THE ANTHROPIC PRINCIPLE AND THE DURATION OF THE COSMOLOGICAL PAST

Milan M. Ćirković
Astronomical Observatory Belgrade,
Volgina 7, 11160 Belgrade-74, Serbia and Montenegro
and
Department of Physics, University of Novi Sad,
Tryg Dositeja Obradovića 4, 21000 Novi Sad, Serbia and Montenegro
E-mail: mcirkovic@aob.aob.bg.ac.yu

Abstract

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 analyzed and applied to several instructive instances. This is not only of historical significance but 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 is not only a clear example of the epistemological significance of the anthropic principle, but also has consequences for such diverse topics as SETI studies, epistemological status of cosmological concepts, theory of observation selection effects, and history of astronomy.

Keywords: history and philosophy of astronomy, cosmology: theory
1 Introduction

The simplest division of 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 which 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 (e.g. North 1965). The resistance to the opposing view (which eventually became what is today called the standard cosmology) was established during most of the nineteenth and early twentieth century 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*, flatly stated: "As a scientist, I simply do not believe that the universe began with a bang." \footnote{Eddington (1928), p. 85. 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 of originating of the world in a finite moment of time.} From the end of the Middle Ages until the Hubble observational revolution in the third decade of the twentieth century, the stationary worldview has been in one way or another the dominant one 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 thermodynamical arrow of time originates in cosmology, has occasionally surfaced (Price 1996; Čirković 2003a, and references therein).
The power of a stationary alternative to the evolutionary models of the universe has been reiterated in particularly colorful 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 (e.g. Hawkins 1971; Grünbaum 1991; Balashov 1994; Kragh 1996), this particular argument has not been discussed in detail so far.

In modern physical cosmology, the position is reversed compared to the situation in first decades of the XX century. The evolving universe with 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; Peebles 1993). Prior to the discovery of the cosmic microwave background (henceforth CMB) in 1965, at least one of the stationary theories—the classical steady state model of Bondi and Gold (1948), as well as Hoyle (1948)—has been a viable and quite popular worldview. After the interpretation of CMB as the remnant of the primordial fireball (Dicke et al. 1965) has become a standard one (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 slant.

- Great pains have been taken to make the initial singularity palatable or to avoid it whatsoever (e.g. Misner 1969; Bekenstein and Meisels 1980; Israelit and Rosen 1989), and the results are still inconclusive from the point of view of most researchers, in spite of the tremendous advances of the new discipline of quantum 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 (e.g. 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 worldview (Price 1996), in which cosmological boundary conditions play the 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 the realistic ones.  

- Recently, various “multiverse” schemes have been proposed (e.g. Linde 1990; 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 multi-fold, ranging from details of the inflationary theory to topology to the fundamentals of quantum mechanics. Some of the proposed multiverses are indeed in a stationary state, even somewhat resembling of 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 “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 points 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.  

Today, the scepticism sometimes encountered against this mode of thinking is even stranger, when various (and in

---

2For instance, if the thermodynamical 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?

3For a historical sketch from the pen of a “contact pessimist” see Tipler (1981).
some cases not quite inexpensive) SETI projects testify to the reasonable
degree of belief in the existence of technological civilizations other than the
human one. Their technological nature (the same one which produces the
problem Davies wrote about) is a \textit{conditio sine qua non} of any sensible SETI
enterprise.

In tight connection with 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 (henceforth
WAP), which states (Carter 1974) that

\[\text{...we must be prepared to take account of the fact that our lo-}\]
\[\text{cation in the universe is \textit{necessarily} privileged to the extent of}\]
\[\text{being compatible with our existence as observers.}\]

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

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

With these formulations of WAP in mind, it is clear why the Davies’ argu-
ment against the Ellis et al. cosmological model can be called \textit{anthropic} at
all: it takes into account the restrictions to be imposed on cosmological mod-
els 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 especially interesting is the cyclic cos-
mosology of Empedocles of Acragas (VI-V century BC), in which the universe
is eternal,\footnote{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.”} consisting of the internally immutable four classic elements, as
well as two opposing forces (Love and Strife, i.e. attractive and repulsive
interactions). The cyclic motion of matter in the universe is governed by
the change in relative intensities of the two interactions (see the excellent
discussion in O’Brien 1969). It is interesting to note that Empedocles’ cos-
mosology is \textit{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 implies that, although this uniformi-
tarianism 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.\footnote{Another pioneering contribution of Empedocles lies exactly in separation (the earliest one in the Western thought!) of the physical nature and artifacts 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.} 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 in Ćirković (2003b), this Empedoclean view—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 trouble as the one facing the classical steady state theory or the one of Ellis et al. 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 of Hutton in \footnote{Another pioneering contribution of Empedocles lies exactly in separation (the earliest one in the Western thought!) of the physical nature and artifacts 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.} below)?

Empedocles may have perceived this himself and he evades the problem in the only natural way he can: 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 instance, Davies 1994). In these states the 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 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—i.e. about 450 BC—nothing of importance (συµεγαλα γευεσθαι) had happened in history. This startling statement has been called “outrageous” by Oswald Spengler, and used to demonstrate the essentially mythological character of the ancient Greek historiography (Spengler 1918; 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 timespan considered small even compared to 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’ worldview, there is a 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 the Book V of his famous poem De Rerum Natura writes the following intriguing verses:

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 the Book V of his famous poem De Rerum Natura writes the following intriguing verses:

6This is clear, for instance, from the fragment A 10 in Diels (1983), preserved by Plutarch, in which it is explicitly asserted that formation and destruction of many worlds occurs 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 (B 2), 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?
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
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.7

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 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 Davies-Tipler (henceforth 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 (Bondi and Gold 1948; see the discussion in the Sec. 3 below). The discrete Markov chain recurrence of the type discussed by Ellis and Brundrit (1979) has also been used in the discussion of 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.

7In translation of William E. Leonard, available via WWW Project Gutenberg (Lucretius 1997).
The essence of Tipler’s (1982) discussion is that, given some usual sym-
metries of spacetime, 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 (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 the universe satisfying
the perfect cosmological principle (i.e. the classical steady state universe)
it is clearly seen from the Penrose diagram shown in Fig. 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 neighborhood \( q + \varepsilon \), in an in-
finitely old universe there would still be at least one intelligent community
at any point \( p \) in spacetime, no matter how big \( |p - q| / \varepsilon \) is.

Here we notice that instead of dealing with temporal parts, we are dealing
with events in spacetime only. Therefore, this argument is intrinsically for-
mulated in terms of a relationist or reductionist theory of time (e.g. 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 (like requirement
to include the creation of life and intelligence among the physically possible
events, etc.), we are led to the same paradoxical conclusion.

However, Tipler (1982) goes farther than Davies’ casual remark given in
the context of an editorial comment, and claims that,

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

This scenario, although not at all fantastic, raises several questions still
lacking elaboration. How could we possibly know that the set of all ”favorably-
Figure 1: Conformal (Penrose) diagram of the classical steady-state universe. Event $p$ is arbitrarily chosen, and with A and B are denoted worldlines of intelligent species existing within and outside of the light cone of $p$. (Reproduced with permission from Tipler 1982.)
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 not postulate an assembly of von Neumann probe designed to search and destroy other von Neumann probes? What is the relative weight of colonizing (vs. 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 at timescales many orders of magnitude shorter than those required for the spontaneous assembly Tipler describes). While one may argue that motivation is necessarily linked to the level of complexity, and therefore one expects the spontaneously assembled self-reproducing automata will have basically the same motivations we perceive in biological systems on Earth (Tipler 2001, private communication), 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 defense of the Milne’s 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 finite past vs. the hypothesis of its eternal existence, he shows both his cosmological interests and appreciation for a melioristic and humanistic worldview:

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.8

If we understand “improvement” of the universe not in strictly ethical terms,9 but as increase in its complexity, the question posed by Haldane is the same as in the DT argument. Complexity may be achieved through either tech-

---

8 Haldane 1945; underlined by the present author.
9 But presumably including that aspect. If we reject pantheism, there is a minimal level of complexity necessary for the subject and very notion of ethics to exist. Therefore, any ethically melioristic cosmos must satisfy specific WAP constraints.
nologization 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 in his 1978. note:

**Weak DT:** 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 version is the one presented in Tipler (1982), as well as in monograph of Barrow and Tipler (1986). Let us formulate it by analogy with the weak argument in the following form:

**Strong DT:** Cosmologies postulating past temporal infinities must be rejected for 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 notice 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 an important historical role), but which should be explicitly discussed:

1. **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 what counts as inhabitable is actually a very subtle one, since requirements of communities of intelligent observers may wildly differ. In any case, we expect that a sufficiently large thermodynamical disequilibrium must exist. Therefore, the question whether a particular model satisfies this auxiliary assumption is contingent upon the answer from the same model to the much more famous problem of Olbers’ paradox. We shall see below how various specific cosmological models enable continuous entropy production over an infinite interval of time.

2. **The existence of arbitrarily old civilizations.** The existence of
such entities can hardly be considered obvious or even probable on any count. While the condition 1 is necessary, it is not a sufficient reason for accepting 2. 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 1 or 2 may seem easy enough, the careful inspection shows that it is a rather difficult endeavor. Models which are characterized as stationary automatically satisfy 1, and the reasons sometimes cited for rejection of 2—mostly in the context of the SETI debate (see below)—are entirely ad hoc. Non-stationary models may violate 1, while retaining infinite number of past temporal events, although this violation is necessarily limited by spatial and temporal scales 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 1, 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 a following auxiliary assumption, analogous with the 1 in the weak case:

1. The requirement of a continuously existing region in which the spontaneous assembly of matter can be achieved. This presumes (i) availability of matter (so that empty models, like the de Sitter world, can be excluded), and (ii) restrictions on the physical state of matter. This second restrictions 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 1 so that it can be brought even into a very superficial accord with the empirical data which 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. More stringent requirements 1 and 2 produce make, for that matter, any hunt for loopholes in the argument itself (and our consequent increase in understanding) much more promising.

For the sake of better understanding of the issues involved, let us consider a counterexample of a cosmological model involving past temporal infinity
which DT argument does not apply to. This is the Lemaitre-Eddington universe, which was quite popular in the 1925-1935 period (e.g. Eddington 1930). This model belongs to the class of general-relativistic models with 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 Bondi’s classic textbook on cosmology (Bondi 1961). Having appeared on the cosmological scene after the realization of the instability of the original Einstein static universe (Einstein 1917), this model

...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 we observe (e.g. Hinckfuss 1975). From the formal point of view, in accordance with the Weyl postulate, the Eddington-Lemaitre universe has an infinite past, i.e. 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, i.e. 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

\[10\] For a preliminary treatment of this topic, see Ćirković 2000.

\[11\] Bondi (1961), p. 118.

\[12\] The fragment B64 of Diels suggests that Anaxagoras endorsed a version of what were
cosmologies it is necessary to invoke a state which 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.\textsuperscript{13} 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 the 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-Augustine principle, the temporal infinity in this model thus collapses into a purely formal notion. Newton-Smith’s formulation of this principle:

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.\textsuperscript{14}

explicitly points out to (macroscopic) indistinguishability of moments in the state of complete thermodynamical equilibrium. The same applies to the distant future of the universe in which, according to many models, the state of

\textsuperscript{13}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.

\textsuperscript{14}Newton-Smith (1980), p. 44.
heat death is bound to occur. Barrow and Tipler (1978), suggest 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 final global singularity. In such a situation a finite cosmic time may be less appropriate than an alternative infinite timescale (e.g. 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 (-∞, 0) interval.

Is such a rescaling just a mathematico-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 is just one guise of the re-scaling of time in the relationist context (Dyson 1979). Many results in the nascent discipline of physical eschatology depend on the Dyson's hypothesis, and it is obvious that it's being true or else has a real, physical consequences.

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

It should be immediately noted that 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 haven't irreversible processes, in accordance with the thermodynamical laws, generated infinite amounts of entropy in the universe by now? This is not just the classical question of the thermodynamical 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

---

15 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.

16 Further discussion of the non-triviality requirement can be found in Newton-Smith (1980). It is important, for instance, in rejecting claims that statements of the form “the moment t = t₀ is now” can in principle describe any event whatsoever. Here we perceive the connection between the anthropic argument and the relationist vs. absolutist controversy in the most plastic manner.
himself used the same argument against the Hoyle-Narlikar conformally invariant cosmology\textsuperscript{17} in his review of the latter in Nature (Davies 1975), and Tipler (1982) mentions it in somewhat restricted sense, as Olbers’ paradox (again, expanded discussion may be found in 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 serious form. Still, this thermodynamical argument against steady-state models is qualitatively different from DT argument we are dealing with, although both show how difficulties arise when currently observable processes are extrapolated backward 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 Strehlitskij 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 \textit{a priori} reasoning are essentially different from the anthropic argument; the former is also known as the \textit{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). DT argument, on the contrary, is not \textit{a priori}: it applies to the physically well-defined sub-class of universes with infinite past and it is firmly based in empirical (though non-standard) evidence—the one on the existence of a technological civilization in vicinity of at least one point of spacetime.

Thus, DT argument can be interpreted as the much stronger version of the familiar “Great Silence” or “astrosociological” problem (e.g. Brin 1983; Kardashev and Strehlitskij 1988; Almar 1989; Girilis and Rudnitskii 1993; Lipunov 1997; also known as the Fermi’s “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 multi-

\textsuperscript{17}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 exposed in Hoyle and Narlikar (1972) and Hoyle (1975) papers. 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 Hoyle-Narlikar and the revised steady-state as separate theories, since the distinction (conservation vs. creation) seems important enough.
tude of advanced extraterrestrial civilizations in our Galaxy. As calculated by many researchers (starting with the pioneering study of 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 became rather well-known in recent years (Chaboyer et al. 1996, 1998; Krauss 1998), and exactly that is 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 $\tau$ 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:

$$K = \exp\left(\frac{T}{\tau}\right) \approx 10^{43,000,000} (1)$$

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 $T \rightarrow \infty$ (in Lipunov’s presentation). Clearly, the DT argument (as well as practically all other aspects of anthropic reasoning) is of great relevance not only for cosmology, but for astrobiology and the prospects for SETI, too. Since the latter topics are of potentially unprecedented 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 reemphasize that (as noted 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 XVIII, XIX and early XX century intellectuals has been that the universe has always existed in conditions not

18 The similarities between the Olbers’ and Fermi “paradoxes” has been discussed 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).
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 appear earlier? It is important to stress that the more general problem of lack of information from the past has its underground history deeply interwoven with the striving for understanding natural history. The problem, as he have hinted, was open as soon as the dogma of creation in 4004 BC was rejected, openly or tacitly. It was, in fact, in the domain of Earth science (rather than in astronomy) where the dam was broken: it is often called the discovery of "deep time" or "geological time" (e.g. Ward 1998; Baxter 2004). And 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 vs. limited information transmitted from those epochs, noting how final causes motivate the whole idea; today, we might cite the Strong Anthropic Principle to the similar ends. Hutton imagined a "world machine": his mechanicistic worldview found 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 one which is bound to return the world to one or more previous stages. Hutton's vision is a geological analog of the Empedoclean cyclic universe; hence the most famous passage of his, ending the 1788 short version of his *Theory of the Earth*:

> 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.\(^{19}\)

But, 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 writes of "mechanism of the globe, by which it is adapted to the purpose of being a habitable world." The Earth was obviously constructed (at some

---

\(^{19}\)Hutton (1788), p. 304.
indefinite epoch, not existing from eternity!) for higher purpose of being a
habitat for life and, eventually, for human domination. Hutton writes 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.20

This seems absurd from the (Whiggish!) point of view of modernity, but was
almost self-evident in XVIII century; on the other hand, Hutton’s view bears
striking similarity to some of the modern teleological usages of the Strong
Anthropic Principle we shall discuss in §7 below.

Note that the age of the Earth (and perhaps the rest of the universe)
was considered indefinite, but not infinite. Infinite age would conflict with
Hutton’s profound Christian religiosity, and he repeatedly implies 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 are only no vestige of the beginning!
The cyclic nature of the world machine erases the relevant information from
previous cycles and “cleans the slate”. But it is still internally inconsistent:
if the world is made for man, how comes that the achievements of previous
generations of humans are also erased? And if we accept pluralism about
abodes of life (which was rather standard in Hutton’s time; see, for instance,
Fontenelle 1767), than 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 better assess the importance of DT argument and its application
to the cosmologies with infinite past, we shall briefly consider the conceptual
foundations of the most famous and historically most influential such cos-
mology, the 1948. model of Hermann Bondi, Thomas Gold and Fred Hoyle
(Bondi and Gold 1948; Hoyle 1948). Although there is some controversy
whether the classical steady-state cosmology represented a single entity or
two disjointed theories (that of Bondi-Gold and the version of Hoyle), we shall

20Hutton (1788), pp. 294-295.
refer to them as the classical steady-state model, discussing, where relevant, particular differences among 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 perfect cosmological principle (henceforth 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 flavor to the classical unlimited entropy argument (“Olbers’ paradox”):

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. [present author’s emphasis]

This way of reasoning is not only deeply founded in the normative physical practice, but is directly responsible for the conceptual simplicity of the classical steady-state, 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 technologival 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 leading to 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.

PCP formulated by Bondi and Gold (1948), can be simply expressed as the homogeneity of the universe in 4-dimensional spacetime. This is just the generalization of so-called Cosmological principle (cf. Milne 1940), which assumes homogeneity in space, but not necessarily in time. Mathematically
speaking, PCP can be formulated as a necessity to have a timelike Killing vector in the classical Robertson-Walker metric. Thus, PCP leads to the line-element of the well-known (de Sitter) form (in usual \( c = 1 \) units):

\[
ds^2 = dt^2 - e^{2Ht} \left[ dr^2 + r^2 \left( d\vartheta^2 + \sin^2 \vartheta d\varphi^2 \right) \right],
\]

(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 thermodynamical considerations as well. Olbers’ paradox testifies that the universe has not reached the state of thermodynamical equilibrium, which is impossible to avoid in an infinitely old static cosmological model (see the celebrated classic discussion in 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 Olbers’ paradox in the static universe. Therefore, the only possible conclusion is that \( H > 0 \), which is the realistic case of the expanding universe.

Part of the appeal of the steady-state concept can be found in 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.

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

\[ f(x) = e^{-3Ht}, \]

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

\[ \langle \tau \rangle = \frac{1}{n} \int_{0}^{\infty} 3nH e^{-3Ho} d\alpha = \frac{1}{3} \frac{H}{H}. \]

This illustrates a beautiful simplicity which PCP imposes on the theory: the average age of galaxies is calculated without any reference to the complicated physics of galaxy formation.\(^{22}\) However, we should keep in mind a historical fact of great importance: 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 \( H \sim 500 \text{ km s}^{-1} \), which was the then reigning Hubble measurement, the Friedman-Lemaître cosmology (which soon became, following a derogatory comment of Fred Hoyle in

\(^{22}\)Parenthetically, modern Big Bang cosmologies are still uncertain as to the average predicted age of galaxies within a factor of about two (see, for instance, Gott 1977; Peebles 1993). Note that this is something very different from the observational uncertainties in determination of, say, age of the oldest globular clusters in the Galaxy. The latter is in practice regarded as \( \textit{limes inferior} \) of the age of the universe. The two are sometimes confused, especially in popular scientific literature, due to the hegemonic position of the standard hot Big Bang paradigm. \( \textit{A priori} \), it is not necessary that age of Galaxy (and galaxies) is determined by cosmological factors at all; classical steady-state cosmology is a good such counterexample. In it the age of any chosen 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”) which 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 (e.g. Harwit 1961).
a BBC radio broadcast, the Big Bang cosmology) has had a serious conflict with the age of the Earth and chemical elements (e.g. Bok 1946). At the time of formulation of the steady-state theory, $\langle \tau \rangle$ was considered small ($\sim 6 \times 10^8$ yrs, due 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

$$\delta(t) = \frac{1}{n} \int_{t}^{\infty} 3nH e^{-3Hx} dx = e^{-3Ht}, \quad (4)$$

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, DT argument quoted above gains force. Since the fraction of galaxies that are older than age $t = 2 \times t_{MW} \approx 2 \times 1.2 \times 10^{10}$ yrs is given by Eq. (4), it follows that there are almost 2% of all galaxies in any large enough comoving volume which are twice the age of the Milky Way. We should keep in mind at all times that our Galaxy is already old enough for the Fermi’s paradox to be formulated (as briefly discussed in §2).

The issue of different predictions of ages of galaxies in different cosmological models has been present on the cosmological scene since the very beginning of controversy between the classical steady-state 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 whether galaxies have approximately the same age, or span a wide distribution, as given by Eq. (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, who in a short note in 1954 (Gamow 1954), pointed out that after the Baade’s revision of cosmological distance and timescales, steady-state theory faces the problem of underestimating ages of galaxies in our vicinity. However, it is clear in the Gamow paper that he does not find
the so far measured galactic ages 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 of 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 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 (Hoyle and Narlikar 1962). 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 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 with 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 suggest 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, Combes and Martinet 1994).

Finally, Hoyle and Narlikar in their 1962 paper indicate (in close connection with their subsequent “radical departure”; see 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 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 collaborators (Ellis 1978; Ellis et al. 1978). A similar cosmological model has been developed in the mid-1990s by 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 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 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 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 them, and that is not accidental, because (in accordance with 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 “center” of the universe (it is most natural to use the term for our pole of the manifold, by analogy with a 3-sphere). Opposite of the center is located 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 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

---

23In this sense, they do not contradict the statement that the classical steady-state model is unique, i.e. that there is only one cosmology satisfying PCP, as Bondi was fond of emphasizing (e.g. Bondi 1961). 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 for explaining the highly special nature of our view of the universe. For the same task, in both the Friedmann models and in the classical steady-state case, Occam’s razor is strong enough.

24This is quite independent from the fact that closed steady state cosmologies do not satisfy observational constraints and can be considered rejected today. As far as the plausibility of the hypothesis that the observable universe is a homogeneous part of the much larger inhomogeneous whole, see for instance Harwit (1995). This feature is inherent to some variants of the inflationary scenario, most notably Linde’s chaotic inflation program.
the form of heavy elements synthesized in stellar nucleosynthesis) toward 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: observ-
able redshift is of purely gravitational origin. The co-present singularity in
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 of Phillips (1994a, b) there are also two singular
points, this time called the northern and southern pole. The Milky Way
galaxy is located in close proximity to the northern pole of the universe (from
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 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, the observed redshift is partially of gravitational 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 to is of secondary type. Primary matter is moving
in the opposite direction (from the southern 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 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 very
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, i.e. the relationship between
the apparent magnitude and redshift of cosmologically distributed sources
of radiation. It is harder to disprove Phillips’ model, since the gravitational
and Doppler redshifts 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 effect (Sunyaev and Zeldovich 1980). The
prediction of 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, private communication). Therefore, we may consider stationary closed cosmologies to be rejected by observations.

However, they are useful for us in the historical sense. DT argument against them continues to hold and is even more forceful than for the case of the classical steady-state. 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. But 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. And 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 (that is, in the vicinity of our present position), and gradually expands to encompass the entire “favorable” 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 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 supercivilization could either exist for a definite, or for indefinite period of cosmic time. In the first alternative, the universe 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 (e.g. Tipler 1994), a humble Humean approach suggests that we choose a “smaller miracle”—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 Ellis et al. and Phillips’ theories) the anthropic argument necessarily leads us to paradoxes, if only we do not restrict the growth of complexity, socio-technological 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 in
which the universe is infinite in both spatial and temporal extension, but in which the conditions favorable to life persist in either a finite or infinite region for an infinite time. The main lesson of the anthropic spatial selection such as our proximity to the boreal pole in Phillips’ model is that this form of self-selection allows for most of the universe to be uninhabitable, and still retain 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 DT argument against closed steady-state theories demonstrates that 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 the humanity exists for a finite time in a relatively stable environment, and expansion over interstellar or even intergalactic lengthscales 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 lengthscales. In a strongly inhomogeneous universe, or universe with random fluctuations on the scales of, say, 1 pc, the argument looses 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 Phillips’ cosmologies, the DT argument can not justifiably be regarded as contingent on anything stronger than WAP, as Barrow and Tipler (1986) tend to do.

7 The Teleological SAP “Counterargument”

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

...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. Widely used definition of Barrow and Tipler (1986) in their influential monograph, has somewhat different overtones from the Carter’s original:

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 the one in 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 SAP in the 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 of 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 the 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\textsuperscript{25} is an encouragement to teleological projects of various kinds, of which 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 to the physical one. The ontological gap between the two seems

\textsuperscript{25}One should, for instance, keep in mind the estimate of Penrose that a priori probability of Big Bang happening in so smooth (low gravitational entropy) manner as to produce the observable universe is only 1 part in \(10^{10^{23}}\)!
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) writes, in connection with his anthropic prediction of the $^{12}\text{C}$ 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 force exist only where the nuclear adjustments happened to be favorable, 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 written in 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...

---

26 A popular account of this problem and the Hoyle’s answer may also be found in Davies’ book on physical eschatology (Davies 1994).
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 the Adam’s dilemma (from The Paradise Lost), one answers in 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 absence of extraterrestrial technology on large scales (that is, both Fermi’s paradox in standard cosmology and 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 important article of 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 reason for 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 Wigner’s result that, within the quantum mechanical formalism, the probability of spontaneous creation of living systems is equal to zero (Wigner 1967, p. 200). Quantum mechanical considerations also motivated Hoyle, in particular in his 1982 paper.

As pointed out by Tipler (2001, private communication), this picture is difficult to defend along several lines. Major problem with this sort of argument is that it assumes that not merely intelligent life, but the specific species Homo sapiens, is doing the selecting of the actual universe. There

---

27 It seems that here one may find a fault in Hoyle’s reasoning. He estimates, 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 of 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.
is no positive reason for belief that humanity is ultimately privileged in this way for participation in “creation” of the universe. On the contrary, as the father of the very label “anthropic principle” Brandon Carter emphasized, every form of intelligent life is in exactly the same situation. Of course, the purpose of such Carter’s opinion is exactly to excise, together with anthropocentrism, the teleological mode of explanation, and the answer 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 in 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, can not 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) shows that teleology need not necessarily to be burdened by dogmas of the times past. The same lesson should, undoubtedly, apply to the teleological mode of accounting for 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 §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, Burbidge and Narlikar in a series of papers published in 1990s (Hoyle 1992; Hoyle, Burbidge, and Narlikar 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 DT argument.

8 Quasi-Stationarity and Intelligent Species

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

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 questions: 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 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 in Hoyle and Burbidge 1992; Hoyle et al. 1993, 1994), it should be mentioned that, as well as in Hoyle’s version of CSS model, negative energy of the creation field transforms into matter with positive energy. However, the creation is not uniform in spacetime, 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 Planck mass ($M_{Pl} \sim 10^{-5}$ g). Each Planck particle ultimately produces about $5 \times 10^{18}$ 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 cosmic microwave background; its anisotropy and local departure from the thermodynamical equilibrium are lost through repeated interactions with 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 their results from 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 QSS 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, QSS does not stand much better against the anthropic arguments. This theory is vulnerable to the DT argument in the same basic manner as CSS cosmology. The fact that we shall encounter galaxies of similar age to the Milky Way inside of the Local Supercluster represents only a gigantic spatial and temporal translation of the problem, which does not bring 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 ”supercruster distribution function” necessarily akin to Eq. 2. This strategy of “passing the buck” is probably one of the chief reasons why 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 his collaborators (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 spacetime foam at 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 toward 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 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.

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 of 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 which 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) write:

> 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 one 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

---

28 This phenomenon in its historical context could be compared to the similar return of (neo) catastrophism on the scene in geology and paleontology (e.g. Clube 1995).
possible approach is the one discussed by Barrow and Tipler in Chapter IX of their monograph: to forbid information transport between individual bubble-universe 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 (i) what is hard to imagine today, does not need to be so for the advanced civilizations which have already technologized a large part or their entire domicile bubble-universe and thus marshaled unbelievable material and intellectual resources, and (ii) 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” (e.g. Morris, Thorne and Yurtsever 1988; Visser 1990). Finally, the third possible strategy lies in possibility that individual bubble-universes (with finite resources, and therefore the finite duration of an active technologized state) may be separated from the Planck spacetime foam at a rate sufficiently high enough 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 supercivi-lizations 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 the sake of completeness. 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 mind-boggling 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 reasoning and survival of intelligent observers. These properties refer to both 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 them are static at large scales, and most are not; the ambiguous sign for the case of classical de Sitter universe stands for the curious historical ambiguity on the meaning of “static”.\textsuperscript{29} Some models are topologically closed, while others are flat or open, and some possess such specific features as (global) singularities and horizons.\textsuperscript{30}

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|c|c|c|c|}
\hline
No. & Model & Static & Closed & Matter & Singular & Horizon & D-T \\
\hline
1. & Einstein & + & + & + & - & - & + \\
2. & de Sitter & + & - & - & - & + & - \\
3. & Eddington- Lemaître & - & - & + & - & + & - \\
4. & Classical SS & - & - & + & - & + & + \\
5. & Ellis et al. & + & + & + & + & - & + \\
6. & Phillips & - & + & + & + & - & + \\
7. & Oscillatory nonsingular & - & + & + & - & - & + & - \\
8. & Revised SS & - & - & + & - & + & + \\
\hline
\end{tabular}
\caption{Comparison of some classical cosmological models on several counts related to the anthropic argument against past temporal infinities.}
\end{table}

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 can not 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

\textsuperscript{29}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.

\textsuperscript{30}It is important to emphasize that the singularities under considerations are the global ones; otherwise, all spacetimes in which at least some worldlines are incomplete should qualify as singular, including the classical steady state theory which is characterized by creation “micro-singularities” (and does not manifestly prevent formation of black hole singularities!).
values of cosmological parameters in the model,\textsuperscript{31} 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 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 CSS theory, the entire theory can be both legitimately and practically derived from an essentially methodological principle as is PCP. \textit{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 the universe satisfying the Perfect Cosmological Principle. In a sense, it would be much easier to formulate PCP for the counterfactual case of lifeless universe, since amplitudes of “local inhomogeneities“ could as well 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 cosmic microwave background observations could evolve as mildly inhomogeneous plasma according to PCP without ever forming galaxies and stars. New matter will simply keep the density of such plasma constant. Very high (again counterfactual) value of the Hubble constant will probably have the same effect. However, once we make an observation of existence of life (and intelligence), 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 Fred Hoyle predicted the existence of 7.65 MeV metastable level in the nucleus of

\textsuperscript{31}And 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.
\(^{12}\text{C}\) on the basis of 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, like the Planck constant and elementary charge. Therefore, fine tuning of the \(^{12}\text{C}\) level is actually only a **manifestation** of the fine tuning of various constants of nature. Conceptually, this manifestation is redundant. However, we can not, as discussed in Barrow and Tipler (1986), backtrack and reconstruct the manner in which the particular values of constants propagate toward 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 back tracking. Still, it is important to note that nobody denies **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 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 XX century by Erwin Schrödinger in his influential *What is Life?* essays (Schrödinger 1944).

It is clear that the weak version of DT argument may be criticized on historico-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 to 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 (e.g. Fischer 1989). For an exception to the prevailing paradigm of discontinuity between the contemporary worldview in the natural sciences and history understood in Spenglerian terms, one may look at the excellent recent study of Victor Clube devoted to cometary neocatastrophism in planetary studies (Clube 1995). This work, under the instructive
The Nature of Punctual Crises and the Spenglerian Model of Civilization presents—in a different, still quite relevant scientific framework—how much the self-contentedness and dogmatical blindness in science in the last century or two could lead toward a de facto wrong factual road. It was first the medieval immutable heavens, and subsequently uniformitarian (anticlerical, ironically enough) dogma on 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 counter-argument 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 which 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 impossibility of 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 universe blossoming with life in case of temporally and spatially limited systems; therefore, it remains very relevant for the Fermi’s paradox and the SETI problem in the Milky Way.) Of course, the stronger Tipler’s version of the anthropic argument, 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 physical universe, will have to explicitly take into account 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.
References

Almar, I. 1989, *Acta Astronautica* 26, 253.
Balashov, Yu. 1990, *Comments Astrophys.* 15, 19.
Balashov, Yu. 1994, *Studies in History and Philosophy of Science* 25B, 933.
Barrow, J. D. and Tipler, F. J. 1986, *The Anthropic Cosmological Principle* (Oxford University Press, New York).
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, *Brit. J. Phil. Sci.* 30, 161.
Bok, B. J. 1946, *Mon. Not. R. astr. Soc.* 106, 61.
Bondi, H. 1961, *Cosmology* (2nd edition, Cambridge University Press, London).
Bondi, H. and Gold, T. 1948, *Mon. Not. R. astr. 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. Jl. R. astr. Soc.* 24, 283.
Burnet, J. 1908, *Early Greek Philosophy* (Adam and Charles Black, London).
Carter, B. 1974, in *Physical Cosmology and Philosophy*, ed. by Leslie, J. 1990. (Macmillan, London).
Chaboyer, B., Demarque, P., Kernan, P. J., Krauss, L. M. and Sarajedini, A. 1996, *Mon. Not. R. astr. Soc.* 283, 683.
Charlier, C. V. L. 1922, *Ark. Mat. Astron. Phys.* 16, No. 22.
Clube, S. V. M. 1995, *Vistas in Astronomy* 39, 673.
Collins, C. B. 1990, *Class. Quantum Grav.* 7, 1983.
Cornford, F. 1965, *Thucydides Mythistoricus* (Greenwood Press Publishers, New York).
Craig, W. L. 1979, *The Kalam Cosmological Argument* (Macmillan, London).
Craig, W. L. 1990, *Brit. J. Phil. Sci.* 41, 473.
Čirković, M. M. 2000, *Serb. Astron. J.* 161, 33.
Čirković, M. M. 2003a, *Found. Phys.* 33, 467.
Čirković, 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).
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. Quart.* 24, 307.
Eddington, A. S. 1928, *The Nature of the Physical World* (Cambridge University Press, London).
Eddington, A. S. 1930, *Mon. Not. R. astr. 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., Maartens, R. and Nel, S. D. 1978, *Mon. Not. R. astr. Soc.* 184, 439.
Ellis, G. F. R. and Brundrit, G. B. 1979, *Q. Jl. R. astr. Soc.* 20, 37.
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).
Fontenelle, Bernard Le Bouyier de 1767, *Conversation on the Plurality of the Worlds* (transl. from French, 2nd edition, London).
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 *Third Decennial US-USSR Conference on SETI*, ed. by Seth Shostak, G. (ASP Conference Series, Vol. 47, San Francisco), 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).
Grünbauern, A. 1991, *Erkenntnis*, 35, 233.
Guthrie, W. K. C. 1969, *A History of Greek Philosophy II* (Cambridge University Press, London).
Haldane, J. B. S. 1945, *Nature* 155, 133.
Harrison, E. R. 1973, *Ann. Rev. Astron. Astrophys.* 11, 155.
Harrison, E. R. 1995, *Q. J. R. astr. Soc.* 36, 193.
Hart, M. H. 1975, *Q. J. R. astr. Soc.* 16, 128.
Harwit, M. 1961, *Mon. Not. R. astr. Soc.* 122, 47.
Harwit, M. 1995, *Astrophys. J.* 447, 482.
Hawking, S. W. and Penrose, R. 1970, *Proc. Roy. Soc. A* 314, 529.
Hawkins, D. 1971, *Philosophy of Science* 38, 273.
Hinckfuss, I. 1975, *The Existence of Space and Time* (Clarendon Press, Oxford).
Hoyle, F. 1948, *Mon. Not. R. astr. Soc.* 108, 372.
Hoyle, F. 1949, *Mon. Not. R. astr. Soc.* 109, 365.
Hoyle, F. 1975, *Astrophys. J.* 196, 661.
Hoyle, F. 1982, *Ann. Rev. Astron. Astrophys.* 20, 1.
Hoyle, F. 1992, Astrophys. and Space Sci. 198, 195.
Hoyle, F. 1994, Home Is Where the Wind Blows (University Science Books, Mill Valley).
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. Roy. Soc. A 290, 162.
Hoyle, F. and Narlikar, J. V. 1972, Mon. Not. R. astr. Soc. 155, 305.
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. astr. Soc. 267, 1007.
Hutton, J. 1788, Theory of the Earth. Transactions of the Royal Society of Edinburgh 1, 209.
Israelit, M. and Rosen, N. 1989, Astrophys. J. 342, 627.
Kalitzin, N. S. 1961, Mon. Not. R. astr. Soc. 122, 41.
Kardashev, N. S. and Strelbitskij, V. S. 1988, in Bioastronomy – The Next Steps, ed. by Marx, G. (Kluwer, Dordrecht), p. 295.
King, I. 1961, Observatory 81, 128.
Kragh, H. 1996, Cosmology and Controversy (Princeton University Press, Princeton).
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).
Linde, A. D., Linde, D. and Mezhlumian, A. 1994, Phys. Rev. D 49, 1783.
Lipunov, V. M. 1997, Astrophys. and Space Sci. 252, 73.
Lucretius 1997, On the Nature of Things (translated by William E. Leonard, e-text version, Project Gutenberg, Urbana).
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. Astr. 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, London).
Novello, M. and Heintzmann, H. 1984, Gen. Rel. Grav. 16, 535.
O’Brien, D. 1969, Empedocles’ Cosmic Cycle (Cambridge University Press, Cambridge).
Oppy, G. 1995, Faith and Philosophy 12, 237.
Peebles, P. J. E. 1993, *Principles of Physical Cosmology* (Princeton University Press, Princeton).

Pegg, D. T. 1971, *Mon. Not. R. astr. Soc.* **154**, 321.

Penrose, R. 1979, in *General Relativity: An Einstein Centenary*, ed. by Hawking, S. W. and Israel, W. (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. astr. Soc.* **269**, 771.

Phillips, P. R. 1994b, *Mon. Not. R. astr. Soc.* **271**, 499.

Popper, K. R. 1978, *Brit. J. Phil. Sci.* **29**, 47.

Price, H. 1996, *Time’s Arrow and Archimedes’ Point* (Oxford University Press, Oxford).

Reber, G. 1982, *Publ. Astr. Soc. Australia*, **4**, 482.

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

Sciama, D. W. 1955, *Mon. Not. R. astr. Soc.* **115**, 3.

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

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

Smolin, L. 1992 *Class. Quantum Grav.* **9**, 173.

Spengler, O. 1918, *Decline of the West* (1996 edition by Alfred A. Knopf Publisher, 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. Jl. R. astr. Soc.* **22**, 133.

Tipler, F. J. 1982, *Observatory* **102**, 36.

Tipler, F. J. 1994, *The Physics of Immortality* (Doubleday, New York).

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, *Brit. J. Phil. Sci.* **29**, 39.

Wigner, E. 1967, *Symmetries and Reflections* (University of Indiana Press, Bloomington).