How contemporary cosmology bypasses Kantian prohibition against a science of the universe[1]

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If someone in my laboratory begins to talk of the Universe,
I tell him that it is time to leave.
Ernest Rutherford[1]

1 Introduction

It is well-known that Kant, in the *Critique of Pure Reason*[2], discusses explicitly the conceptual limitations to which all our cosmological speculations are subjected. He suggests that the universe as a whole, the object of cosmological explanation, is not an object of possible experience, and, consequently, of knowledge; whence his renunciation of a cosmology as a science, i.e. of a rational cosmology that can explain the cosmos in its totality. His meditations on cosmology claim to prove that the ultimate basic questions potentially pertaining to cosmology about the universe – its finiteness in space, its origin in time – do not stand up to critical examination and are rationally insoluble: it is possible to give apparently cogent reasons to support opposite views in both questions, but then one arrives at what seems to be a contradiction (the so-called cosmological antinomies), and neither answer can be definitely accepted.

But how does Kant reach this result and, above all, what is its epistemological effect on modern cosmology, on its scientific status, in particular in the light of the cosmological principle, generally considered a cornerstone in history and in the foundations of cosmology, and one of the fundamental tenets of its modern standard relativistic models?

[1]We thank Michel Ghins, Gino Tarozzi and Jos Uffink for their meaningful comments to a preceding presentation of this argument.

[1]Unruh (1987, 110). See also Disney (2000, 1133) and Ćirković (2002, 128).

[2]Second book of *Transcendental Dialectics*. Here we are not concerned with what Kant actually said; on the contrary we are discussing cosmological problems in a generic Kantian style.

2 Kant's attitude

Kant distinguishes between *understanding* and *reason*: the former applies to experience, but not the latter. Reason is the faculty that guides a priori deductions from premises to consequences. Understanding works through *concepts*, which apply to *intuition* – either sensible or pure – whereas reason involves *ideas*. The latter cannot be applied to experience, since they have no empirical correspondent. They are called *transcendental* when they determine the use of understanding in the whole realm of experience. Hence transcendental ideas refer to the notion of *totality*.

Since ideas have no empirical application, they seem useless from a cognitive point of view; nonetheless they provide a guide for understanding. Therefore it is true that in process of knowing, ideas play no *constitutive* role, but they play a *regulative* one.

In particular, reason can push understanding either from premises to consequences, or vice versa from consequences to premises; the former is the *progressive* use of reason, the latter the *regressive* one. The progressive use goes from *condition* to *conditioned*, vice versa it holds for the regressive use. It subsists a similarity between the progressive use and the development of a mathematical *succession*, of which one knows the general term that is the condition; for instance:

$$\frac{1}{2^n} \quad n = 1, 2, 3 \ldots \rightarrow \frac{1}{2}, \frac{1}{4}, \frac{1}{8} \ldots,$$

whereas the regressive case is analogous to a series, of which one does not know if it converges; for instance:

$$\sum_{n=1}^{\infty} \frac{1}{2^n} = \frac{1}{2} + \frac{1}{4} + \frac{1}{8} + \ldots = 1 \qquad \text{converging series}$$

$$\sum_{n=1}^{\infty} n = 1 + 2 + 3 + \ldots = \infty \qquad \text{diverging series}$$

Cosmological ideas concern the *unconditioned* totality of *phenomena*[3]. The *composition* of all phenomena, that is the *universe*, deserves particular attention. Kant aims to show that the notion of the universe is an idea, so that it has a regulative scientific value and not a constitutive one. On this matter he develops the following proof:

K1. In the progressive use of reason the condition determines each conditioned member, as occurs in the case of successions. On the other hand, in

[3] Contrary to Kant, we avoid ascribing a cognitively devaluating character to the term "phenomenon" (*Erscheinung*).

the regressive use the conditioned determines the condition only if the conditioned is *intuited* in its totality. That is, in our mathematical metaphor, only if the series *converges*. For instance, all parts, into which a segment is divisible, are intuitable in their totality[4].

K2. The notion of universe is not intuitable in its totality; therefore it is like a divergent series. That is, it is an idea, i.e. it concerns the unconditioned.

If the universe is an idea, then a *rational cosmology*, that is a partly a priori science of the universe, considered as a whole, is not possible. Given this impossibility, one might ask if a completely *empirical* cosmology is not possible as well. According to Kant, though enriched by empirical data, a science must have a synthetic a priori foundation. This is impossible, because the universe does not belong to the realm of *possible experience*. Even though in modern science we do not believe that a totally a priori part is necessary, we introduce many theoretical terms, which have a definition substantially independent from experience. It follows that today ripe physical theories have an a priori part as well, although it is not necessarily a priori, that is this part could be changed in future research. Hence the Kantian problem is in a certain sense still alive. We will see that the solution of the problem lies precisely in the fact that the a priori part of cosmology must be completely revisable.

Nevertheless the universe is not a mere fancy (*Hirngespinste*)[5], indeed it plays a regulative role for science. That is the universe is not removed from experience in the sense that it is a schema formulated without the guide of intuition, but it is something unconditioned, namely it is beyond the limits of experience. In our mathematical analogy, it is a diverging series.

Hence when reason asks if the universe has a beginning in time or an end in space, it finds arguments favouring both a positive (*thesis*) and a negative answer (*antithesis*), so that reason is not able to decide. The common-sense necessity of finding a limit to space and time favours a thesis, whereas the impossibility of intuiting such a limit favours an antithesis. Moreover Kant underlines that the thesis is more reassuring, albeit less likely, whereas the antithesis is less popular but more likely.

The solution of the two *antinomies* is dialectic. To understand Kant's proposal, one can reflect on the fact that there is a difference between the following two pairs of statements:

x smells $\qquad$ x does not smell

[4] It should be noted that here the problem is not infinity, but *boundlessness*.

[5] *Critique of Pure Reason* (A 222, B 269).

x smells good x does not smell good

The first pair, in fact, is *contradictory*, that is one of the sentences must be false and the other true, whereas the second is a dialectic *contrariness*, that is the statements could be both false, if, for instance, x is odourless. The cosmological antinomies are similar to the latter.

3 The scientific character of cosmology

We can reformulate the Kantian problem in the following manner. Let o be an object belonging to a collection identified by the set of predicates P. Then, if one observes a certain number of objects of the category P, for which Ux holds, one can suppose that:

G. For every x, if Px, then Ux.

G. concerns a potentially *infinite* set of objects, which could stay in different parts of space and time. Can we suppose that G. holds good for each P-object in the universe? If the number of investigated P-objects is sufficiently large and diversified, the answer could be "yes". The reason is that G. could be part of a theoretical background with a certain capacity to represent reality. This is a realist *justification of induction*[6].

Now, we can ask: if G. holds for every P-object, does it give information about the universe? No, because we have no issue about the universe as an unitary object. To understand this point, let us consider the following example: a big box is filled with objects of different kinds. Although through observations one can generalise about one or more kinds of objects, one cannot affirm anything about the box as a whole. In order to transform generalisations about kinds of objects into generalisations about the box, one has *already* to know something about the box as a whole. But we know nothing about the whole, i.e. concerning either the box or the universe. The whole is indeed the problem[7]. Inductive reasoning, employed as a form of argument-by-experience, is not useful in cosmology:

> In so far as inductive reasoning is the attempt to provide good reasons for inferring something about unobserved instances, on the basis of observed instances, it has to do with the inference to further *instances* of some regularity or *law*. However, the problem faced in cosmology is not that of finding a warrant in

[6] See for instance Glymour (1980, 110): "Confirmation or support is a relation among a body of evidence, a hypothesis and a theory".

[7] For instance, Agazzi (1991).

> experience for establishing *laws*. This is the task of ordinary physics (Munitz 1965, 62).

The aim of cosmology, rather, is to say something about *the* box, its dimensions and its global properties, that is its being that self-contained and singular "thing" to which our objects (the observed universe) belong. For this purpose, we do not need a law, but – as we will see later – a model of the universe. Consequently, if "nothing certain is known of what the properties of the spacetime continuum may be as a whole", as Einstein said in 1929[8], the universe as a whole could have properties different from those discoverable in its local parts.

On the contrary, to justify cosmological induction, Sciama (1961) looks at the so-called *interconnectedness of the universe*: each part interacts with each other part; these interconnections have the same importance both between local and very distant regions, so that, at least in principle, it would be possible to obtain some understanding (or, even, completely deduce the nature) of the whole from any of its parts. Sciama's argument seems strong, but actually it presupposes what it wishes to prove. Indeed we know with certainty only that the visible universe is interconnected, but in order to extrapolate this issue to the whole universe, the cosmological induction that the interconnectedness alleges to show is necessary.

Moreover, the expression "the universe as a whole" is susceptible to different interpretations. According to Munitz (1986, 60-69), there are two basic ways to understand it: realist and pragmatist. For the first interpretation the "universe" is the name of an existing entity, with its own inherent properties and an intelligible structure; "the universe as a whole" designates just this entity, whose existence is independent of, and antecedent to, every cosmological investigation. The aim of cosmology is to discover its structure and its properties, by a continuous research process consisting of improving the correspondence between the statements of cosmological theories about the universe and the independent objectively existing facts about its peculiarities. The second interpretation, on the contrary, does not presuppose as necessary the existence of an independent entity; the concept "the universe as a whole" is only a theoretical construction, that plays a merely pragmatical role, introduced implicitly or explicitly by every cosmological model. Munitz (1986, 61) explains the meaning of this concept, that here comes into being only with the elaboration of the cosmological model itself, in this way: "The maximally comprehensive domain of physical objects, processes, and phenomena as this is defined, described, and made intelligible by means of the conceptual resources employed in the given model".

[8] Quoted in Kragh (2007, 142).

Our concept is then inserted in a general schema, by which it is possible to interpret observational data (i.e. of the observable universe), to make predictions and inferences about what lies beyond the observable region. All this without presupposing an entity antecedent to cosmological inquiry: on the contrary, the meaning and sense of the term "the universe as a whole" emerge through the evaluation of different competing models[9].

We adhere to the first interpretation both for personal philosophical convictions and for a simple "a priori" reason: if cosmology were considered, from an instrumentalist perspective, only as a mere account of observational data, without presupposing a *real* existence of the cosmos, then our Kantian problem of cosmology as a science would simply disappear, because one limits the epistemological import of cosmology only to the visible universe.

Many aspects of cosmology have always been problematic, but this one, pertaining its own most classic definition, crosses its entire modern history. More than fifty years ago, for instance, Gerald James Whitrow and Herman Bondi (Whitrow-Bondi 1954) already discussed about the possibility of a cosmology as a science: Whitrow maintains that physical cosmology will remain a border-line subject, whose origin is really ancient, between sciences and philosophy, whereas Bondi affirms, as in his book *Cosmology*[10], that cosmology is a recent young branch of physics, not of philosophy. Recently, this debate has been renewed by Disney (2000), a British extragalactic observational astronomer, and Ćirković (2002), a Serbian astronomer and philosopher: the former lists all particular difficulties for cosmology as a science and other general criticisms to the cosmologists' methodology and achievements: cosmology would rest on a very small database, and some of its recent claims would be very overblown, manifesting an enormous gap between observation and theory; the latter replies harshly, discovering all the epistemological fallacies in Disney's criticism, considered old-fashioned, like those of Dingle[11].

With respect to this cognitive situation, many scholars maintain that cosmology, as a science of the whole universe, is not possible. For instance Agazzi (1991), but also Barrow (1988), a cosmologist, affirms that cosmology is not a science of the universe, but only a science of the *visible* universe[12]: whether the universe is literally a complete, unique, and intelligibly

[9]See also Munitz (1965, 58-63).

[10]Bondi (1952); see also Bondi (1957).

[11]A brief allusion to Dingle's criticism is at the end of this paper.

[12]How is the visible universe composed? Whenever there has been enough time for radiation emitted by an object to reach an observer, then that object belongs to the "visible" (or "observable") universe (of that observer), thus we can define it as the space inner to a sphere, centered on the observer, whose radius is that of the cosmological horizon (the so-called *surface of last scattering*, when the universe became transparent).

structured whole is an irresolvable problem, since we can refer, by direct experience, only to the observed universe. Rosen (1991), for instance, sustains that the material universe as a whole lies outside the domain of science, because it is a unique phenomenon and, as such, is inherently irreproducible, thus cosmology is basically metaphysics[13]. At the heart of the *uniqueness problem* there is the difficulty to distinguish physical laws from boundary conditions, that is, general features from particular aspects of our universe: "What appears to be an inviolable physical law may just be a consequence of the particular boundary conditions that happen to hold in this particular universe", says Ellis (2006, 2)[14]. The distinction between what is individual and what is universal, for the universe as a unique system, breaks down. This theme of the uniqueness of the universe is, however, another cosmological problem with respect to the justification of induction seen before, but both constitute what gives cosmology its particular unique nature as a presumptive science[15].

4 The cosmological principles

However, to overcome, at least partially, the *impasse*, it is first of all necessary to remember – with Kanitscheider (1990), Harrison (2000) and van Fraassen (2002) – that cosmology does not produce a complete description of the Universe, with a capital "U", but it formulates possible models of a few important physical features of the Universe[16]. If at every age, a culture constructs its *own* model – religious, artistic, philosophical or scientific – of the Universe[17], and each model is only one of many possible representations, "a different cosmic picture that is like a mask fitted on the face of the unknown Universe" (Harrison 2000, 13), then each of our contemporary cosmological models, too, really explains only the model *u*niverse and not the actual *U*niverse. "The universe is what a cosmological model says it is", Munitz (1986, 62) declares lapidary.

Secondly, Einstein already in his 1917 paper, introduced, but without

Obviously, the *observable* universe could be very different (smaller, but also bigger) from the *actual* universe.

[13]Therefore, cosmological *schemes* (the inflationary big bang, for example), although of immense value for science, should not be considered *theories*, but only attempts to *describe*, and not scientifically *explain*, the fabric of the cosmos.

[14]See also Bergmann (1970).

[15]For a recent survey on cosmology and its intrinsic philosophical problems see Ellis (2007).

[16]This does not mean that we endorse what Munitz calls the pragmatic approach, but only that in order to accomplish a scientific cosmology, one has to renounce a science of everything in a literal sense.

[17]In the history of science we can distinguish, for example, between the Pythagorean model, the Atomist model, the Aristotelian model, and so on.

elevating it into a general principle, what would be called, and better formalised, by the English astrophysicist Edward Milne in 1933, the "cosmological principle"[18], according to which[19]:

The universe, at a given cosmic time[20], *is spatially homogeneous and isotropic on sufficiently large scales*[21].

The expression "large scales" relates to the fact that the actual universe possesses local irregularities, so it is evidently inhomogeneous at the scales of galaxies and clusters of galaxies. However, to give a precise definition of what is meant by "sufficiently" is not easy: in any case, to be meaningful, this term must be small compared to the universe as a whole, or to that portion of it, which, at a particular moment, is theoretically observable[22]. Strictly speaking, homogeneity and isotropy mean, respectively, an absence of both privileged points and directions. However, the cosmological principle is not alone: the universe is not only homogeneous and isotropic, but also it looks the same to all observers. The cosmological principle is a development of this last observer-equivalence (from a certain point of view more fundamental but less powerful) statement, usually called the *Copernican principle*[23]. It formally states:

[18] However it should be emphasised that "Milne is often credited with the enunciation of this principle, even though he repeatedly accords the honour to Einstein's celebrated cosmological paper of 1917 [...] Yet, the formulation is quite absent from Einstein's pioneering work; the term seems to have been first introduced as a tool for systematization by Robertson in his review paper on the state of cosmology in 1933 [...] Einstein spoke of uniformity only to conform with what he took to be the facts as presented to us by the astronomers. There is no doubt that in Milne's eyes the principle refers to a theoretical, yet covert aspect of Einstein's thought" (Kerszberg 1987, 351). The name "cosmological principle" was coined, according to Milne himself, by the German astronomer Erwin Freundlich. For other etymological aspects see Kragh-Rebsdorf (2002), where, on p. 39, we are reminded that: "Whereas in his early works Milne considered the cosmological principle to be a hypothesis of the large-scale structure of the world, from 1935 onward he regarded the principle 'simply as a definition, defining what system we propose to consider' ".

[19] We do not consider the perspective of the inflationary universe, see for instance Turner (2001).

[20] It is beyond the limits of this paper to discuss the important problem of the definition of a cosmic time. It is enough to say that it can be defined if homogeneity and isotropy themselves hold.

[21] See Weinberg (1972), Peebles (1993).

[22] Weinberg (1993, 24), for instance, speaks about scales at least as large as the distance between clusters of galaxies, about 100 million light years; Ohanian (2000, 689), instead, refers to distances superior or equal to 100 megaparsecs.

[23] The reason for this name is evident: Copernicus reminds us that Earth has no special status in the solar system. A similar consideration could be extended to our solar system, our galaxy and so on. In Rowan-Robinson's (1996, 62) opinion, however, the first clear

No place, in the universe, is in a central or specially favoured position.

Together, these two principles affirm that the general picture of the universe, as seen by an observer from different locations, is essentially the same, that is, every observer is equivalent to every other one and the universe, as seen from Earth, is the same as seen by other observers at other points (this is the homogeneity); and also they affirm that there is no observable difference between different directions: the universe appears the same to every observer from whichever perspective in the sky (this is the isotropy). Sometimes the cosmological principle formulation includes the Copernican principle, as in Milne's original form of 1933: "Not only the laws of nature, but also the events occurring in nature, the world itself, must appear the same to all observers, wherever they may be, provided that their space-frames and time-scales are similarly orientated with respect to the events which are the subject of observation". As Rowan-Robinson (1996, 63) underlines, the cosmological principle explicates the Copernican principle in almost the strongest possible way. Furthermore, the Copernican principle makes it possible to derive the homogeneity by extrapolating it directly from the isotropy, utilising the observational evidence that the universe seems to exhibit spherical symmetry around us[24]. We note, finally, that this equivalence of distribution of matter relative to any observer is confirmed only if observations are carried out simultaneously.

By means of this principle, it is possible to transform statements about objects contained in the universe into statements about the universe itself: the cosmological principle "unites the universe into a homogeneous whole", Harrison (1985, 175) summarises. But what about the evolution in time?

statement of this principle is due to Giordano Bruno – even if, since the Italian philosopher lacks any more precise astronomical knowledge, his statement tastes of a poetic, psychological, and even political flavour; others, too, trace its origins (although completely metaphysical-religious) back to Cardinal Nicholas of Cusa, who, in the fifteenth century, in *De Docta Ignorantia*, wrote: "The fabric of the world has its centre everywhere and its circumference nowhere" (see Pagels (1985, 146), Harrison (1985, 174)), and he suggested that: "Wherever the observer is placed in the universe that will appear to him to be the centre" (see Whitrow-Bondi (1954, 276), Kragh (2007, 46)). Harrison (1985, 250) traces its birth back even to Democritus, and – reminding us that Lucretius said: "The universe stretches away just the same in all directions without limit" – he notes that the concept of cosmic homogeneity originated with Anaxagoras and the atomists, and re-emerged in the late Middle Ages.

[24]See Bondi (1952, 13) and Weinberg (1993, 23-4). It should be remembered that homogeneity by no means implies isotropy: in Gödel's model, for instance, the universe is homogeneous but not isotropic; the same holds for a universe with a large-scale magnetic field pointing everywhere in the same direction and having the same magnitude at every point.

The cosmological principle can be generalised in the following way:

The universe, at all cosmic times, *is spatially homogeneous and isotropic on sufficiently large scales.*

The last principle must not be confused with what defenders either of the steady-state[25] or of the inflationary universe call the *perfect cosmological principle*:

Universe, considered at large scale, is immutable, *that is it is temporally homogeneous as well*[26].

Thus, if cosmological principle requires only homogeneity and isotropy in space at each cosmic time, perfect cosmological principle adds the further requirement that the physical distribution is the *same* at every cosmic time. For instance, a universe homogeneously filled by a magnetic field of magnitude M at time t_1 and homogeneously filled with a magnetic field of magnitude $2M$ at time t_2 is always spatially homogeneous, but not temporally homogeneous.

This principle is at the heart of the aforementioned steady-state cosmological model, an alternative to the hot big bang model developed in 1948 by the British astronomer Herman Bondi and the American astronomer Thomas Gold[27], and, separately, by the British astronomer Fred Hoyle[28]. Bondi and Gold developed a deductive approach using the perfect cosmological principle axiomatically, while Hoyle's more mathematical version derived the basic features of the steady-state model using field theory, adding a term to Einstein's gravitational field equations. The steady-state theory considers the universe stationary, that is its general aspect is the same, but this does not signify an absence of large-scale motions. The most prominent characteristic of this model is that if the universe always has to look the same, irrespective of the place and time of the observer, then a continuous spontaneous creation of matter needs to keep the density of the expanding universe constant (otherwise, granted the expansion, the average density of matter would decrease with time as galaxies move away from one another). According to Dennis Sciama (1961, 167), the steady-state model is superior

[25] For instance Jaakkola (1989).

[26] Einstein's formulation was a form of perfect cosmological principle as well, but his static model of the universe was highly unstable under perturbations, and it was empirically falsified by subsequent expansion observations.

[27] Bondi-Gold (1948).

[28] Hoyle (1948). He called this principle the *wide* cosmological principle, in contraposition with the usual, and by him adjectivized *narrow*, cosmological principle.

because, if one aim of science is to show that the features of the universe are not accidental (a valid theory ought to be indifferent to the choice of initial conditions), and only a universe as a whole unchanging in time should concede this possibility, then the steady-state model "is the only one in which the properties of galaxies and the cosmical abundance of the elements can be calculated without any accidental initial conditions. This model is the one that satisfies the perfect cosmological principle"[29].

Today this theory is abandoned by most cosmologists, and the principal reason for this abandonment is the discovery of cosmic background radiation, "the final nail in the coffin of the steady-state theory", as Stephen Hawking eloquently said[30]; also properties of radio sources and cosmic helium abundance (about one quarter of the total cosmic mass) are more suitably explained in a big bang model than in a steady-state one.

5 How is a scientific cosmology possible?

Now we have generalisations about the content of the box and a principle about the global structure of the box, but by means of which theory we should connect the former with the latter? Again it was Einstein in his 1917 paper who gives the answer: *general relativity*, the theory that in almost complete solitude he had just established.

To sum up, contemporary cosmology is made possible by the following three issues:

1. astrophysical generalisations, which come from observations. In our previous metaphor, the former are analogous to the generalisations on the content of the box. Thus cosmology is fed by astrophysics.

2. the cosmological principle. We have outlined sufficiently this concept in the preceding paragraph.

3. general relativity. It is our best theory of gravity, the dominant force on the cosmic scale. Obviously, though general relativity is the basic ingredient of cosmology, electromagnetism, thermodynamics and particle physics play a secondary but important role. The consequences, for the geometry of space, of the cosmological principle are expressed in the so-called *Robertson-Walker line element*, which constitutes the spacetime metric of the universe. Using the metric tensor of this line element in the field equations of general relativity, we get an equation with different solutions, each representing a special model of the universe.

In the next paragraph we will pose the following question: what is the

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[29] Only future observations, he continues, will decide whether the universe *really* satisfies this principle (see also McMullin (1994)).

[30] See his Public Lecture at http://www.bbc.co.uk/science/space/spaceguide/hawking/transcript2.shtml.

epistemological status of the cosmological principle? Now, however, before entering into that crucial *philosophical* aspect, it is important and, above all, useful, to set the cosmological principle in its effective *scientific* background, casting a quick glance at the peculiarities of modern cosmology and at its main aspects, in order to understand why this principle is so determinant in the last century cosmology, and why it is accepted today by virtually all cosmologists, whatever their theoretical persuasions are.

We can briefly divide cosmology topics into three separate sections – *cosmography*, *theoretical cosmology*, and *cosmogony* –, bearing in mind, however, the importance and richness of their interconnections[31].

The first aspect, *cosmography*, concerns objects in the universe, our cataloguing them, and charting their positions and motions. From our observation point (the Earth), our only information about them is contained in the directional distribution, and spectral composition, of their electromagnetic radiation.

The second aspect, *theoretical cosmology*, is the research for a theoretical framework where information from cosmography can be organised and comprehended. Physical laws, established on and near Earth, are employed and – "outrageous extrapolation" (Berry, *ibid.*)! – are applied throughout the universe. The latter is an important assumption, because we need really "to escape" from the narrow limits of our observation point. We note that even though laws of physics are valid *throughout* the universe, this does not mean that they are valid *for* the universe as a whole, an extrapolation even more problematic than the preceding one, which, as we have just seen, is based on the cosmological principle.

The third and last aspect, *cosmogony*, is the most hazardous part of cosmology, where laws of physics are extrapolated to the most distant times and places, in order to study both the remote past (and the origin, supposing that it exists) and remote future of the universe.

In this very general picture of modern cosmology, the physical-mathematical power of the cosmological principle resides in the fact that we are able to determine, by its apparently simple assumptions, some remarkable features concerning the metric which describes cosmological spacetime. Indeed, a direct consequence of homogeneity is the existence, as already suggested, of a universal cosmic time; moreover, the cosmological principle implies that the three-dimensional physical space of the universe must either be static, or expanding, or contracting, uniformly (to our observational knowledge it is expanding)[32]. Another immediate mathematical consequence of the

[31] See Berry (1976, 1).

[32] The simple assumptions of homogeneity and isotropy make it possible to deduce *kinematically* the *Robertson-Walker metric*, that is to say, before involving a *dynamical*

principle of homogeneity is that the relative speed of any two galaxies must be proportional to the distance between them[33], and this is precisely the famous empirical law found by Hubble, a law that is at the foundations of big bang cosmologies[34].

Finally let us look briefly at the cosmological principle's observational supports. First of all, it has been confirmed in a spectacular fashion by the detection, in 1965, of cosmic microwave background radiation, that is the relic heat left over from the big bang (the oldest thing in the universe so far discovered!). This radiation bathes the whole universe, and its temperature (2.725 °K), according to a large variety of experiments on various scales of directions, does not vary by more than roughly one part in 100,000 from one side of the sky to the other. This highly uniform distribution of intensity indicates that the universe was extremely isotropic and homogeneous even as far back as about 300,000 years after the big bang (i.e. since radiation went out of equilibrium with matter). In addition, the number counts of distant radio sources show that their average distribution is the same in all directions; the distribution of distant optical galaxies and the distribution of intensity of the cosmic X-ray background radiation seem extremely uniform as well.

To sum up, nowadays astronomers observe isotropy, and cosmologists postulate homogeneity. However, the empirical pedigree of the cosmological principle has been sometimes challenged: Ellis (1978), for instance, by elaborating a particular model of an inhomogeneous and isotropic universe completely consistent with all available empirical data, warns about an uncritical acceptance of this principle, sustaining that it is guaranteed more by philosophical commitments than by empirical evidences[35]. We will see in the next paragraph that this epistemological position is at least problematic.

6 The epistemological status of the cosmological principle

In order to look for an answer to the question concerning the philosophical status of the cosmological principle, and its being a non directly verifiable as-

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approach constituted by Einstein's equations!

[33]See Weinberg (1993, 22), Ohanian-Ruffini (1997, 453).

[34]We note – with Weinberg (*ibid.*, 23) – that we can read this fact *both* in the sense that Hubble's observations are an indirect confirmation of the truth of the cosmological principle, *and*, contrariwise, in the sense that the cosmological principle, taking it for granted on a priori grounds, confirms, or implies, Hubble's law. The meaning of our paper is precisely a methodological argumentation favouring the former approach.

[35]Collins-Hawking (1973) even argue that if the universe were not isotropic life might not exist.

sumption[36], one can scan the epistemologically most careful handbooks and treatises of cosmology and relativity: for instance Penrose (2005), Rindler (1977; 2006), D'Inverno (1992), Harrison (2000) etc[37]. Even if agreement as to its validity and its utility is very remarkable, there is wide divergence of view as to its necessity, significance and logical position: it is not always clear if the cosmological principle is adopted either as an idealisation dictated by the lack of more precise information, or if it is proposed as normative, that is as a restriction on all possible models of the universe. However, in the literature there are essentially three kinds of justifications for the cosmological principle[38]:

A. Leibnizian. One can generalise the Copernican point of view, that is there are no reasons favouring the fact that we find ourselves in a special part of the universe. Therefore, if the visible universe is homogeneous and isotropic, then the whole universe should be the same. For instance, Weinberg (1993, 23) says: "Since Copernicus we have learned to beware of supposing that there is anything special about mankind's location in the universe. So if the universe is isotropic around us, it ought to be isotropic about every typical galaxy".

B. Baconian. The visible universe is homogeneous and isotropic, therefore, one can generalise to the whole universe the same properties, as Schutz (1985, 319) affirms:

> The simplest approach to applying general relativity is to use the remarkable large-scale uniformity we observe. We see, on scales of 10^3 Mpc, not only a uniform average density but uniformity in other properties: types of galaxies, their clustering densities, their chemical composition and stellar composition. We therefore conclude that, on the large scale, the universe is homogeneous. What is more, on this scale the universe seems to be isotropic about every point.

C. Kantian. The cosmological principle is an a priori postulate that makes scientific cosmology possible. For instance Coles-Lucchin (1995, 6) affirm: "It would be very difficult for us to understand the universe if physical conditions, or even the laws of physics themselves, were to vary dramatically from place to place". This last Kantian justification often contains an ulterior working hypothesis needed to overcome our present (only present?) ignorance of the universe as a whole and useful to obtain more progress in

[36]See Ellis (1975).

[37]To our knowledge the best cosmological book from an epistemological point of view is Bergia (2002), which unfortunately has not been translated into English.

[38]On this topic see also Raychaudhuri (1979, 2-7), who distinguishes three possible justifications: mathematical, deductive, and empirical.

cosmological investigations: Bondi (1952, 13) calls it a *simplicity postulate*, that is the universe should be as simple as possible, hence it is uniform. As Rowan-Robinson (1996, 63) points out: "The mathematical difficulties of describing and discovering the properties of an inhomogeneous universe are formidable. We therefore have to hope that the homogeneous models [...] are a reasonable approximation on the large scale, bearing in mind that there is so far no successful explanation of why this idealised state of affairs should hold".

Now, it is clear that these three kinds of justifications are not always separated in cosmological literature, but they often go together. Listen to the following statement by George Gamow, that contains all three: the Copernican generalisation is evident, the Baconian viewpoint resides in the middle, and the necessary apriority is a little hidden, but really important, being repeated in those lapidary verbs (our italics) that do not concede alternatives to the possibility of the cosmological enterprise:

> In studying the structure [of the universe] we *must* accept the Copernican point of view and deny to man the honour of a privileged position in the universe; in other words, we *must* assume that the structure of space is very much the same in distant regions as it is in the part we can observe. We *cannot* suppose that our particular neighbourhood is specially adorned with beautiful spiral galaxies for the enjoyment of professional and amateur astronomers. (Gamow 1957, 390)

The proponents of the steady-state theory (Bondi and Gold) were probably guided more immediately by this last form of an a priori principle[39], both for the possibility of the cosmology[40] and for its natural intelligibility (it sometimes seems that they too preferred to save the perfect cosmological principle as opposed to the principle of conservation of energy). However, once again we meet an eclectic position, since in other contexts their adoption of the perfect cosmological principle seems neither categorical nor apodictic, but conditional, that is empirically falsifiable: "If it should turn out to be false then progress in cosmology will be infinitely more difficult to achieve" (Bondi 1952, 141).

Against the Baconian point of view, the argument proposed by Barrow holds, according to which, whether the universe is either finite, or infinite

[39] Bondi and Gold deduced some central issues of their theory from the perfect cosmological principle, whereas Hoyle adopted them at the beginning of his theory, then noticing the validity of the perfect cosmological principle as a welcome consequence.

[40] "The entire subject of cosmology rests on the assumption that our terrestrially obtained knowledge of the physical world can be applied to the universe at large", affirmed Bondi (1952, 141).

in space, the visible universe is a meaningless part of the whole, thence this generalisation is not well-founded.

Against the Kantian point of view, one should observe that, following quantum and relativistic revolutions, it is clear to everyone that no part of science could be completely a priori.

The Leibnizian point of view is more sophisticated than the others, but in our opinion it too is mistaken. Indeed it is based on a sort of Laplacean principle of insufficient reason, or Keynesian[41] principle of indifference, that is based on an a priori probabilistic argument of the kind:

There are no reasons to believe that various parts of the universe are different, therefore they are similar.

Harrison (1985, 174), for instance, calls this argument "the location principle", that states: "It is improbable that human beings have privileged location in the physical universe"[42]. Many epistemologists have correctly contested these sorts of arguments, since they are based on ignorance. At best, in our opinion[43], one could apply a sort of *principle of reasonable similarity*, that is:

We have good reasons for believing that the universe is similar in all its parts.

In other words, the form of these kinds of principles must be a positive, not a negative one. But till now we have no reasons favouring such similarity independently of the application of cosmology.

Then, which is the correct justification of the cosmological principle? The answer is much simpler. To begin with we can read again the brief proposition, with which Einstein introduced the cosmological principle in 1917:

> Wenn es uns aber nur auf die Struktur im grossen ankommt, dürfen wir uns die Materie als über ungeheure Räume gleichmässig ausgebreitet vorstellen, so dass deren Verteilungsdichte eine ungeheuer langsam veränderliche Funktion wird. (Einstein 1917,

[41] See Keynes (1921, chap. IV), where one can also find a very useful historical retrospective.

[42] In Harrison's (2000, 140) opinion, the Copernican principle, similar to his location principle, asserts too much: it appears "to perpetuate the belief that a center, somewhere or other, exists", whereas "we may say with certainty only that a central location in the cosmos is improbable".

[43] See Fano (2004).

> 148)
>
> But if we now are concerned only with the global structure, we could represent matter as uniformly extended in the immensity of space, so that its density distribution becomes a function, which changes extremely slowly. (our translation)

Einstein places no particular emphasis on this hypothesis, that is he introduces it with absolute naturalness, because without any special reflection he follows the *hypothetico-deductive* method, which he himself, Carnap and Hempel were to elaborate a few decades later.

Indeed in his celebrated 1934 paper he begins with these famous words:

> If you wish to learn from the theoretical physicist anything about the methods which he uses, I would give you the following piece of advice: Don't listen to his words, examine his achievements. (Einstein 1934, 163)

And in the following he explains how theoretical physics works:

> We have now assigned to reason and experience their place within the system of theoretical physics. Reason gives the structure to the system; the data of experience and their mutual relations are to correspond exactly to consequences in the theory. On the possibility alone of such a correspondence rests the value and the justification of the whole system, and especially of its fundamental concepts and basic laws. But for this, these latter would simply be free inventions of the human mind which admit of no *a priori* justification either through the nature of the human mind or in any other way at all. (*ibid.*, 165)

Thus, contrary to most scientists of the third millennium, Einstein is completely aware that in theoretical physics a part of the theory not only does not have a direct justification, but it does not need it at all. For this part receives empirical meaning only indirectly through the whole theoretical network, as definitely clarified by Hempel (1952), and Carnap (1956), in the fifties. This point of view will become notorious as the "received view" and in spite of its low capacity to describe real science, in our opinion it remains the best way of giving empirical meaning to theoretical terms of science.

Moreover Einstein is conscious as well that he himself is one of the creators (maybe the most important) of this new methodology, not completely understood by Galileo, Newton and the scientists of nineteenth century:

> On the contrary the scientists of those times were for the most part convinced that the basic concepts and laws of physics were not in a logical sense free inventions of the human mind, but rather that they were derivable by abstraction, i.e. by a logical process, from experiments. It was the general Theory of Relativity which showed in a convincing manner the incorrectness of this view. For this theory revealed that it was possible for us, using basic principles very far removed from those of Newton, to do justice to the entire range of the data of experience in a manner even more complete and satisfactory than was possible with Newton's principles. (*ibid.*, 166)

In the same years cosmologists reached a full comprehension of the hypothetico-deductive method of their science during the lively polemic, which burst out between the cosmologists Dingle and Milne in the thirties[44], and which concluded with the victory of the latter, who was one of the most prominent promoters, as already mentioned, of the role of the cosmological principle in contemporary cosmology[45]. It is noteworthy that today cosmologists seem to have forgotten this. Nevertheless, recent cosmology can be counted as one of the fields in which the hypothetico-deductive method, with its combined way of validation and explanation, has reached its most remarkable success. The following reflections by McMullin clearly epitomise how work on cosmology proceeds incessantly:

> The success of hypothetico-deductive methods when applied to the most distant regions of the universe as well as to the universe taken as a whole testifies quite strongly to its fundamental unity. So far as one can see, it might *not* have worked out this way. When the spectra of distant stars, or the velocities of distant galaxies, continue to be interpretable by schemes derived from terrestrial processes, confidence quite properly grows in the assumption that these schemes are not just conventions imposed

[44]Dingle's attacks were principally aimed at the so-called rationalistic cosmophysics (of Milne, Dirac, Eddington) and at the cosmology that he saw as esoteric, arrogant, and degraded into a pseudo-scientific state. Such cosmology was too based on an uncritical reliance on mathematics and general principles of an a priori nature: "Instead of the induction of principles from phenomena we are given a pseudo-science of invertebrate cosmythology", he thundered (quoted in Kragh (2007, 248-9)). On the contrary, according to Milne, facts are used to test theoretical models, not to generate them, whereas for Dingle we should derive, *à la* Galileo, general principles from observations, not deduce conclusions from a priori principles like Milne's hypothetico-deductive method. Therefore, the cosmological principle, since it transcends observation and cannot be derived from induction alone, appeared to Dingle an idealised assumption forced upon us by our ignorance of the cosmos.

[45]On this subject see Gale (2007).

for convenience's sake or because our minds cannot operate otherwise, but that all parts of the universe are united in a web of physical process which is accessible, through coherent and ever-widening theoretical constructs created and continually modified by us. (McMullin 1981, 35)

7 Concluding remarks

We shall now return to Kant's problem. The most recent relativistic cosmology – based on the above mentioned epistemology – solves the Kantian antinomy in an odd way: the thesis holds for both space and time, that is time has a beginning and space, though unlimited, is finite. But these conclusions are highly *hypothetical* and not without problems.

To sum up: how is it possible that contemporary cosmology bypassed Kant's prohibition? The answer is very simple: modern science does not necessitate of any a priori foundations. Relativistic cosmology is founded on the cosmological principle, which makes the *convergence* possible of the regressive use of reason relatively to the totality of phenomena. So that the universe becomes a concept; i.e. it is no longer an idea. On the other hand, the cosmological principle is partially confirmed indirectly, as already seen, by the numerous correct predictions of the whole theory.

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