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THE ANTHROPIC PRINCIPLE AND THE DURATION OF THE COSMOLOGICAL PAST

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The place of an anthropic argument in the discrimination between various cosmological models is to be reconsidered following the classic criticisms of Paul C. W. Davies and Frank J. Tipler. Different versions of the anthropic argument against cosmologies involving an infinite series of past events are analysed and applied to several instructive instances. This not only is of historical significance but also presents an important topic for the future of cosmological research if some of the contemporary inflationary models, particularly Linde's chaotic inflation, turn out to be correct. Cognitive importance of the anthropic principle(s) to the issue of extraterrestrial intelligent observers is reconsidered in this light and several related problems facing cosmologies with past temporal infinities are also clearly defined. This issue not only is a clear example of the epistemological significance of the anthropic principle but also has consequences for such diverse topics as the search for extraterrestrial intelligence, epistemological status of cosmological concepts, theory of observation selection effects, and history of modern astronomy.

KEYWORDS: history and philosophy of astronomy, cosmology: theory

> How many kingdoms know us not!
> Blaise Pascal, *Thoughts* (207)

1 INTRODUCTION

The simplest way to divide all cosmologies is into two broad classes: those postulating the eternal universe and those which postulate some origin of the Universe, or at least the part of it that cosmologists are currently inhabiting. Eternal universes (and here by eternal I mean those with no beginning or end, or even only those with no beginning) are the only ones that could pretend to adopt some sort of stationarity, a condition which is of singular importance in many branches of physics (among other issues because the law of energy conservation is closely connected with a translational symmetry of time), and which is certainly seen as greatly simplifying the solution of specific problems everywhere. For a long period of time, after the dogma of Creation in 4004 BC was abandoned, the Universe has been considered eternal, although great minds, such as Newton's, began to perceive some of the difficulties associated with such a proposition (see for example North (1965)). The resistance to the

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opposing view (which eventually became what is today called the standard cosmology) was established during most of the nineteenth and early twentieth centuries and is epitomized in the words of one of the pioneers of modern astrophysics, Sir Arthur Eddington, who in his authoritative Gifford lectures for 1927, published under the title *The Nature of the Physical World* (Eddington, 1928), flatly stated: As a scientist, I simply do not believe that the Universe began with a bang. (Eddington, 1928, p. 85)[†]. From the end of the Middle Ages until the Hubble observational revolution in the third decade of the twentieth century, the stationary world view has been in one way or another dominant among the educated classes. This explains, among other issues, the dramatic reaction of most of the scientific community, including Lord Kelvin, Holmes, Eddington, Crookes, Jeans and others, to the discoveries of Clausius, Boltzmann and others, which all imply a unidirectional flow of time and physical change. Interestingly enough, even during this epoch the idea, (today one of most investigated issues in physics) that the thermodynamic arrow of time originates in cosmology has occasionally surfaced (Price, 1996; Ćirković, 2003a, and references therein).

The power of a stationary alternative to the evolutionary models of the Universe has been reiterated in particularly colourful form during the great cosmological controversy in late 1940s, 1950s and early 1960s (Kragh, 1996). Although during this period of conflict between the Big Bang and the classical steady-state theories numerous and very heterogeneous arguments appeared on both sides of the controversy, the argument based on the anthropic principle was only explicitly formulated a decade after the disagreements ended. As is well known, of course, the debate ceased when empirical arguments persuaded by far the largest part of the cosmological community that a universe of finite age is the only acceptable theoretical concept. However, the argument based on the anthropic principle has been further developed during the 1980s and has gained relevance in a new and developing field of quantum cosmology (together with other aspects of anthropic reasoning). The present paper is dedicated to detailed consideration of the content and range of applications of that argument. In spite of the huge volume of writings on the philosophical aspects of stationary cosmologies (see for example Hawkins (1971), Grünbaum (1991), Balashov (1994) and Kragh (1996)), this particular argument has not been discussed in detail so far.

In modern physical cosmology, the position is reversed compared with the situation in first decades of the twentieth century. The evolving Universe with a definite beginning enjoys almost universal support, at least in the last three decades (for a comprehensive reviews of the field, see Weinberg (1972), Harrison (1973) and Peebles (1993)). Prior to the discovery of the cosmic microwave background (CMB) in 1965, at least one of the stationary theories, namely the classical steady-state model of Bondi and Gold (1948) as well as of Hoyle (1948), has been a viable and quite popular world view. After the interpretation of CMB as the remnant of the primordial fireball (Dicke *et al.*, 1965) has become standard (Sunyaev and Zeldovich, 1980), the evolutionary paradigm became universally dominant.

However, this is not the end of the story. There are at least two reasons (apart from appreciable historical interest) to study arguments pertaining to the cosmologies with infinite past even after 1965, both dealing with the boundary conditions, but with significantly different slants.

(i) Great pains have been taken to make the initial singularity palatable or to avoid it whatsoever (see for example Misner (1969), Bekenstein and Meisels (1980) and Israelit and Rosen (1989)), and the results are still inconclusive from the viewpoint of most researchers, in spite of the tremendous advances of the new discipline of quantum

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[†] These words of Eddington preceded for more than two decades the coining of the expression 'Big Bang', so they should not be interpreted as a critique of a particular model (after all, the first model which could, in a loose sense, be called a Big Bang model, was constructed by Lemaître only in 1931), but as rejection of the general concept that the world originated at a finite moment of time.

cosmology. The issue of a compulsory nature to the initial singularity in the classical context has remained a problem ever since the famous singularity theorems (see for example Hawking and Penrose (1970)). This has been aggravated in view of the very special nature of such a singularity entropy-wise (Penrose, 1979; Ćirković, 2003a). The significance of such a discourse is emphasized by recent attempts to build an atemporal world view (Price, 1996), in which cosmological boundary conditions play a crucial role. It is particularly interesting to consider in this context counterfactual cosmological models (such as the classical steady-state), and to compare their temporal aspects and their boundary conditions with those of realistic models.[†]

(ii) Recently, various 'multiverse' schemes have been proposed (see for example Linde (1990) and Smolin (1992)), in which our visible Universe is only part of a larger structure (for a partial list of such theories, see Bostrom (2002)). Motivations for this sweeping generalization have been multifold, ranging from details of the inflationary theory to topology to the fundaments of quantum mechanics. Some of the proposed multiverses are indeed in a stationary state, even somewhat resembling the classical steady-state theory. If these (still rather novel) propositions are to be taken seriously, their impact on several distinct cosmological concerns have to be investigated. One of the problems pertaining to the question of whether there are 'one or many universes' is that of the validity of various anthropic arguments, among them the argument against an infinite series of past events as discussed here.

The modern version of the anthropic argument against the past infinite series of events (or past temporal infinity in relationist terms; see the discussion below) has appeared in a short notice by Paul C. W. Davies appearing in *Nature* in June 1978 (Davies, 1978). In this succinct critique of the Ellis *et al.* (1978) static cosmological model he pointed out that

> there is also the curious problem of why, if the Universe is infinitely old and life is concentrated in our particular corner of the cosmos, it is not inhabited by technological communities of unlimited age.

As mentioned by Barrow and Tipler (1986) in their encyclopaedic monograph, this is historically the first instance in which an anthropic argument has been used against a cosmology containing a past temporal infinity, and it is indeed fascinating that nobody had considered it before. The surprise is strengthened by the fact that such cosmologies in scientific or half-scientific form have existed since the very dawn of science. Simultaneously, since ancient times a belief in the existence of other *inhabited* worlds has been present, in one form or another (for a historical sketch from the pen of a 'contact pessimist', see Tipler (1981)). Today, the scepticism sometimes encountered against this mode of thinking is even stranger, when various (and in some cases not quite inexpensive) search for extraterrestrial intelligence (SETI) projects testify to the reasonable degree of belief in the existence of technological civilizations other than the human civilization. Their technological nature (the same that produces the problem that Davies wrote about) is a *conditio sine qua non* of any sensible SETI enterprise.

Closely connected to this issue is the definition of anthropic principles. Although we shall later discuss some other anthropic principles, for the moment it is enough to define the weak anthropic principle (WAP), which states (Carter, 1974) that

> . . . we must be prepared to take account of the fact that our location in the universe is *necessarily* privileged to the extent of being compatible with our existence as observers.

[†] For instance, if the thermodynamic arrow of time depends on the cosmological boundary conditions, as suggested several times since Boltzmann, the notion of time in the everyday world ultimately depends on the low-entropy nature of the initial Big Bang singularity. However, are we to discard the existence of an arrow of time in a steady-state universe in which there is no initial singularity and no net increase in entropy?

An alternative definition has been given by Barrow and Tipler (1986):

> The observed values of all physical and cosmological quantities . . . take on values restricted by the requirement that there exist sites where carbon-based life can evolve and by the requirement that the Universe be old enough for it to have already done so.

With these formulations of WAP in mind, it is clear why the Davies' argument against the Ellis *et al.* cosmological model can be called *anthropic* at all; it takes into account the restrictions to be imposed on cosmological models following the existence of a specialized subclass of intelligent observers, namely the 'technological communities'.

An ancient echo of this type of argumentation can be recognized in the surviving fragments of some of the most distinguished ancient philosophers of nature. From our point of view the cyclic cosmology of Empedocles of Acragas (sixth to fifth century BC), in which the Universe is eternal,[†] consisting of the internally immutable four classic elements, as well as two opposing forces (Love and Strife, i.e. attractive and repulsive interactions), is especially interesting. The cyclic motion of matter in the Universe is governed by the change in relative intensities of the two interactions (see the excellent discussion by O'Brien (1969)). It is interesting to note that Empedocles' cosmology is *uniformitarian*, in the sense that all six basic constituents (four elements and two forces between them) are present in each instant of time in accordance with the eternal principles of mutual exchange. In some of the surviving fragments, Empedocles implied that, although this uniformitarianism may seem counterintuitive, as we see things coming into being and vanishing, this is just our special perspective (today we would say *anthropocentrism* or observation *selection effect*) and not the inherent state of nature.[‡] This is strikingly similar to the uniformitarian notions present in some of the most authoritative cosmological models of the twentieth century, and we shall return to it in subsequent discussion of the classical steady-state theory (Balashov, 1994).

As discussed in some detail by Ćirković (2003b), this Empedoclean view, namely that biological evolution and the appearance of consciousness and intelligence are contingent upon cosmological processes, coupled with the notion of the eternal Universe leads to the same sort of difficulty as that facing the classical steady-state theory or the Ellis *et al.* model criticized by Davies. Why then, in the supposed infinity of time, are 'men and women, beasts and birds' of finite, and relatively small, age? Where are traces of previous infinite cycles of the 'world machine' (cf. the discussion by Hutton described in section 4 below)?

Empedocles may have perceived this himself and he evaded the problem in the only natural way that he could: by postulating two singular states in the beginning and in the middle of each of his great cycles. These singular states are moments (in the absolute time!) of complete dominance of either Love (an ancient equivalent of the modern initial and/or final singularities) or Strife (no true equivalent, but similar to the modern version of heat death in the ever-expanding cosmological models (see for example Davies (1994)). In these states, life, with its complex organizational structure, is impossible and therefore they serve as *termini* for the duration of any individual history of life and intelligence. In other words, the information about anything that was before is destroyed in the singular events. Strikingly, *the maximal duration of any form of life and/or intelligence is determined exclusively by cosmological*

[†] It seems clear that Empedocles held a sort of the absolutist theory of the nature of time. In particular, the fragment B16 of the Diels collection reads (according to the translation of Burnet (1908)): 'For of a truth they (Strife and Love) were aforetime and shall be; nor ever, methinks, will boundless time be emptied of that pair.'

[‡] Another pioneering contribution of Empedocles lies exactly in separation (the earliest one in Western thought!) of the physical nature and artefacts of human cognizance. See, for instance, the Diels' fragment B8, reading (in Burnet's translation): 'There is no coming into being of aught that perishes, nor any end for it in baneful death; but only mingling and change of what has been mingled. Coming into being is but a name given to these by men.' Even more telling along the same lines are fragments B11 and B15.

laws! Therefore, there are no arbitrarily old beings, and anthropic argument is inapplicable. We shall meet the same strategy over and over again in the history of cosmological ideas.

In the very first chapter of the history of Thucydides, there is a famous statement that before his time, that is about 450 BC, nothing of importance (συ μεγαλα γευεσθαι) had happened in history. This startling statement has been called 'outrageous' by Oswald Spengler (1918) and used to demonstrate the essentially mythological character of the ancient Greek historiography (see also Cornford (1965)). It may indeed be outrageous from the modern perspective, but it does motivate a set of deeper questions, ultimately dealing with cosmology. The fact that Thucydides did not know (or did not care to know) about previous historical events does not change the essential perception of *finiteness* of human history inseparable from the Greek thought. This property starkly conflicts with the notion of an *eternal continuously existent world*, as it was presented in both modern and ancient cultures. Obviously, it is irrelevant which exact starting point we choose for unfolding historical events. In any case, the number of these events is finite, and the time span considered small even compared with the specific astronomical timescales (some of which, like the precession period of equinoxes, were known in the classical antiquity, as is clear from the discussion in *Timaeus*), not to mention anything about a past temporal infinity. Although there was no scientific archaeology in the ancient world, it was as natural then as it is now to expect hypothetical previous civilizations inhabiting Oikumene to leave some traces: in fact, an infinite number of traces for an eternally existent Oikumene! There are indications that pre-Socratic thinkers have been aware of the incompatibility of this 'Thucydidean' finiteness of historical past with the eternal nature of the world. We have already mentioned the solution (periodic singular states) proposed by Empedocles himself. Even earlier, in the fragmentary accounts of the cosmology of Anaximandros, we find an evolutionary origin of humankind in some finite moment in the past, parallel with his basic postulate of separation of different worlds from *apeiron* and their subsequent returning to it.[†] In Anaxagoras' world view, there is famous tension between the eternity of the world's constituents and the finite duration of *movement* (and, therefore, relational time) in the world. In the same time, it seems certain that Anaxagoras, together with Anaximandros and Empedocles, was an early proponent of the evolutionary view, at least regarding the origin of humankind (Guthrie, 1969).

Subsequently, with the Epicurean school, this issue became an argument for the finite origin of the Universe. Most eloquently, it has been put forward in Roman times by Lucretius, who in Book V of his famous poem *De Rerum Natura* writes the following intriguing verses (in a translation by William E. Leonard, available via WWW Project Gutenberg (Lucretius, 1997)):

> Besides all this,
> If there had been no origin-in-birth
> Of lands and sky, and they had ever been
> The everlasting, why, ere Theban war
> And obsequies of Troy, have other bards
> Not also chanted other high affairs?
> Whither have sunk so oft so many deeds
> Of heroes? Why do those deeds live no more,
> Ingrafted in eternal monuments

[†] This is clear, for instance, from the fragment A10 in the work of Diels (1983), preserved by Plutarch, in which it is explicitly asserted that formation and destruction of many worlds occur within the global temporal infinity. In the continuation of the very same excerpt from *Stromateis*, an evolutionary doctrine is attributed to Anaximandros: '... Farther he says that at the beginning man was generated from all sorts of animals, since all the rest can quickly get food for themselves, but man alone requires careful feeding for a long time; such a being at the beginning could not have preserved his existence.' (Fairbanks, 1898). Hyppolites quotes Anaximandros as emphasizing the nature of *apeiron* as eternal (B2), obviously in opposition to mankind, which has a fixed beginning in time. Even more intriguing is the doctrine ascribed to Anaximandros by Cicero: 'It was the opinion of Anaximandros that gods have a beginning, at long intervals rising and setting, and that they are the innumerable worlds. But who of us can think of god except as immortal?' Did he have in mind essentially what we today denote as supercivilizations?

> Of glory? Verily, I guess, because
> The Sun is new, and of a recent date
> The nature of our universe, and had
> Not long ago its own exordium.

For scientific-minded Lucretius, the shortness of human history is very strange on the face of hypothesis of the eternal existence of the world. Although the reference to 'eternal monuments' may sound naive, it is clear that he had in mind any form of transmission of information from the past to the present, and an infinite amount of information from an infinite past. His empirical assessment clearly shows the absence of such information. Therefore, an explanation is needed. The simplest explanation, as Lucretius was highly aware, is to assume that the world is of finite (and relatively small) age. This is *exactly* what modern cosmologists Davies and Tipler have had in mind when constructing the anthropic argument.

2 THE DAVIES–TIPLER ARGUMENT: MODERN FORMULATION

The anthropic argument against steady-state theories hinted at by Davies in the quotation above has been subsequently expanded and elaborated by Tipler (1982), and it seems only just to refer to its modern form as the Davies–Tipler (DT) argument. In the latter work it has been shown that this argument applies to 'all universes which do not change with time in the large', and particularly those which satisfy the so-called perfect cosmological principle (PCP) (Bondi and Gold, 1948) (see the discussion in section 3 below). The discrete Markov chain recurrence of the type discussed by Ellis and Brundrit (1979) has also been used in the discussion by Tipler (1982), although, as we shall discuss below, its use is largely superfluous, since even a much weaker hypothesis produces the same disastrous effects for the cosmologies with past temporal infinities.

The essence of Tipler's (1982) discussion is that, given some usual symmetries of space–time, for each event p, its past light cone intersects all world lines corresponding to the history of an intelligent species. Thus, at least one out of an infinite number of such species could travel along the time-like geodesic to p (or just send signals). Since p may be any event, like our reading of Tipler's (1982) paper, or any other occurrence in the Solar System, it is completely unexpected that we are not already part of an intelligent community of an arbitrarily long age. For the case of a universe satisfying the PCP (i.e. a classical steady-state universe) it is clearly seen from the Penrose diagram shown in Figure 1. Again, it is important to stress *non-exclusivity* of this argument; even if 99.99% (or indeed any fraction less than unity) of intelligent communities arising at, say, q would not expand further than some limited neighbourhood $q + \varepsilon$, in an infinitely old universe there would still be at least one intelligent community at any point p in space–time, no matter how large $|p - q|/\varepsilon$ is.

Here we note that, instead of dealing with temporal parts, we are dealing with events in space–time only. Therefore, this argument is intrinsically formulated in terms of a relationist or reductionist theory of time (see for example Newton-Smith (1980)). However, it is not contingent upon acceptance of any particular theory of time. Both relationist and absolutist pictures can accommodate the anthropic argument, provided that some additional specific requirements are satisfied. Conversely, if these requirements are not satisfied, the argument is inapplicable, no matter whether we regard time as contingent upon world events or an absolute background to any event. In the absolutist picture, we need to speak of infinite number of non-trivial past events in time, instead of the time itself, which remains completely irrelevant to the argument. If such a series of events satisfy some additional constraints (such as requirement

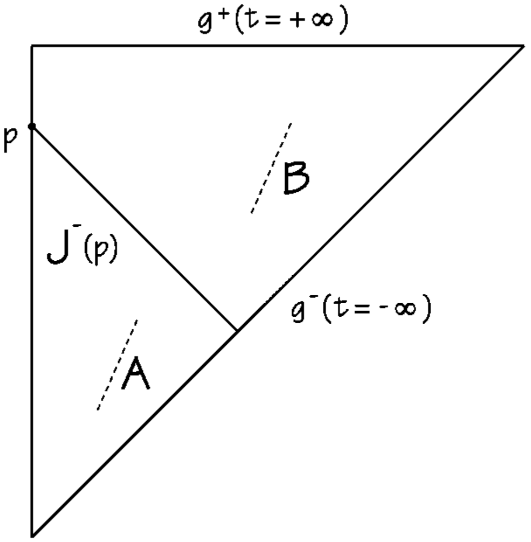

Figure 1. Conformal (Penrose) diagram of a classical steady-state universe. Event *p* is arbitrarily chosen, and with A and B are denoted world lines of intelligent species existing within and outside of the light cone of *p*. (Reproduced with permission from Tipler (1982).)

to include the creation of life and intelligence among the physically possible events), we are led to the same paradoxical conclusion.

However, Tipler (1982) went farther than Davies' casual remark given in the context of an editorial comment and claimed that

> [s]ince all possible evolutionary sequences have occurred to the past of *p*, one of these evolutionary sequences consists of the random assembly, without assistance of any intelligent species whatsoever, of a von Neumann probe out of the atoms of interstellar space. Such a random assembly would occur an infinite number of times to the past of *p*, by homogeneity and stationarity in an infinite universe. At least one of these randomly assembled probes would have the motivations of a living being, that is to expand and reproduce without limit.

This scenario, although not at all fantastic, raises several questions still lacking elaboration. How could we possibly know that the set of all 'favourably motivated', spontaneously assembled von Neumann probes is of non-zero measure in the set of all such probes. The question of motivation, which is not so easily quantifiable, becomes crucial here. For instance, why should we not postulate an assembly of von Neumann probes designed to search and destroy other von Neumann probes? What is the relative weight of colonizing (versus destructive, altruistic, introvert, etc.) motivation, and how can one determine it? This motivation problem is avoided if we stick to a more restrictive requirement that only communities of evolved intelligent beings create such probes (i.e. create them on timescales many orders of magnitude shorter than those required for the spontaneous assembly that Tipler described). While one may argue that motivation is necessarily linked to the level of complexity, and therefore one expects that spontaneously assembled self-reproducing automata will have basically the same motivations that we perceive in biological systems on Earth (Tipler, 2001), this issue is not clear at all.

Among the precursors of the anthropic argument of Davies and Tipler, one may list the great British biologist, chemist, philosopher and author John B. S. Haldane (1892–1964). His keen interest in cosmological issues has been characterized by his defence of the Milne cosmological model in which (at least according to one timescale) the Universe is of finite age, and fundamental constants change with time. In the following interesting passage, through comparing the hypothesis of the origin of the Universe in the finite past versus the hypothesis of its eternal existence, he shows both his cosmological interests and appreciation for a melioristic and humanistic world view (Haldane, 1945) (the present author's emphasis is shown in italics):

> On the first hypothesis, why was it not created better; on the second, *why has it not got better in the course of eternity*? . . . On neither theory have we very strong grounds for hoping that the world will be a better place a million, let alone a thousand, years hence, than it is today. But on Milne's theory the laws of nature change with time. The Universe has a real history, not a series of cycles of evolution. Although, from one point of view, the past is infinite, life could not have started much before it did, or have got much further than it has at the present date. If this is so, human effort is worth while and human life has a meaning.

If we understand 'improvement' in the Universe not in strictly ethical terms,[†] but as an increase in its *complexity*, the question posed by Haldane is the same as in the DT argument. Complexity may be achieved through either technologization or 'biologization' of the Universe, and both lead to paradoxical consequences.

3 TWO VERSIONS AND RELATED ARGUMENTS

Let us introduce the following terminology. By the *weak DT argument* we shall denote the version introduced by Davies (1978) note as follows.

Weak DT argument: *Cosmologies postulating inhabitable past temporal infinities must be rejected due to the absence of traces of arbitrarily old civilizations in our past light cone.*

The *strong DT argument* is that presented by Tipler (1982), as well as in the monograph by Barrow and Tipler (1986). Let us formulate it by analogy with the weak argument in the following form.

Strong DT argument: *Cosmologies postulating past temporal infinities must be rejected due to the absence of activities of spontaneously assembled self-reproducing automata in our past light cone, provided that matter in our past light cone satisfies constraints enabling such spontaneous assembly.*

In spite of the clumsiness of the latter formulation, it is clear, upon careful inspection, that the auxiliary assumptions in the stronger version are significantly more general than those in the weak version. As far as both versions are concerned, it is very important to note that they do not guarantee the existence of the entities under consideration. Let us consider the weak version first as the more important from the overall point of view of this work. It contains two stringent requirements which have been usually tacitly assumed (and played rather an important historical role), but which should be explicitly discussed.

(i) *The requirement of continuous inhabitability of at least a large enough region of causally connected space*. This should be regarded as a form of restriction on spatial inhomogeneities of the cosmological model under consideration. The question of what counts as inhabitable is actually very subtle, since requirements of communities of intelligent observers may wildly differ. In any case, we expect that a sufficiently large thermodynamic disequilibrium must exist. Therefore, the question of whether a particular model satisfies this auxiliary assumption is contingent upon the answer from the same model to the much more famous problem of the Olbers paradox. We shall see below how various specific cosmological models enable continuous entropy production to occur over an infinite interval of time.

[†] But presumably including that aspect. If we reject pantheism, there is a minimal level of complexity necessary for the subject and the very notion of ethics to exist. Therefore, any ethically melioristic cosmos must satisfy specific WAP constraints.

(ii) *The existence of arbitrarily old civilizations.* The existence of such entities can hardly be considered obvious or even probable on any count. While condition (i) is necessary, it is not a sufficient reason for accepting (ii). Obviously, apart from the physical environment, there are other reasons of a subtler and less quantifiable nature which could put an upper limit to the age and growth of civilizations even in a continuously inhabitable universe.

Now we perceive what is the ultimate recourse to the proponents of large-scale stationarity (as well as opponents of the usage of anthropic principle for discriminating between the cosmological models). While the rejection of either (i) or (ii). may seem easy enough, the careful inspection shows that it is a rather difficult endeavour. Models which are characterized as stationary automatically satisfy (i), and the reasons sometimes cited for rejection of (ii) (mostly in the context of the SETI debate (see below)) are entirely *ad hoc*. Non-stationary models may violate (i), while retaining an infinite number of past temporal events, although this violation is necessarily limited by the spatial and temporal scales that our observations are probing. Limits following from the observations are already too relaxed for us to conclude that this is a sufficient reason for the rejection of (i), even apart from the fact that no infinitely old non-stationary model has ever been investigated in much detail.

The strong DT argument necessarily endorses the following auxiliary assumption, analogous with the (i) in the weak case.

(i') *The requirement of a continuously existing region in which the spontaneous assembly of matter can be achieved.* This presumes, firstly, availability of matter (so that empty models, like the de Sitter world, can be excluded) and secondly, restrictions on the physical state of matter. This second restriction is hard to make precise in the general case, but it seems clear that we should exclude cases, for instance, in which the matter is at temperatures high enough for any level of organization to be immediately destroyed by thermal motions.

It is generally much more difficult to construct an infinitely old cosmological model violating (i') so that it can be brought even into a very superficial accord with the empirical data that any realistic theory must satisfy. However, since the physical issues involving a spontaneous assembly of the desired sort are not clear, we shall in further discussion concentrate on the weak version of the argument, while only occasionally referring to the stronger version. The more stringent requirements that (i) and (ii) produce make, for that matter, any hunt for loopholes in the argument itself (and our consequent increase in understanding) much more promising.

So that the issues involved can be better understood, let us consider a counterexample of a cosmological model involving past temporal infinity which DT argument does not apply to (for a preliminary treatment of this topic, see Ćirković (2000)). This is the Lemaître–Eddington universe, which was quite popular in the 1925–1935 period (see for example Eddington, 1930). This model belongs to the class of general-relativistic models with a cosmological constant and without the Big Bang. Therefore, it was very appealing from the point of view of resolving the age discrepancies between cosmological models and various astrophysical and geological timescales (Bok, 1946; Kragh, 1996). A good description of this model can be found in the classic textbook on cosmology by Bondi (1961). Having appeared on the cosmological scene after the realization of the instability of the original Einstein (1917) static universe, this model (Bondi, 1961, p. 118)

> ... has therefore an infinite past which was spent in the Einstein state. This has greatly attracted investigators since it seemingly permits an arbitrarily long timescale of evolution. The picture of the history of the Universe derived from this model, then, was that for an infinite period in the distant past there was a completely homogeneous distribution of matter in equilibrium in the Einstein state until some event started off the expansion,

> which has been going on at an increasing pace ever since. The condensation of the galaxies and the stars from the primeval matter took place at the time the expansion began, but this development was stopped later by the decrease of average density due to the progress of the expansion.

This model is a good physical representation of the situation often considered in philosophical studies of distinction between the relationist and absolutist theories of time: the situation in which an absolutely unchanged universe suddenly transforms into changing world that we observe (see for example Hinckfuss (1975)). From the formal point of view, in accordance with the Weyl postulate, the Eddington–Lemaître universe has an infinite past, that is the initial state is given by the formal limit $t \to -\infty$. However, this is a 'false' infinity, at least in the context of anthropic reasoning, because the period of time in which there are conditions enabling the creation of intelligent observers is necessarily finite. In addition, this period is approximately equal to the time past since the beginning of the expansion. In the Leibnitz–Berkeley–Machian relationist picture, the time itself does not really exist before the onset of instabilities, that is the universal expansion. The period of complete homogeneity can be regarded as a state analogous to the epochs of complete dominance of Love or Strife in the cosmology of Empedocles or, even more accurately to the time before the motion began in Anaxagoras' cosmology.[†] In both cosmologies it is necessary to invoke a state that prevents propagation of information from an arbitrarily distant past to the present epoch. In both cases this goal is achieved by postulating states with a sufficiently high degree of symmetry.[‡] Obviously, in the case of the Eddington–Lemaître universe, the anthropic argument is inapplicable, since the *effective past* is finite. Intelligent observers (or spontaneously assembled von Neumann probes!) possess only a finite time for technologization of their cosmic environment. This is valid for the generic version of the Eddington–Lemaître model. Of course, the model pretending to describe the real Universe is normalized to the present expansion rate, and therefore we conclude that this effective age is similar to the age of galaxies, or again of the order of H_0^{-1} (H_0 being the present-day measured value of the Hubble 'constant'). Therefore, the incompatibility argument in the core of the DT argument is lost and reduces to the much weaker Fermi 'paradox', as we shall see in further discussion.

Probably the more physical and meaningful way of restating the entire situation is to reject the notion of an infinite age of the Eddington–Lemaître model as a hollow formalism. A principle sometimes ascribed to Aristotle or St Augustine tells us that there is no time without a changeable world. The state of perfect equilibrium in the Eddington–Lemaître model in the $t \to -\infty$ limit is exactly such an unchangeable state, without means of determining either direction or the rate of passage of time. In the sense of a modal version of the Aristotle–St Augustine principle, the temporal infinity in this model thus collapses into a purely formal notion. The formulation by Newton-Smith (1980, p. 44) of this principle, namely

> There is a period of time between the events E_1 and E_2 if and only if relative to these events *it is possible* for some event or events to occur between them,

explicitly points to (macroscopic) indistinguishability of moments in the state of complete thermodynamic equilibrium. The same applies to the distant future of the Universe in which,

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[†] The fragment B64 of Diels suggests that Anaxagoras endorsed a version of what were to become the absolutist or Newtonian (or Platonist in the parlance of Newton-Smith) theory of time. In this description of Anaxagoras' cosmology, preserved in Simplicius' commentaries on Aristotle's *Physics*, it is emphasized that the world itself was created at the beginning of motion, but that *before that time* everything was static. As in the Eddington–Lemaître universe, the time axis can be formally extended backwards to $-\infty$.

[‡] Of course, this interpretation of the Eddington–Lemaître universe is not mandatory. It may as well be said that stars and galaxies have existed indefinitely as such before the expansions starts. Of course, in this case the anthropic argument becomes valid at any epoch in the finite past, even before the start of the expansion, since it reduces to the application in the static Einstein universe. However, there are additional arguments against such interpretation of the Eddington–Lemaître model. For instance, as shown in an instructive study by Pegg (1971), the model with indefinite past containing stars can be rejected as a consequence of a very grave form of the Olbers paradox.

according to many models, the state of heat death is bound to occur. Barrow and Tipler (1978) suggested that a formally infinite future should be substituted with a finite interval, through an appropriate coordinate transformation. A sort of counterexample, confirming the general thesis that the cosmic time established by the Weyl postulate should not be regarded as sacrosanct, is the diverging number of (possible) events in the finite temporal vicinity of either the initial or the final global singularity. In such a situation a finite cosmic time may be less appropriate than an alternative infinite timescale (see for example Misner (1969).[†] For instance, the ever-decreasing number of events in the world approaching future heat death (in the framework of some particular cosmological model) could well be described, in the relationist picture, with the finite time interval remaining; therefore, the time between the initial singularity and the final heat death could be represented by a $(-\infty, 0)$ interval.

Is such a rescaling just a mathematical–philosophical perversion lacking any relevance for the physical world? It seems that the answer is firmly in the negative. While the elaboration lies beyond the scope of the present paper, it is enough to point out that the famous ‘biological scaling hypothesis’ of Freeman Dyson (1979) is just one guise of the rescaling of time in the relationist context. Many results in the nascent discipline of physical eschatology depend on the Dyson hypothesis, and it is obvious that whether it is true or not has real physical consequences.

In brief, the past temporal infinity in the Eddington–Lemaître model is *trivial* from the anthropic point of view, and therefore the DT argument is inapplicable. Thus, one should reduce the realm of applicability of the latter argument to cosmological models containing *non-trivial past infinities*, that is an infinite chain of non-trivial events.[‡] The residual problem in each case is what is traditionally called the Fermi (or the ‘Great Silence’) paradox.

It should be immediately noted that the DT argument, as outlined above, is different from the unlimited entropy argument usually used against cosmologies with past infinities (although the two are related, as we shall see): why have not irreversible processes, in accordance with the thermodynamic laws, generated infinite amounts of entropy in the Universe by now? This is not just the classical question of the thermodynamic disequilibrium between the dark night sky and bright stars, but also the question of our very existence, which is obviously contingent upon the large-scale disequilibrium. Davies (1975) himself used the same argument against the Hoyle–Narlikar conformally invariant cosmology[§] in his review of the latter in *Nature*, and Tipler (1982) mentioned it in a somewhat restricted sense, as the Olbers’ paradox (again, an expanded discussion may be found in the book by Barrow and Tipler (1986)). The classical steady-state theory alleviates this problem by the continuous creation of matter, and an additional assumption that newly created matter is in a low-entropy state, but cosmologies excluding creation of matter (such as, for instance, the Einstein original static universe, or the Hoyle–Narlikar conformally invariant cosmology) are faced with this argument in a very

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[†] This obtained a poetic description in Lord Byron’s *Cain* (1821):

With us acts are exempt from time, and we
Can crowd eternity into an hour,
Or stretch an hour into eternity.

[‡] Further discussion of the non-triviality requirement can be found in the book by Newton-Smith (1980). It is important, for instance, in rejecting claims that statements of the form ‘the moment $t = t_0$ is now’ can *in principle* describe any event whatsoever. Here we perceive the connection between the anthropic argument and the relationist versus absolutist controversy in the most plastic manner.

[§] There is a slight confusion in the literature as to which of several different cosmological models is correctly called the Hoyle–Narlikar cosmology. Here, we attach this name only to the conformally invariant model with a conserved number of particles and variable particle masses, such as in the papers by Hoyle and Narlikar (1972) and Hoyle (1975). Although, as shown by Narlikar and Arp (1993), several features of this model can be incorporated into the revised steady-state theory (which postulates creation of matter, i.e. non-conservation of the *number* of particles), we shall explicitly treat the Hoyle–Narlikar and the revised steady-state models as separate theories, since the distinction (conservation versus creation) seems important enough to do this.

serious form. Still, this thermodynamic argument against steady-state models is qualitatively different from the DT argument that we are dealing with, although both show how difficulties arise when currently observable processes are extrapolated backwards in the past eternity. The latter argument is based, essentially, on the diametrically opposed process: growth of complexity, which results in emergence of technological communities at some finite time (Kardashev and Strelnitskij, 1988). In the former case, we perceive increases in entropy in our laboratory experiments; in the latter case, we perceive our laboratories themselves as (in a sense) the very products of our former observations.

In addition, attempts to reject the hypothesis of the infinite age of the universe by a Kantian form of *a priori* reasoning are essentially different from the anthropic argument; the former is also known as the *kalam* cosmological argument (Craig, 1979). One of the latest of these attempts has been made by Gerald Whitrow (1978), which immediately caused many, chiefly negative, reactions (Popper, 1978; Bell, 1979; Davies, 1983; Grünbaum, 1991; Oppy, 1995) (see, however, Craig (1979, 1990)). The DT argument, on the contrary, is not *a priori*; it applies to the physically well-defined sub class of universes with an infinite past and it is firmly based on empirical (although non-standard) evidence, that is on the existence of a technological civilization in vicinity of at least one point of space–time.

Thus, the DT argument can be interpreted as the much stronger version of the familiar 'Great Silence' or 'astrosociological' problem (see for example Brin (1983), Kardashev and Strelnitskij (1988), Almar (1989), Gindilis and Rudnitskii (1993) and Lipunov (1997) (also known as the Fermi 'paradox'). Fermi's legendary question, 'Where are they?', applies to the absence of any observable technologization of the Universe, as confronted by optimistic views on the multitude of advanced extraterrestrial civilizations in our Galaxy.[†] As calculated by many researchers (starting with the pioneering study by Hart (1975)), the timescale for the colonization of the Milky Way galaxy by a technological society only a very little ahead of us in the technological sense is very much smaller than the age of our Galaxy. The age of the Galaxy is, of course, finite and has become rather well known in recent years (Chaboyer *et al.*, 1996; Krauss, 1998); that is exactly the point at which the anthropic argument is much more severe. As put dramatically by Lipunov (1997):

> There are two observational ... facts: (1) the age of the Universe is $T = 10^{10}$ years and (2) the time τ for the exponential development of our civilization is of the order of some tens of years. For the sake of simplicity, we can adopt $\tau = 100$ years, which is obviously an overestimate. A gigantic dimensionless number arises, characterizing the growth of a technological civilization over the time of existence of the universe:
>
> $$K = \exp\left(\frac{T}{\tau}\right) \approx 10^{43\,000\,000}(!)$$
>
> It is sufficient to say that theoretical physics has never dealt with such large dimensionless numbers. ... In fact, it can be confirmed that the probability of absence of 'space miracles' in our Universe is $10^{-43\,000\,000}$, i.e., it is equal to zero! Nevertheless, nobody has discovered them even after 20 years of searches. On the contrary, a Great Silence of the Universe has been revealed.

The extension of this argument on both spatial and temporal scales leads directly to the anthropic argument. Instead of a very large age, we wish to investigate the limit $T \to \infty$ (in Lipunov's presentation). Clearly, the DT argument (as well as almost all other aspects of anthropic reasoning) is of great relevance not only for cosmology but also for astrobiology and the prospects for SETI, too. Since the latter topics are of potentially unprecedent significance to the social and cultural history of human race, this reaffirms the necessity of investigating all arguments of relevance to the question of survival and evolutionary histories of intelligent observers in the cosmological context. This is a convenient point to re-emphasize that (as noted

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[†] The similarities between the Olbers and the Fermi 'paradoxes' has been discused by Almar (1989). For our purposes the most important fact is that in both cases it is the finite age of the Universe and not its expansion which is the dominant physical factor (Wesson *et al.* 1987).

among others, by Lipunov himself) before Einstein and Friedmann, but after the breakdown of the medieval creation dogma, there were no principal differences between the two arguments. The traditional view of eighteenth, nineteenth and early twentieth century intellectuals has been that the Universe has always existed in conditions not very different from those observable around us today. This makes the fact that the DT argument appeared on the cosmological scene so late rather strange.

4 AN EARTH SCIENCE INTERLUDE

Could it have appeared earlier? It is important to stress that the more general problem of the apparent lack of information from the past has its underground history deeply interwoven with the striving for understanding natural history. The problem, as we have hinted, was open as soon as the dogma of creation in 4004 BC was rejected, tacitly or not. It was, in fact, in the domain of Earth sciences (rather than in astronomy) where the dam was broken; it is often called the discovery of 'deep time' or 'geological time' (see for example Ward (1998) and Baxter (2004)). It was not accidental that the man usually credited for this discovery, Scottish naturalist James Hutton (1726–1797), was the first to reflect on the basic issue of habitability of the indefinitely (or even infinitely) old Universe.

Following the lead of Gould (1987), we may approach Hutton's solution of the problem of the duration of the past versus limited information transmitted from those epochs, noting how final causes motivate the whole idea; today, we might cite the strong anthropic principle (SAP) to similar ends. Hutton imagined a 'world machine'; his mechanicistic world view found an excellent field of applicability in the geology of his day. Erosion of the soil is compensated by the uplifting of mountains; any other particular tendency is contrasted with an opposite tendency that is bound to return the world to one or more previous stages. Hutton's vision is a geological analogue of the Empedoclean cyclic universe; hence the most famous passage of his, ending the short version of his *Theory of the Earth* (Hutton, 1788, p. 304):

> If the succession of worlds is established in the system of nature, it is in vain to look for anything higher in the origin of the earth. The result, therefore, of our present enquiry is that we find no vestige of a beginning – no prospect of an end.

However, contrary to the standard textbook (and often quite Whiggish) history, portraying Hutton as the standard bearer of modern scientific outlook, this view of the 'world-machine' was not motivated so much by the desire to explain the observed phenomena, as by the metaphysical invocation of final causes. The final cause in question was nothing less than what modern astrobiologists would call *planetary habitability*; time and again, Hutton wrote of the 'mechanism of the globe, by which it is adapted to the purpose of being a habitable world'. The Earth was obviously constructed (at some *indefinite* epoch, not existing from eternity!) for the higher purpose of being a habitat for life and, eventually, for human domination. Hutton (1788, pp. 294–295) wrote about

> . . . a world contrived in consummate wisdom for the growth and habitation of a great diversity of plants and animals; and a world peculiarly adapted to the purpose of man, who inhabits all its climates, who measures its extent, and determines its productions at his pleasure.

This seems absurd from the (Whiggish!) point of view of modernity but was almost self-evident in the eighteenth century; on the other hand, Hutton's view bears a striking similarity to some of the modern teleological usages of the SAP that we shall discuss in Section 7 below.

Note that the age of the Earth (and perhaps the rest of the Universe) was considered indefinite, but not infinite. An infinite age would conflict with Hutton's profound Christian religiosity, and he repeatedly implied that the ultimate questions of the beginning and the end of the world are not part of the scientific discourse. However, with profound subtlety, he builds an insurance against Lucretian 'eternal monuments' in his choice of words: not that there is no beginning – there is only no *vestige* of the beginning! The cyclic nature of the world machine erases the relevant information from previous cycles and 'cleans the slate'. However, it is still internally inconsistent; if the world is made for man, how is it that the achievements of previous generations of humans are also erased? If we accept pluralism about abodes of life (which was rather standard in Hutton's time (see for example de Fontenelle (1990)), then it is very difficult to conceive an explanation for the failure of intelligent beings to overcome the slow processes of erosion and decay which erase information from previous cycles. Empedocles at least postulated catastrophic singular events encompassing the entire universe; Hutton's world machine is much less efficient in this respect. This dichotomy is important to keep in mind before we return to the grand cosmological scene.

5 CLASSICAL STEADY-STATE THEORY

In order to assess better the importance of the DT argument and its application to the cosmologies with an infinite past, we shall briefly consider the conceptual foundations of the most famous and historically most influential such cosmology, the 1948 model of Bondi and Gold (1948) and Hoyle (1948). Although there is some controversy whether the classical steady-state cosmology represented a single entity or two disjointed theories (that given by Bondi-Gold and the version put forward Hoyle), we shall refer to them as the classical steady-state model, discussing, where relevant, particular differences between the two versions (Hoyle 1949). While Hoyle's version is generally superior, being formulated in the language of the classical field theory, for our purposes it is, in fact, the PCP of Bondi and Gold (1948) that makes the important point most clearly. Its essentially non-mathematical character makes it even more transparent in the sense of giving the core formulation of uniformitarianism in cosmology (Balashov 1994).

One fact that remained largely overlooked is that the classical steady-state cosmology displayed one of the very first instances of anthropic reasoning in modern science. In the founding paper, Bondi and Gold (1948) gave a specific anthropic flavour to the classical unlimited entropy argument ('the Olbers paradox') (the present author's emphasis in shown in italics):

> A static universe would clearly reach thermodynamical equilibrium after some time. An infinitely old universe would certainly be in this state. There would be complete equilibrium between matter and radiation, and (apart possibly from some slight variations due to gravitational potentials) everything would be at one and the same temperature. There would be no evolution, no distinguishing features, no recognizable direction of time. That our universe is not of this type is clear not only from astronomical observations but from local physics and indeed *from our very existence*.

This way of reasoning is not only deeply founded in the normative physical practice but also is directly responsible for the conceptual simplicity of the classical steady-state theory, praised even by its adversaries such as Sir Martin Ryle. However, it is also important to perceive that the paragraph quoted above contains a characteristic example of the anti-Empedoclean double standard deeply rooted in modern science. Namely, our existence is taken into account in physical theory when it is convenient, in this particular example when it comes to proving that the entropy of the Universe is far from the maximal value. At the same time, other consequences of our existence as a technological civilization, which lead to the DT argument, are conveniently ignored. It can be hardly contested that it was exactly our capability to adapt and technologize nature which led, among all other things, to advances in mathematics and astronomy, resulting in the formulation of the classical steady-state theory. In what follows, we shall show how the DT argument is operationalized in the context of this theory.

The PCP formulated by Bondi and Gold (1948) can be simply expressed as the homogeneity of the universe in four-dimensional space-time. This is just the generalization of so-called cosmological principle (Milne 1940), which assumes homogeneity in space, but not necessarily in time. Mathematically speaking, the PCP can be formulated as a necessity to have a time-like Killing vector in the classical Robertson–Walker metric. Thus, the PCP leads to the line element of the well-known (de Sitter) form (in the usual $c = 1$ units)

$$\mathrm{d}s^2 = \mathrm{d}t^2 - \exp(2Ht)\left[\mathrm{d}r^2 + r^2\left(\mathrm{d}\vartheta^2 + \sin^2\vartheta\,\mathrm{d}\varphi^2\right)\right], \tag{1}$$

where H is the true constant and can take any real value. Now, $H = 0$ leads to a static universe, which can be discarded not only on clear observational grounds, but (even more interesting from our point of view) from the thermodynamic considerations as well. The Olbers paradox testifies that the Universe has not reached the state of thermodynamic equilibrium, which is impossible to avoid in an infinitely old static cosmological model (see the celebrated classic discussion by Bondi (1961)).† The case $H < 0$, which corresponds to the universal contraction, presents a situation in which the radiation of distant sources is shifted to the violet end of the spectrum, resulting in an infinitely bright sky background in the manner still less acceptable than in the case of the Olbers paradox in a static universe. Therefore, the only possible conclusion is that $H > 0$, which is the realistic case of an expanding universe.

Part of the appeal of the steady-state concept can be found in the words of Sciama (quoted according to Kragh (1996)):

> The steady-state theory opens up the exciting possibility that the laws of physics may indeed determine the contents of the Universe through the requirement that all features of the Universe be self-propagating.... The requirement of self-propagation is thus a powerful new principle with whose aid we see for the first time the possibility of answering the question why things are as they are without merely saying: it is because they were as they were.

However, as we shall see below, the germ of doom lies exactly in the concept of self-propagation, since it seems to be incapable of correctly accounting for a specific ‘feature’ of the Universe, namely us. In other words, if we accept the Empedoclean picture (in which the biological and mental evolution is an inherent and necessary part of the cosmological evolution), then, although it has to be self-propagating, the rise of intelligence at the same time *must not* be self-propagating.

The basic violations of uniformity that we empirically notice in the Universe are galaxies. Newly created matter is *continuously* condensed in galaxies, and although the details of this process have remained controversial (Sciama, 1955; Harwit, 1961), mainly because insufficient theoretical work was devoted to it prior to the universal rejection of the steady-state picture in mid-1960s, the predictive power of the PCP is manifested here once again. The

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† The $H = 0$ case corresponds to the infinite Euclidean static universe, similar to the Einstein (1917) original static model. The difference lies in topology, since the Einstein model is topologically closed. However, the Einstein model also (albeit trivially) satisfies the PCP. Although we cannot delve deeper into this topic, it is worth noting that the DT argument applies to flat Euclidean as well as to Einstein closed static models. The absence of the large-scale expansion in these static models makes the expansion of life and intelligence significantly easier. Even the hierarchical distribution of galaxies and supergalactic structures, as in the Charlier (1922) original fractal model (Kalitzin 1961) or in Segal’s (1978) chronometric cosmology, does not alleviate this problem. No distance is out of reach in an infinitely old static universe. Moreover, we may speculate, following Barrow and Tipler (1986), that the absence of global relativistic effects such as shear and torsion in such universes makes the technologization of ever larger spatial volumes even more important, since there are no negative-entropy sources for information processing other than the matter fields. Of course, the basic problem of all static cosmologies is the Olbers paradox, that is global thermodynamic disequilibrium; so in a sense the existence of even a single intelligent observer is *reductio ad absurdum* of such cosmologies!

answer offered by the steady-state outlook to the question of the age distribution of galaxies on a sufficiently large scale is essentially independent of physical details of galaxy formation. In the classical steady-state model, the distribution function of galaxies is simply

$$f(x) = \exp^{-3Ht}, \tag{2}$$

where H is the Hubble constant, a true constant in contradistinction to the Friedmann models. Taking into account equation (2) the average age of galaxies is simply

$$\langle \tau \rangle = \frac{1}{n} \int_0^\infty 3nH \exp^{-3H\alpha} \, \mathrm{d}\alpha = \frac{1}{3} H^{-1}. \tag{3}$$

This illustrates a beautiful simplicity which the PCP imposes on the theory; the average age of galaxies is calculated without any reference to the complicated physics of galaxy formation.[†] However, we should keep in mind a historical fact of great importance, namely that the estimates of the Hubble constant relevant in the late 1940s were in gross violation of what we today know as the plausible interval for that quantity. For $H \sim 500\,\mathrm{km\,s^{-1}}$, which was the then reigning Hubble measurement, the Friedman–Lemaître cosmology (which soon became, following a derogatory comment of Hoyle in a BBC radio broadcast, the Big Bang cosmology) is in serious conflict with the age of the Earth and chemical elements (see for example Bok (1946)). At the time of the formulation of the steady-state theory, $\langle \tau \rangle$ was considered small (about 6×10^8 years, owing to the gross overestimate of the value of Hubble constant), and the Milky Way has already been an extraordinary old galaxy, which certainly implied that surrounding galaxies are far less probable to achieve the same degree of chemical and biological evolution. Although this circumstance in fact does not alleviate the DT argument, it certainly does have a significant psychological effect, making problems with technologization literally much more distant.

The fraction $\delta(t)$ of galaxies older than the age t is given by

$$\delta(t) = \frac{1}{n} \int_t^\infty 3nH \exp^{-3Hx} \, \mathrm{d}x = \exp^{-3Ht}. \tag{4}$$

This is the mathematical root of the problem, reflecting the fact that the exponential function is everywhere finite. For instance, if we take $\langle \tau \rangle$ to be an order of magnitude higher, in accordance with the today's best knowledge on the magnitude of the Hubble constant, the DT argument quoted above gains force. Since the fraction of galaxies that are older than age $t = 2t_{\mathrm{MW}} \approx 2 \times 1.2 \times 10^{10}$ years is given by equation (4), it follows that there are almost 2% of all galaxies in any large enough comoving volume which are *twice* the age t_{MW} of the Milky Way. We should keep in mind at all times that our Galaxy is *already* old enough for the Fermi paradox to be formulated (as briefly discussed in Section 2).

The issue of the different predictions of the ages of galaxies in different cosmological models has been present on the cosmological scene since the very beginning of controversy

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[†] Parenthetically, modern Big Bang cosmologies are still uncertain as to the average *predicted* age of galaxies within a factor of about 2 (see for example Gott (1977) and Peebles (1993)). Note that this is something very different from the *observational* uncertainties in the determination of, say, the age of the oldest globular clusters in the Galaxy. The latter is in practice regarded as *limes inferior* of the age of the Universe. The two are sometimes confused, especially in popular scientific literature, owing to the hegemonic position of the standard hot Big Bang paradigm. *A priori*, it is not necessary that the age of the Galaxy (and galaxies) is determined by cosmological factors at all; classical steady-state cosmology is a good counterexample of this. In it the age of any galaxy is a random variable. However, in the standard model it is the irreversibility of the Hubble expansion (i.e. the cosmological 'arrow of time') that necessarily links cosmology with galactic cosmogony. This, of course, does not imply that the classical steady-state model does not have inherent difficulties with the physics of galaxy formation (see for example Harwit (1961)).

between the classical steady-state theory and what will ultimately be called the standard Big Bang model. This problem is attractive because of the possibility of observational verification on spatial scales smaller than those required for most of the other cosmological tests. Studies of convenient age indicators in a large enough sample of galaxies could, in principle, be performed in order to answer the question of whether galaxies have approximately the same age or span a wide distribution, as given by equation (2). In practical terms, however, the task is extremely difficult, since even the age of the Milky Way (by far the best-known galaxy, of course) has not been known with less than 20% uncertainty until very recently. Therefore this sort of empirical evidence has not been actually used very much against the classical steady-state model. The age-based attack on the steady-state theory was initiated by Gamow (1954), who in a short note, pointed out that after Baade's revision of cosmological distance and timescales, steady-state theory faces the problem of underestimating the ages of galaxies in our vicinity. However, it is clear in Gamow's paper that he does not find the galactic ages measured so far very convincing. The same age discrepancy issue has been raised by the great American observational astronomer, Ivan King, who in 1961 pointed out that the ages of stellar populations in most nearby galaxies are estimated to be about $2H_0^{-1}$, which is not in agreement with the first-order prediction of the steady-state theory (King, 1961). In a short but very comprehensive reply to this objection, Hoyle and Narlikar (1962) have suggested several weaknesses in this argument and put forward at least one problem which outlived the cosmological controversy and remains puzzling to this day. First of all, they pointed out that judging confidently the age of galaxies means knowing with certainty the evolutionary effects dictated by intragalactic physics. As a crucial example, they offer the uncertain status of the morphological types of galaxies: are they constants for all times, or do they change with cosmic time? The latter alternative precludes any conclusion based on assumptions relating stellar populations to the morphological type (a standard procedure in astrophysics) unless we know the exact law of evolutionary change. It is interesting to note that Hoyle and Narlikar in connection with this point suggested a scheme of transformation of Hubble's morphological types which is still an acceptable hypothesis today. Some observational indications to that effect, as well as theoretical explanations bearing on the nature of dark matter, have only recently been reported (Braine and Combes, 1993; Pfenniger *et al.*, 1994).

Finally, Hoyle and Narlikar (1962) indicated (in close connection with their subsequent 'radical departure' (Hoyle and Narlikar (1966)) the possibility of temporal correlations due to collective effects. This idea will be realized in detail in the so-called revised or quasi-steady-state model of the 1990s. If galaxies are formed in groups (i.e. on the higher level of structure), it may be assumed that the galactic ages are correlated. Therefore, it is natural to expect that galaxies in the vicinity of the Milky Way (those amenable to detailed observations and age measurements) will have similar ages (both among themselves, and in comparison with our Galaxy).

6 CLOSED STEADY-STATE MODELS

As we have discussed in the introductory part of this study, the DT argument has been used for the first time against a stationary cosmological model with closed topology advanced by George F. R. Ellis and his co-workers (Ellis, 1978; Ellis *et al.*, 1978). A similar cosmological model has been developed in the mid-1990s by the American physicist Peter Phillips (1994a, b). These models, sharing several key similarities, we shall call the *closed steady-state models*. Their basic characteristic is that stationarity is achieved by rejection of the 'usual' cosmological principle (not to mention the PCP). In other words, the temporal steady state is paid for by abandoning spatial homogeneity.† It is a matter of philosophical taste whether one considers the price too high or not.‡ However, it is difficult to avoid being disturbed by the elaboration of Ellis *et al.* that,

> while isotropy is directly observable, homogeneity (on a cosmological scale) is not. In the standard discussions the assumption of homogeneity is made *a priori*, either directly, or in some equivalent form (e.g. as the assumption that the Universe is isotropic for *all* observers . . .), and so is not subjected to observational verification. Accordingly, the standard 'proof' of the expansion of the Universe is based on an unverified *a priori* assumption.

With the intention of investigating consequences of abandoning the homogeneity postulate and retaining the Einstein field equations, Ellis and his collaborators have reached a model of a topologically closed universe with two privileged 'points'. We are located near one of them, and that is not accidental, because (in accordance with the WAP) it is expected for us to be located in the regions possessing the necessary properties for the origination and evolution of complex (biological) systems. This occurs near the 'centre' of the Universe (it is most natural to use the term for our pole of the manifold, by analogy with a 3-sphere). The opposite of the centre is located at the singularity surrounded by hot matter, simulating in this manner the initial singularity in the Friedmann models. However, in this static model, the singularity is *co-present* with everything that exists, not preceding it. Obviously, it makes the model more appealing from the epistemological point of view; although laws of nature break down at singularity, in the Ellis *et al.* model it is not forever inaccessible in the past but could, in principle, be investigated using the methods and apparatus of modern science. This co-present singularity can be intuitively understood as being the 'enclosure' or 'mantle' surrounding the Universe. Its major purpose is to play the role of a recycling facility in the global cosmological ecology, since the static nature of the Universe makes recycling of high-entropy matter necessary. In the framework of this model it is achieved through a streaming of high-entropy matter (mainly in the form of heavy elements synthesized in stellar nucleosynthesis) towards the singularity, where it is dissociated and returned to the Universe in the form of low-entropy matter (presumably hot single baryons). In this manner the total entropy stays the same at all epochs. Beside this streaming (which does not change the net mass distribution), there is no systematic motion; the observable red shift is of purely gravitational origin. The co-present singularity in the Ellis *et al.* model bears a resemblance to the *apeiron* of Anaximandros out of which worlds are formed and unto which they ultimately dissociate.

In the cosmological model proposed by Phillips (1994a, b) there are also two singular points, this time called the northern and southern poles. The Milky Way galaxy is located in close proximity to the northern pole of the Universe (for the same anthropic reasons as in the Ellis *et al.* model). In contradistinction to the Ellis *et al.* model, here we have a systematic motion of galaxies, in direction from the northern pole to the southern pole. This motion, however, is laminar and stationary, so that the Universe in general always offers the same picture to a typical observer. Metric coefficients are independent of time, and in this sense the model could be considered static. This is a situation somewhat similar to the famous de Sitter cosmological solution for an empty universe, which is nominally static, although we now interpret it as describing the exponential expansion. Since this large-scale motion is present,

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† In this sense, they did not contradict the statement that the classical steady-state model is unique, that is that there is only one cosmology satisfying the PCP, as Bondi (1961) was fond of emphasizing. This methodological advantage of the classical steady-state model over all other cosmological models remains unscathed. As we shall see, closed steady-state models are forced to invoke WAP to explain the highly special nature of our view of the Universe. For the same task, both in the Friedmann models and in the classical steady-state case, Occam's razor is strong enough.

‡ This is quite independent of the fact that closed steady state cosmologies do not satisfy observational constraints and can be considered rejected today. The plausibility of the hypothesis that the observable Universe is a homogeneous part of the much larger inhomogeneous whole (see for example Harwit (1995)). This feature is inherent in some variants of the inflationary scenario, most notably Linde's chaotic inflation programme.

the observed red shift is partially of gravitational origan and partially of Doppler origin. In the Phillips model there are two postulated types of matter, which he calls primary and secondary matter, where the matter to which we are accustomed is of secondary type. Primary matter is moving in the opposite direction (from the southern pole to the northern pole), so that the generalized form of matter conservation is preserved, while the two types of matter never interact except in singular points at the poles. The details of the thermodynamics of this model have been elaborated in better detail than in the Ellis *et al.* model (Phillips 1994b), wherein some observational tests of this version of closed stationary models have been proposed.

These empirical tests are fatal to closed stationary models. In the original paper of Ellis *et al.* (1978), it is shown that this model is not able to account properly for the so-called (m, z) curve, that is the relationship between the apparent magnitude and red shift of cosmologically distributed sources of radiation. It is harder to disprove the Phillips model, since the gravitational and Doppler red shifts are delicately entangled. The cleanest test could be the measurement of peculiar motion of distant sources with respect to the universal reference frame as defined by the microwave background radiation. This experiment is possible to perform in the case of rich galaxy clusters, by means of the Sunyaev–Zeldovich (1980) effect. The prediction of the Phillips model is that more distant clusters will tend to have significantly larger peculiar motions than those nearby. Recent measurements indicate that this is not the case, and there is no meaningful way to save the theory (Phillips, 2001). Therefore, we may consider stationary closed cosmologies to be rejected by observations.

However, they are useful for us in the historical sense. The DT argument against them continues to hold and is even more forceful than for the case of the classical steady-state theory. It is reasonable to assume that, in closed universes, the cross-section for contact (and technologization) of an advanced civilization could literally cover a large fraction of the entire universe. Since our position is necessarily privileged in these universes (hence we observe galaxies and the limiting singularity to be nearly isotropic around our position), it is only plausible to assume that the same anthropic reasons which establish such a situation are acting for any intelligent community which could ever arise in such a universe. However, in that case, where the choice of places of birth of intelligent observers is necessarily finite, it is very easy to see that the world line of any civilization older than ours will pass through the present of the Solar System. In these models, again, conditions for the emergence of intelligent observers (in a limited spatial region, admittedly) persist for an infinite time, and arbitrarily old civilizations are a possibility. The difference in the nature of large-scale motions in the two models considered is irrelevant for our purposes, since the peculiar motions of nearby (with respect to any intelligent observers) galaxies are in any case much smaller than the rate by which the contact cross-section for advanced civilization increases.

One could imagine the situation in which an advanced civilization emerges in a privileged region of space (i.e. in the vicinity of our present position) and gradually expands to encompass the entire ‘favourable’ spatial region (being of finite size, as just a part of the finite Universe). It is reasonable to argue that in the infinite past such a scenario happened at least once (by the same token as the conclusions of Ellis and Brundrit (1979) apply with respect to spatial infinity). There are two possible follow-ups. Such a supercivilization could exist either for a definite or for an indefinite period of cosmic time. In the first alternative, the Universe that we currently inhabit must be ‘recycled’, as Davies warned; no mechanism for such a ‘de-technologization’ is known or even envisaged at present. Since we can envisage (if only very vaguely) the methods through which advanced communities of intelligent beings may technologize ever larger spatial volumes of the Universe, and in the case of a topologically closed universe, even the entire such universe (see for example Tipler (1994)), a humble Humean approach suggests that we choose a ‘smaller miracle’ namely that a supercivilization can exist for an indefinite time.

In any case, we may safely conclude that in the universes of finite size and infinite age (as modelled by the Ellis *et al.* and the Phillips theories) the anthropic argument necessarily leads us to paradoxes, if only we do not restrict the growth of complexity, sociotechnological advance of intelligent societies and their technologization of the environment by definitional *fiat*. It goes without saying that the situation is equally grave for the other model universes which are infinite in both spatial and temporal extension, but for which the conditions favourable to life persist in either a finite or an infinite region for an infinite time. The main lesson of the anthropic spatial selection such as our proximity to the boreal pole in the Phillips model is that this form of self-selection allows for most of the Universe to be uninhabitable and still to retain the DT argument. This is valid even in the case in which the universe is infinite and uninhabitable except for the finite region around our present location.

As we can see in retrospect, the very fact of applying the DT argument against closed steady-state theories demonstrates that the PCP is too strong a requirement for the operation of the argument. As Tipler (1982) stressed, only stationarity and limited local properties are required. From a philosophical point of view, it should be noted that it is also necessary that the rise of intelligent communities and their expansion are possible within a given astrophysical environment. This is self-evident, since humanity exists for a finite time in a relatively stable environment, and expansion over interstellar or even intergalactic length scales is, if not yet a reality, at least quite conceivable from our point of view. The ultimate reason for this is our empirical knowledge on the constancy of physical laws and their modes of operation over these length scales. In a strongly inhomogeneous universe, or a universe with random fluctuations on the scales of, say, 1 pc, the argument loses its power. However, according to the WAP selection, while free to ask questions about possible physical origin of such a hypothetical bizarre behaviour, we should not seek to confirm our conjectures by performing experiments and observations in the real world, because such specific circumstance would preclude our existence (Earman, 1987). Therefore, it seems that in the cases similar to the Ellis *et al.* and the Phillips cosmologies, the DT argument cannot justifiably be regarded as contingent on anything stronger than the WAP, as Barrow and Tipler (1986) tend to do.

7 THE TELEOLOGICAL STRONG ANTHROPIC PRINCIPLE 'COUNTERARGUMENT'

One of the possible recourses for a steady-state proponent in this quandary concerns invoking SAP in its teleological interpretation. It is necessary, therefore, to pause for a moment and to consider the meaning and possible interpretations of SAP, since it has been and still is a considerable source of confusion in the field of anthropic research. In the famous exposition by Carter (1974), several important anthropic principles were defined. Among them, the most speculative and thought provoking has been exactly SAP which states:

> ... the Universe (and hence the fundamental parameters on which it depends) must be such as to admit the creation of observers within it at some stage.

Unfortunately, there is no such thing as the definition of SAP. The widely used definition by Barrow and Tipler (1986) in their influential monograph, has somewhat different overtones from Carter's original version:

> The Universe must have those properties which allow life to develop within it at some stage in its history.

As noted and discussed in some detail by Earman (1987) and Bostrom (2002), these definitions are not equivalent, and that by Barrow and Tipler certainly possesses (as, parenthetically, the entire monograph) strong teleological overtones. While one can plausibly argue that there is in fact nothing particularly ‘strong’ about the SAP in Carter’s formulation if it is regarded as pointing to *blanks* for future physical explanation (Balashov 1990), the somewhat heated discussion of this issue is outside the scope of the present study. Without entering into a general debate on the merits and shortcomings of the teleological discourse in cosmology, it should be noted that it arose as a natural reaction to the overuse of the Copernican principle in natural sciences, and particularly in cosmology. From this overuse follows, for instance, uncritical (and often even unconscious) acceptance of cosmological homogeneity, discussed in the section devoted to closed steady-state models. From a prejudice that nothing in our position is special, one may draw bizarre conclusions, for example that it requires explanation that we are not right now located in intergalactic space, since the latter fills more than 99.99% of the volume of the Universe, and any spatial location not in it is truly exceptional on a grand scale. Understanding that we live in *a priori* very improbable Universe[†] is an encouragement to teleological projects of various kinds, of these, not all must be unscientific (Barrow and Tipler, 1986; Tipler, 1994). One of strategies for refuting the usage of the DT argument lies exactly in assuming that the appearance of intelligent observers is not only of low probability, but in the literal sense impossible. This has been acknowledged, among others, by Ellis and Brundit (1979), who concluded that ‘the existence of life on our own planet does *not* prove that this probability is non-zero’. With that kind of approach, our existence is a miracle, which has happened for some inexplicable theological reason. This is an extreme anti-Empedoclean attitude in the framework of which the biological (or at least anthropological and psychological) evolution is completely transcendent compared with the physical evolution. The ontological gap between the two seems irreducible. This attitude is traditionally (although in a shallow, and sometimes openly incorrect, interpretation) linked to the major religious doctrines, but it is interesting to note that the same sort of thinking is to be found in writings of thinkers of opposite (or at least anticlerical) orientation, such as Sir Fred Hoyle.

In his extraordinarily interesting and well-written autobiographical reminiscences, Hoyle (1994) wrote, in connection with his anthropic prediction of the ^{12}C level, but also, probably, alluding to some of the stranger consequences of his own steady-state outlook:[‡]

> All of this suggested to me what I suppose might be called profound questions. Was the existence of life a result of a set of freakish coincidences in nuclear physics? Could it be that the laws of physics are not the strictly invariant mathematical forms we take them to be? Could there be variations in the forms, with the Universe being a far more complex structure than we take it to be in all our cosmological theories? If so, life would perforce exist only where the nuclear adjustments happened to be favourable, removing the need for arbitrary coincidences, just as one finds in the modern formulation of the weak anthropic principle. Or is the Universe teleological, with the laws deliberately designed to permit the existence of life, the common religious position? A further possibility, suggested by the modern strong anthropic principle, did not occur to me in 1953 – namely, that it is our existence that forces the nuclear details to be the way they are, which is essentially the common religious position taken backwards. Before ridiculing this last possibility, as quite a few scientists tend to do, it is necessary, as I pointed out before, to explain the condensation of the universal wave function through the intervention of human consciousness.

Even more explicit is the discussion presented in his philosophically oriented review article (Hoyle 1982):

> In *Steady State Cosmology Revisited* (University College Cardiff Press, 1980) I estimated (on a very conservative basis) the chance of random shuffling of amino acids producing a workable set of enzymes to be less than 10^{-40000}. . . . Rather than accept a probability less than 1 in 10^{40000} of life having arisen through the ‘blind’ forces of nature, it seems better to suppose that the origin of life was a deliberate intellectual act. By ‘better’ I mean less likely to be wrong.. . .

[†] One should, for instance, keep in mind the estimate of Penrose that the *a priori* probability that the Big Bang happens in such a smooth (low-gravitational-entropy) manner as to produce the observable Universe is only 1 part in $10^{10^{123}}$!

[‡] A popular account of this problem and Hoyle’s answer may also be found in Davies’ (1994) book on physical eschatology.

> Suppose you were a superintellect working through possibilities in polymer chemistry. Would you not be astonished that polymers based on the carbon atom turned out in your calculations to have the remarkable properties of the enzymes and other biomolecules? Would you not be bowled over in surprise to find that a living cell was a feasible construct? Would you not say to yourself, in whatever language supercalculating intellects use, 'Some supercalculating intellect must have designed the properties of the carbon atom, otherwise the chance of my finding such an atom through the blind forces of nature would be less than 1 part in 10^{40000}.' Of course you would, and if you were a sensible superintellect you would conclude that the carbon atom is a fix.

In this manner, to Adam's dilemma (from *The Paradise Lost*), one answers in the affirmative: yes, the celestial bodies truly exist for the sake of the Earth and human beings. Hutton would be happy with this solution! The explanation of the absence of extraterrestrial technology on large scales (i.e. both the Fermi paradox in standard cosmology and the DT problem in an eternal universe) lies in the fact that the probability of the spontaneous conception and subsequent evolution of any intelligent observers is *exactly zero*.[†] The very title of the important article by Kardashev and Strelnitskij (1988), 'Supercivilizations as possible products of the progressive evolution of matter', is simply *wrong* on this view, since there are underlying *physical* reasons for the impossibility of transition between evolution of matter and that of life, and later mind itself (presumably leading to the state of 'supercivilization'). Before we reject this as an obsolete and ridiculously dogmatic viewpoint, one should note that this view is probably the only way known so far capable of *prima facie* accounting for the often-overlooked result obtained by Wigner (Wigner 1967, p. 200) that, within the quantum mechanical formalism, the probability of spontaneous creation of living systems is equal to zero. Quantum-mechanical considerations also motivated Hoyle, in particular in his 1982 paper.

As pointed out by Tipler (2001), this picture is difficult to defend along several lines. The major problem with this sort of argument is that it assumes that not merely intelligent life, but also the specific species *Homo sapiens*, is doing the selecting of the actual Universe. There is no positive reason for belief that humanity is ultimately privileged in this way for participation in the 'creation' of the Universe. On the contrary, as the father of the very label 'anthropic principle', Brandon Carter emphasized that every form of intelligent life is in exactly the same situation. Of course, the purpose of Carter's opinion is exactly to excise, together with anthropocentrism, the teleological mode of explanation, and the answer that we consider in this section is manifestly teleological. However, it is not necessary to be dogmatic either way in considering these issues. This danger may be avoided on account of a general attitude (see, for instance, the discussion by Sklar (1985)) that a metaphysical conjecture can be accepted as an explanatory hypothesis, if capable of accounting for the existing empirical evidence, and in particular in cases where the empirical evidence is slim.

Along these guidelines, one may speculate that more intelligent and more advanced species would be better at 'creating' universes than we could ever hope to be (Harrison, 1995). Even in the cases of manifestly teleological schemes, such as the omega-point theory of Tipler (1994), there is nothing inherently advantageous in belonging *specifically* to *Homo sapiens sapiens*. Our future descendants, the beings who will ultimately realize the purpose of the universe in reaching the omega point, cannot with certainty be characterized as closer to us than we are to birds and fishes. By openly recognizing the issue of the melioristic universe in all its ramifications, Tipler (1994) showed that teleology does not necessarily need to be burdened

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[†] It seems that here one may find a fault in Hoyle's reasoning. He estimated, on the biochemical bass, that the probability of a spontaneous assembly of the first living cell is smaller than 10^{-40000} and from this draws a conclusion that the Universe must be much older than H_0^{-1}, as well as that a variation in the classical panspermia hypothesis must be a correct explanation for the presence of life on Earth. However, the panspermia hypothesis only increases the available 4-volume for random physical processes to bring about life; this volume still remains finite. On the other hand, the universe of the classical steady-state theory (as well as Hoyle's later revised steady-state alternative) is truly infinite in both space and time.

by dogmas of times past. The same lesson should, undoubtedly, apply to the teleological mode of accounting for the DT argument in universes with an infinite past series of events.

Fortunately, we are *not* in the actual position to choose between these alternatives, since our observable Universe is certainly of finite age. However, this dilemma can resurface if we find that the larger whole in which the observable Universe is just an embedded part, possesses a structure characterized by the past temporal infinity. We shall return to this point in Section 7. For the moment, it should be noted that there is another possible recourse for the steady-state picture, which Hoyle has used in the latest phase of his cosmological thinking. This is the argument of the quasi- or revised steady-state theory developed by him and co-workers in a series of papers published in the 1990s (Hoyle, 1992; Hoyle *et al.*, 1993, 1994). Here we basically have a novel strategy in the fight with entropy, and we now investigate whether it is any more successful in dealing with the DT argument.

8 QUASI-STATIONARITY AND INTELLIGENT SPECIES

Although the classical steady-state theory is now universally considered defunct, there are some recent developments to be considered in light of the preceding analysis. One of them is the emergence of the 'quasi'-steady-state theory as an attempt to overcome the difficulties with observational evidence against an unchangeable universe of the PCP, and in favour of a hot state in the cosmic past (Hoyle *et al.*, 1993). The roots of this attempt can be found in Hoyle's (1949) early work in which, comparing the merits of his and the Bondi–Gold version of the classical steady-state theory, he wrote:

> Bondi and Gold . . . , in discussing the continuous creation of matter, have avoided the introduction of a quantitative theory by making the hypothesis that the Universe, when taken on a sufficiently large scale satisfies the wide (perfect) cosmological principle. Since the wide cosmological principle is very far from being satisfied over regions with linear dimension less than about 10^{24} cm, such a hypothesis immediately raises the following question:
>
> What considerations determine the scale necessary for the wide cosmological principle to be approximately satisfied?

Insofar as we can detect inhomogeneities in the Universe in the form of galaxies, clusters and other large-scale structure, we can set the spatial scale for the application of the (restricted) cosmological principle. It is not *obvious* which intervals similarly characterize the smoothing of temporal fluctuations. Of course, the relevant scale can be introduced by a definitional *fiat*, thereby effectively introducing a new constant of nature, which is generally unsatisfactory. Taking amplitudes of such fluctuations to be similar to the conventional Hubble time directly led Hoyle (with fascinating consequence) to the idea of mini big bangs in the revised steady-state theory. Without going into technical details (presented by Hoyle and Burbidge (1992) and Hoyle *et al.* (1993, 1994)), it should be mentioned that, as well as in Hoyle's version of the classical steady-state model, negative energy of the creation field transforms into matter with positive energy. However, the creation is not uniform in space–time but occurs in discrete creation events, so-called 'mini-bangs'. In each individual 'mini-bang' about 10^{16} solar masses (a characteristic mass of superclusters of galaxies) is created in the form of particles with the Planck mass ($M_{\mathrm{Pl}} \sim 10^{-5}$ g). Each Planck particle ultimately produces about 5×10^{18} baryons which react at high energies, producing light chemical elements. The distribution of creation events creates the characteristic cellular structure seen in the large galaxy surveys of the last decade. The thermal energy of matter expanding from the creation events is the ultimate origin of the all-pervading CMB; its anisotropy and local departure from the thermodynamical equilibrium are lost through repeated interactions with a specific form of cosmic dust: elongated metallic whiskers ('needles') created and distributed through space by the supernovae explosions of the first generation of stars.

The revised steady-state theory possesses a continuity with the earlier work of Hoyle and Narlikar, mainly the results from their 1966 study (Hoyle and Narlikar 1966), where the rejection of smooth continuous creation of the previous theory has been emphasized in the very title of the paper ('A radical departure from the "steady-state" concept in cosmology'). This model, in its elaboration of 1990s, includes some of the elements of recent (particularly observational astrophysical) developments and so is more modern and closer to the prevailing trends in science. At the same time, however, its structure is complicated and possesses none of the beautiful simplicity of the classical steady-state theory. Although detailed discriminatory observational tests of the new model have not been performed yet, the probability that they will give results expected by the quasi-steady-state proponents is small indeed. Moreover, the findings connected with the chemical abundances of the primordial matter, as well as the deep galaxy fields, point to the lack of support for some of the basic tenets of this model.

However, the quasi-steady-state theory does not stand up to the anthropic arguments much better. This theory is vulnerable to the DT argument in the same basic manner as classical steady-state cosmology. The fact that we shall encounter galaxies of similar age to the Milky Way inside the Local Supercluster represents only a gigantic spatial and temporal translation of the problem, which does not brings us closer to its solution. Galaxies and technological civilizations of the appropriate age will be present in other superclusters, which could be of an arbitrary age, obeying only the self-similar 'supercluster distribution function' necessarily akin to equation (2). This strategy of 'passing the buck' is probably one of the chief reasons why the DT argument has needed so much time to be formulated. It may eventually solve our psychological difficulty concerning past temporal infinity, but not the physical problem itself. If we do not forbid information transport between the superclusters by definitional *fiat*, the problem remains as acute as in the classical steady-state case.

9 STATIONARY MULTIVERSE?

Recently the idea of stationarity on very large scales has been reanimated in the form of several similar inflationary scenarios. A typical example is the work of Andrei Linde and co-workers (Linde, 1988, 1990; Linde *et al.*, 1994), as well as Vilenkin (1992, 1995). In these models (known under labels such as 'chaotic' or 'eternal' inflation), bubbles are formed out of space–time foam at the Planck energy, each bubble evolving into an individual universe in its own right, with specific topologies, geometries, laws of nature, coupling constants, etc. The entire process of separation and inflation of these individual bubble universes has no beginning or end, and therefore the entire ontological background of these processes (for which the appropriate name of *multiverse* is coined) is stationary. A significant similarity between classical C-field cosmology and inflationary scenarios in general has been noted recently (Hoyle, 1992; Narlikar, 1984). The manifestation of that swing of the pendulum backward from extreme evolutionism towards some form of stationarity can be seen in the very titles of several recent papers, such as 'From the Big Bang theory to the theory of a stationary universe' (Linde *et al.*, 1994).[†] It is still too early to estimate whether this should be regarded as the general tendency to recover some of the advantages of 'stationary' cosmologies (and, possibly, a counter-reaction to the overemphasis on 'evolutionary uncertainties' frequently employed in astrophysics as an *ad hoc*, or rather ignoramus, recipe). Future historians of science will have to discuss this question.

[†] This phenomenon in its historical context could be compared with the similar return of (neo)catastrophism on the scene in geology and paleontology (see for example Clube (1995)).

The role of ‘local inhomogeneities’, which is played by galaxies in the classical steady-state model, is played by entire individual bubble universes in the multiverse theories. As suggested by Linde (1990), different ways of breaking the initial complete symmetry of the single ‘unified’ force of nature will occur in different bubble universes, and so a wild variety of physical conditions are likely to arise. It is natural to ask, therefore, whether the DT anthropic argument applies to those quantum cosmological models that are in a global stationary state. It should be immediately clear that the inflationary scenarios have great relevance for the entire problem of existence of life in the Universe. As an illustration, in a conclusion to their highly technical paper on some aspects of inflation, Novello and Heintzmann (1984) wrote:

> Two possibilities arise to have a sufficiently old universe: either S_0 [the present-day scale factor of our Universe] is large – which means that the Universe was never very dense and thereby never very hot (this would guarantee biological conditions for all of the cosmic epoch); or $1/H_0$ is very large and S_0 small. In this case biological reactions will only occur (or reoccur) in the late expanding phase and existence of life would only occur at a finite time; whereas, in the first case, life could have existed eternally in the Universe, leading to the intriguing hypothesis that there may be colonies in space which are infinitely more intelligent than we are.

There are several methods to escape the conclusions of the DT argument in the multiverse case. The simplest is to reject the very notion of ‘eternal’ inflation. This possibility (differently motivated) has been investigated by Vilenkin (1995) and Borde and Vilenkin (1994). The goal of these studies is to show that, under a general range of physical conditions, the initial singular beginning is compulsory, from which it immediately stems that the entire multiverse is of finite age. The outcome is not unambiguous. Another possible approach is that discussed by Barrow and Tipler (1986, Chapter IX): to forbid information transport between individual bubble universes by physical reasons. The ‘environment’ surrounding the bubble universes is false vacuum at energies close to the Planck energy, which makes any communication hard to imagine, to say the least (but see Garriga *et al.* (1999)). This conclusion may be challenged on the grounds that, firstly, what is hard to imagine today does not need to be so for the advanced civilizations that have already technologized a large part or their entire domicile bubble universe and thus marshalled unbelievable material and intellectual resources and, secendly, it may well be possible to communicate between two bubble universes in a non-classical way, that is using (or creating!) the complex topological structure of the multiverse. The latter method would rely on some version of the well-known concept of ‘wormholes’ (see for example Morris *et al.* (1988) and Visser (1990)). Finally, the third possible strategy lies in the possibility that individual bubble universes (with finite resources, and therefore the finite duration of an active technologized state) may be separated from the Planck space–time foam at a rate sufficiently high to achieve a state equilibrium with the formation and evolution of generic intelligent communities. Such an equilibrium will reflect the state in which most of ‘young’ universes are uninhabited either by their native supercivilizations or by an external (‘colonizing’) supercivilization of an arbitrary age. However, it goes without saying that this is extremely speculative, and therefore is mentioned here just for completness. Otherwise, one cannot escape an agreement with the judgement of Barrow and Tipler that

> this . . . objection is much weaker in the inflation steady-state universe situation than it is in the standard steady-state universe model, for it is far from clear that it is possible to develop technology which will allow intelligent life to exist . . . in the steady state region.

10 LESSONS AND MORALS

From the impressive reaches of the multiverse inflationary theories, let us return to the classical cosmology and try to summarize our conclusions so far. Several classical cosmological models have been compared in Table 1 with respect to some properties relevant for the anthropic

Table 1. Comparison of some classical cosmological models on several counts related to the anthropic argument against past temporal infinities.

Number	*Model*	*Static*	*Closed*	*Matter*	*Singular*	*Horizon*	*DT*
1	Einstein	+	+	+	−	−	+
2	de Sitter	+−	−	−	−	+	−
3	Eddington–Lemaître	−	−	+	−	+	−+
4	Classical steady state	−	−	+	−	+	+
5	Ellis *et al.*	+	+	+	+	−	+
6	Phillips	−	+	+	+	−	+
7	Oscillatory non-singular	−	+	+	−	−	+−
8	Revised steady state	−	−	+	−	+	+

reasoning and survival of intelligent observers. These properties refer to dynamics, topology and application of the DT argument. Taken together, they illustrate the range (certainly not exhaustive) of classical cosmological thought and the close connection of the entire anthropic reasoning to other physically defined properties of particular models. All models presented in Table 1 possess a past temporal infinity in at least one sense (i.e. according to one of the major theories of the ontological status of time discussed above). Some of these are static an large scales, and most are not; the ambiguous sign for the case of the classical de Sitter universe represent the curious historical ambiguity on the meaning of 'static'.[†] Some models are topologically closed, while others are flat or open, and some possess such specific features as (global) singularities and horizons.[‡]

In the last column of Table 1, the applicability of the DT argument, according to our study, is presented. In the case of the Eddington–Lemaître model, the outcome strongly depends on the detailed physical properties of the initial equilibrium state. In most versions of this model, the anthropic argument is clearly inapplicable, although the strong version of the argument may be operational in some specific versions. The dependence on the physical detail also plays a crucial role in considerations of non-singular cyclical models (singular models cannot be justifiably called oscillatory at all). Here the real issue is information transport between the successive phases of contraction and expansion. If the physical conditions are too extreme at the point of the smallest radius, the information on the previous cycle will be erased, and the subsequent phase will essentially be a completely new universe, 'from scratch'. These conditions, in turn, depend on the exact values of cosmological parameters in the model,[§] as well as in unknown physics on which the concept of a bounce critically depends. In addition, the duration of expanding and contracting phase must be long enough for the advanced technological communities to arise (WAP constraint), or (in the stronger version) for the process of spontaneous creation of probes (and probes causally connected with the region beyond the bounce at that!) to occur. Since various combinations of parameters are possible in this class of models, it is not possible to give a generic answer on the applicability question.

A criticism usually encountered from people for the first time facing such an anthropic argument concerns the relationship of laws and instances in cosmology. How can such an argument based on a single instance of intelligent and technological life be used as a general

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[†] Metric coefficients do not change with time in this model, and for that reason it was conceived and received as static, at least in the first decades after 1917; according to the modern view, it is an exponentially expanding model.

[‡] It is important to emphasize that the singularities under considerations are global; otherwise, all space–times in which at least some world lines are incomplete should qualify as singular, including the classical steady-state theory which is characterized by creation 'microsingularities' (and does not manifestly prevent formation of black-hole singularities!).

[§] If these parameters are allowed to vary between the cycles in a random manner, there is no reason to believe in an infinite number of cycles at all; the cosmological constant, which is one of these parameters, could change the sign and become strongly positive, which would lead to an ever-expanding (although topologically still closed!) universe.

argument against a wide spectrum of specific physical cosmologies, such as the classical steady-state theory certainly is. There are two possible answers to this basic *non sequitur*. First of all, there is no generic form of cosmological model; as shown clearly by Balashov (1994) in the detailed analysis of classical steady-state theory, the entire theory can be both legitimately and practically derived from an essentially methodological principle as is the PCP. *Mutatis mutandis*, the rejection of such a theory can be both legitimately and practically done on the account of argument pointing out the self-contradictory nature of particular instances of PCP application. Let us reiterate; there is no inherent need for life to exist in a universe satisfying the PCP. In a sense, it would be much easier to formulate the PCP for the counterfactual case of a lifeless universe, since amplitudes of 'local inhomogeneities' could also be either much smaller or much larger from the narrow range required for satisfying the WAP constraints. For instance, the counterfactual universe with amplitude of fluctuations several orders of magnitude smaller than those detected in the real Universe through CMB observations could evolve as mildly inhomogeneous plasma according to the PCP without ever forming galaxies and stars. New matter will simply keep the density of such plasma constant. A very high (again counterfactual) value of the Hubble constant will probably have the same effect. However, once we make an observation of the existence of life (and intelligence), the PCP requires that we have the same in all ages and in infinitely many places.

The second aspect of the dilemma is contained in the ambiguous status of the biological and psychological evolution in our picture of the Universe. It seems clear that we are dealing with a double standard here. When Hoyle predicted the existence of the 7.65 MeV metastable level in the nucleus of ^{12}C on the basis of the existence of carbon and carbon-based life (Hoyle *et al.*, 1953; Hoyle, 1994), it was quite clear that this level does not exist separately from the entire scope of physical sciences. On the contrary, it was clear from the beginning that the energy and all relevant properties of this level can in *principle* be reduced to the particular numerical values of the constants of nature, such as the Planck constant and elementary charge. Therefore, fine tuning of the ^{12}C level is actually only a *manifestation* of the fine tuning of various constants of nature. Conceptually, this manifestation is redundant. However, we cannot, as discussed by Barrow and Tipler (1986), backtrack and reconstruct the manner in which the particular values of constants propagate towards creating the observed energy of this level. This is just a technical matter, because the carbon nucleus is an extremely complicated quantum system, and there is simply not enough sophistication and calculating power in the present-day nuclear physics to perform such backtracking. Still, it is important to note that nobody denies the *principal* possibility of such reconstruction, which can be achieved in a matter of decades if the development of numerical science and computers continues at the present pace. The same idea applies, *mutatis mutandis*, to other examples of the so frequently discussed 'anthropic coincidences'.

However, a significant resistance is encountered when the same reasoning applies to systems which are more complex than nuclei, say living and intelligent beings. Still, there is no evidence whatsoever that living systems are in any way different from usual physical systems except in the level of complexity (Davies, 1999). Views sometimes expressed to the contrary can be regarded only as remnants of the obsolete vitalistic doctrines. Indications that the mental processes occurring in intelligent beings can be in *principle* ultimately reduced in a manner essentially the same as is conjecture for the carbon nucleus have been gathered by Tipler (1994) and Stapp (1985). Similar thoughts have been expressed earlier in the twentieth century by Erwin Schrödinger (1944) in his influential *What is Life?* essays.

It is clear that the weak version of DT argument may be criticized on historical–sociological arguments. Let us assume that there is an absolute maximum for the development of any community of intelligent beings, and that the contact cross-section of this maximum is small. In that case, if the rate of emergence of intelligent communities is sufficiently low in comparison with the Hubble expansion rate, in the finite relaxation time it is possible to achieve the equilibrium in which arbitrarily large fraction of the comoving 3-volume is non-technologized. This could be called the Spenglerian model of intelligent communities (see for example Fischer (1989)). For an exception to the prevailing paradigm of discontinuity between the contemporary world view in the natural sciences and history understood in Spenglerian terms, one may look at the excellent recent study of Victor Clube (1995) devoted to cometary neocatastrophism in planetary studies. This work, under the instructive title 'The nature of punctual crises and the Spenglerian model of civilization' presents, in a different but still quite relevant scientific framework, how much the self-contentedness and dogmatical blindness in science in the last century or two could lead towards a *de facto* wrong factual road. It was first the medieval immutable heavens and subsequently uniformitarian (anticlerical, ironically enough) dogma on the exclusiveness of slow evolutionary change, which impeded (and to a degree still impedes) acceptance of the truth about the significance of catastrophic events originating in our cosmic environment. The specific problem with the Spenglerian model lies exactly in the mentioned need for *non-exclusivity*; as the teleological counterargument becomes valid only if the probability of spontaneous creation of life (and/or von Neumann probes) is for some reason exactly equal to zero, and not only very small, so here the number of civilizations that are capable of escaping the Spenglerian 'curse' must be exactly zero in order for the explanation to work in an infinitely old universe. This is even harder to imagine than the previous case because, if the proponents of the impossibility of the spontaneous creation of life can enlist quantum mechanics on their side, the proponents of the Spenglerian model have to show that sociology and history are in a sense more universal than quantum mechanics itself! (Of course, the Spenglerian model remains a strong palliative to naive concepts of a universe blossoming with life in the case of temporally and spatially limited systems; therefore, it remains very relevant for the Fermi paradox and the SETI problem in the Milky Way.) Of course, the stronger version of the anthropic argument given by Tipler related to spontaneously assembled von Neumann probes is entirely immune to this type of criticism.

The core lesson of the entire case for the anthropic argument against cosmologies containing past temporal infinities is, however, located on a deep epistemological level. As a side effect of both the Copernican revolution and the Cartesian dualism, the implicit rejection of the pre-Socratic picture of the inseparability of the cosmological, biological and anthropological domains led to an inevitable delay in noticing a powerful and specific cosmological argument. Further discussions on this topic, as well as further discussions of the future of the *physical* Universe, will have to take into account explicitly the existence and activities of intelligent observers. This will manifest itself not only in retrodictions about the cosmological past, as the original anthropic argument of Dicke and Carter has been traditionally used, but also through the predictive aspect of cosmology. These considerations will necessarily be of a multidisciplinary character, so desirable in this latest epoch of development of our picture of the Universe.

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References

Almar, I. (1989) *Acta Astronaut.* **26**, 253.
Balashov, Yu. (1990) *Comments Astrophys.* **15**, 19.
Balashov, Yu. (1994) *Stud. History Philosophy Sci.* **25B**, 933.
Barrow, J. D., and Tipler, F. J. (1986) *The Anthropic Cosmological Principle*, Oxford University Press, Oxford.
Baxter, S. (2004) *Ages in Chaos: James Hutton and the Discovery of Deep Time*, Forge Books, New York.
Bekenstein, J. D., and Meisels, A. (1980) *Astrophys. J.* **237**, 242.
Bell, J. (1979) *Br. J. Phil. Sci.* **30**, 161.
Bok, B. J. (1946) *Mon. Not. R. Astron. Soc.* **106**, 61.
Bondi, H. (1961) *Cosmology*, 2nd edition, Cambridge University Press, Cambridge.
Bondi, H., and Gold, T. (1948) *Mon. Not. R. Astron. Soc.* **108**, 252.
Borde, A., and Vilenkin, A. (1994) *Phys. Rev. Lett.* **72**, 3305.
Bostrom, N. (2002) *Anthropic Bias: Observation Selection Effects*, Routledge, New York.
Braine, J., and Combes, F. (1993) *Astron. Astrophys.* **269**, 7.
Brin, G. D. (1983) *Q. J. R. Astron. Soc.* **24**, 283.
Burnet, J. (1908) *Early Greek Philosophy*, Adam and Charles Black, London.
Carter, B. (1974) In J. Leslie, (ed.), *Physical Cosmology and Philosophy*, Macmillan, London, 1990.
Chaboyer, B., Demarque, P., Kernan, P. J., Krauss, L. M., and Sarajedini, A. (1996) *Mon. Not. R. Astron. Soc.* **283**, 683.
Charlier, C. V. L. (1922) *Ark. Mat. Astron. Phys.* **16**, No. 22, 1.
Clube, S. V. M. (1995) *Vistas Astron.* **39**, 673.
Cornford, F. (1965) *Thucydides Mythistoricus*, Greenwood, New York.
Craig, W. L. (1979) *The Kalam Cosmological Argument*, Macmillan, London.
Craig, W. L. (1990) *Br. J. Phil. Sci.* **41**, 473.
Ćirković, M. M. (2000) *Serb. Astron. J.* **161**, 33.
Ćirković, M. M. (2003a) *Found. Phys.* **33**, 467.
Ćirković, M. M. (2003b) *Astron. Astrophys. Trans.* **22**, 879.
Davies, P. C. W. (1975) *Nature* **255**, 191.
Davies, P. C. W. (1978) *Nature* **273**, 336.
Davies, P. C. W. (1983) *God and the New Physics*, Simon & Schuster, New York.
Davies, P. C. W. (1994) *The Last Three Minutes*, Basic Books, New York.
Davies, P. C. W. (1999) *The Fifth Miracle*, Simon & Schuster, New York.
de Fontenelle, B. Le B. *Conversation on the Plurality of the Worlds* (H. A. Hargleaves, Trans., original work published in French in 1767), University of California Press, Berkeley.
Dicke, R. H., Peebles, P. J. E., Roll, P. G., and Wilkinson, D. T. (1965) *Astrophys. J.* **142**, 414.
Diels, H. (1983) *Presocratic Fragments*, Naprijed, Zagreb.
Dyson, F. J. (1979) *Rev. Mod. Phys.* **51**, 447.
Earman, J. (1987) *Am. Phil. Q.* **24**, 307.
Eddington, A. S. (1928) *The Nature of the Physical World*, Cambridge University Press, Cambridge.
Eddington, A. S. (1930) *Mon. Not. R. Astron. Soc.* **90**, 668.
Einstein, A. (1917) *Sitz. Preuss. Akad. Wiss.*, 112, 142.
Ellis, G. F. R. (1978) *Gen. Rel. Grav.* **9**, 87.
Ellis, G. F. R., and Brundrit, G. B. (1979) *Q. J. R. Astron. Soc.* **20**, 37.
Ellis, G. F. R., Maartens, R., and Nel, S. D. (1978) *Mon. Not. R. Astron. Soc.* **184**, 439.
Fairbanks, A. (1898) *The First Philosophers of Greece*, K. Paul, Trench & Trubner, London.
Fischer, K. P. (1989) *History and Prophecy – Oswald Spengler and the Decline of the West*, Peter Lang, New York.
Gamow, G. (1954) *Astrophys. J.* **59**, 200.
Garriga, J., Mukhanov, V. F., Olum, K. D., and Vilenkin, A. (2000) *Int. J. Theor. Phys.* **39**, 1887.
Gindilis, L. M. and Rudnitskii, G. M. (1993) In G. Seth Shostak (ed.), *Third Decennial US–USSR Conference on SETI*, ASP Conference Series, Vol. 47, San Francisco, California, USA, p. 403.
Gott, J. R. (1977) *Ann. Rev. Astron. Astrophys.* **15**, 235.

Gould, S. J. (1987) *Time's Arrow, Time's Cycle*, Harvard University Press, Cambridge, Massachusetts.

Grünbaum, A. (1991) *Erkenntnis*, **35**, 233.

Guthrie, W. K. C. (1969) *A History of Greek Philosophy II*, Cambridge University Press, Cambridge.

Haldane, J. B. S. (1945) *Nature* **155**, 133.

Harrison, E. R. (1973) *A. Rev. Astron. Astrophys.* **11**, 155.

Harrison, E. R. (1995) *Q. J. R. Astron. Soc.* **36**, 193.

Hart, M. H. (1975) *Q. J. R. Astron. Soc.* **16**, 128.

Harwit, M. (1961) *Mon. Not. R. Astron. Soc.* **122**, 47.

Harwit, M. (1995) *Astrophys. J.* **447**, 482.

Hawking, S. W., and Penrose, R. (1970) *Proc. R. Soc. A* **314**, 529.

Hawkins, D. (1971) *Philosophy Sci.* **38**, 273.

Hinckfuss, I. (1975) *The Existence of Space and Time*, Clarendon, Oxford.

Hoyle, F. (1948) *Mon. Not. R. Astron. Soc.* **108**, 372.

Hoyle, F. (1949) *Mon. Not. R. Astron. Soc.* **109**, 365.

Hoyle, F. (1975) *Astrophys. J.* **196**, 661.

Hoyle, F. (1982) *Ann. Rev. Astron. Astrophys.* **20**, 1.

Hoyle, F. (1992) *Astrophys. Space Sci.* **198**, 195.

Hoyle, F. (1994) *Home Is Where the Wind Blows*, University Science Books, Mill Valley.

Hoyle, F., and Burbidge, G. R. (1992) *Astrophys. J.* **399**, L9.

Hoyle, F., Burbidge, G. R., and Narlikar, J. V. (1993) *Astrophys. J.* **410**, 437.

Hoyle, F., Burbidge, G. R., and Narlikar, J. V. (1994) *Mon. Not. R. Astron. Soc.* **267**, 1007.

Hoyle, F., Dunbar, D. N. F., Wensel, W. A., and Whaling, W. (1953) *Phys. Rev.* **92**, 649.

Hoyle, F., and Narlikar, J. V. (1962) *Observatory* **82**, 13.

Hoyle, F., and Narlikar, J. V. (1966) *Proc. R. Soc. A* **290**, 162.

Hoyle, F., and Narlikar, J. V. (1972) *Mon. Not. R. Astron. Soc.* **155**, 305.

Hutton, J. (1788) *Trans. R. Soc. Edinburgh* **1**, 209.

Israelit, M., and Rosen, N. (1989) *Astrophys. J.* **342**, 627.

Kalitzin, N. S. (1961) *Mon. Not. R. Astron. Soc.* **122**, 41.

Kardashev, N. S., and Strelnitskij, V. S. (1988) In G. Marx (ed.), *Bioastronomy – The Next Steps*, Kluwer, Dordrecht, p. 295.

King, I. (1961) *Observatory* **81**, 128.

Kragh, H. (1996) *Cosmology and Controversy*, Princeton University Press, Princeton, New Jersey.

Krauss, L. M. (1998) *Astrophys. J.* **501**, 461.

Linde, A. D. (1988) *Phys. Lett. B* **211**, 29.

Linde, A. D. (1990) *Inflation and Quantum Cosmology*, Academic Press, San Diego, California.

Linde, A. D., Linde, D., and Mezhlumian, A. (1994) *Phys. Rev. D* **49**, 1783.

Lipunov, V. M. (1997) *Astrophys. Space Sci.* **252**, 73.

Lucretius (1997) *On the Nature of Things* (translated by W. E. Leonard, e-text version, Project Gutenberg, Urbana).

Milne, E. A. (1948) *Kinematic Relativity*, Clarendon, Oxford.

Misner, C. W. (1969) *Phys. Rev.* **186**, 1328.

Morris, M. S., Thorne, K. S., and Yurtsever, U. (1988) *Phys. Rev. Lett.* **61**, 1446.

Narlikar, J. V. (1984) *J. Astrophys. Astron.* **5**, 67.

Narlikar, J. V., and Arp, H. (1993) *Astrophys. J.* **405**, 51.

Newton-Smith, W. H. (1980) *The Structure of Time* (Routledge and Kegan Paul, London).

North, J. (1965) *The Measure of the Universe: A History of Modern Cosmology*, Oxford University Press, Oxford.

Novello, M., and Heintzmann, H. (1984) *Gen. Relativistic Gravitation* **16**, 535.

O'Brien, D. (1969) *Empedocles' Cosmic Cycle*, Cambridge University Press, Cambridge.

Oppy, G. (1995) *Faith Philosophy* **12**, 237.

Peebles, P. J. E. (1993) *Principles of Physical Cosmology*, Princeton University Press, Princeton, New Jesey.

Pegg, D. T. (1971) *Mon. Not. R. Astron. Soc.* **154**, 321.

Penrose, R. (1979) In S. W. Hawking, and W. Israel (eds) *General Relativity: An Einstein Centenary*, Cambridge University Press, Cambridge, p. 581.

Pfenniger, D., Combes, F. and Martinet, L. (1994) *Astron. Astrophys.* **285**, 79.

Phillips, P. R. (1994a) *Mon. Not. R. Astron. Soc.* **269**, 771.

Phillips, P. R. (1994b) *Mon. Not. R. Astron. Soc.* **271**, 499.

Phillips, P. R. (2001) *Private communication*.

Popper, K. R. (1978) *Br. J. Phil. Sci.* **29**, 47.

Reber, G. (1982) *Publ. Astron. Soc. Aust.* **4**, 482.

Schrödinger, E. (1944) *What is Life?*, Cambridge University Press, Cambridge.

Sciama, D. W. (1955) *Mon. Not. R. Astron. Soc.* **115**, 3.

Segal, I. E. (1978) *Astron. Astrophys.* **68**, 343.

Sklar, L. (1985) *Philosophy and Spacetime Physics*, University of California Press, Berkeley, California.

Smolin, L. (1992) *Class. Quant. Grav.* **9**, 173.

Spengler, O. (1918) *Decline of the West*, 1996 edition, Alfred A. Knopf, New York.

Stapp, H. P. (1985) *Found. Phys.* **15**, 35.

Sunyaev, R. A., and Zeldovich, Ya. V. (1980) *Ann. Rev. Astron. Astrophys.* **18**, 537.

Tipler, F. J. (1981) *Q. J. R. Astron. Soc.* **22**, 133.
Tipler, F. J. (1982) *Observatory* **102**, 36.
Tipler, F. J. (1994) *The Physics of Immortality*, Doubleday, New York.
Tipler, F. J. (2001) *Private Communication*.
Vilenkin, A. (1992) *Phys. Rev. D* **46**, 2355.
Vilenkin, A. (1995) *Phys. Rev. Lett.* **74**, 846.
Visser, M. (1990) *Phys. Rev. D* **41**, 1116.
Ward, P. D. (1998) *Time Machines: Scientific Explorations in Deep Time*, Copernicus Books, New York.
Weinberg, S. (1972) *Gravitation and Cosmology*, Wiley, New York.
Wesson, P. S., Valle, K., and Stabell, R. (1987) *Astrophys. J.* **317**, 601.
Whitrow, G. J. (1978) *Br. J. Phil. Sci.* **29**, 39.
Wigner, E. (1967) *Symmetries and Reflections*, University of Indiana Press, Bloomington, Indiana.