usefulness, insofar as they are used to predict statistical properties and provide a scientific explanation for large-scale observations. In particular, a relativistic model of the universe defines a physical system, the dynamics of which, as far as is known, can be effectively interpreted in terms of cosmic evolution. As a result, it is possible to establish cosmological laws, which can be distinguishable in terms of the domain from which their explanatory power emanates. In addition to this consistent framework for large-scale data, standard cosmology provides a specific strategy for defining some global properties of that physical system. Insofar as they are interpreted as properties of the universe as a totality, this possibility rekindles old debates about the existence of the whole as an object of scientific analysis.

Are contemporary cosmologists in a better position than Kant? The answer is an unqualified yes because relativistic models allow the whole to be constrained not only according to rationalist terms but also taking into account physical considerations. The standard cosmological model makes it possible that cosmic evolution can be treated as a physical phenomenon. However, this does not imply that all Kantian objections have been solved. On the contrary, the Kantian conclusion that the universe is not an empirical object is more present than ever because cosmological horizons within general relativity inevitably constrain our epistemological domain. Additionally, because the empirical evidence is not sufficient to unequivocally select a unique cosmological model, the discussion about the under-determined global properties depends ultimately on philosophical preferences. Given the current theoretical alternatives, the standard model is claimed to be the best reasonable option. There is nothing special about this selection among possible models, in the sense that it is based on standard criteria that are also applied in other sciences. What becomes problematic is the realist interpretation of such properties because, in the absence of the corresponding empirical referent, they entirely depend on the philosophical approach, which in turn implicitly assumes the existence of the totality. Certainly, the assumption of the cosmological principle seems to be absolutely reasonable, but it implies beforehand the consideration of a global system.

Due to the fact that there is no direct empirical counterpart, claims about under-determined global properties are not robust. Given the risky extrapolations of local laws to the extreme conditions in the very early universe, and considering the acknowledged effective character of the model, it seems highly likely that future discoveries will lead cosmologists to prefer a different model that, barely including new elements on the present-known observational spectrum, will imply significant changes in the global conception of the universe. Among the possible innovations, there could be epistemological implications. In fact, some epistemological constraints are perceived within the standard model as a result of contingent elements, such as the tremendous size of our actual universe. Be that as it may, the present explanatory mechanisms from physical cosmology have cosmogonic implications considered outside the reach of science until recently. As a matter of fact, although cosmology is not able to forcefully respond to the so-called 'big questions' (Ellis, 2014: 5), it is already able to offer some powerful conclusions, such as that the cosmos does not always look the same.

Finally, it is argued that there is insufficient evidence so far to support from physical cosmology a notion of the universe as a physical object. Methodologically, local laws are assumed to be valid at large scales, avoiding the necessity of laws living on a metaphysical plane. Ideally, although each model requires a set of initial or boundary conditions to be specified, cosmology aspires to asymptotically account for the entire universe. In practice, as Kant claimed, searching for successive explanations for the specific initial conditions that led to our actual universe within a big-bang framework regresses to primary initial conditions that may be conceived as inexplicable premises without reference to anything outside the universe itself (see, e.g., Stevenson, 2012: 129). Additionally, those theoretical frameworks, such as some models of cosmic inflation, giving rise to different universes are not yet sufficiently justified to sustain the ontological claim of a multiverse.

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