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THE ANTHROPIC ARROW OF TIME AND REALISTIC WORLD MODELS: ON PRICE AND ATEMPORAL UNIVERSE

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SUMMARY: In recent attempts at building an atemporal ("tenseless") picture of the physical world, insufficient attention is devoted to processes giving rise to the cosmological arrow of time. Having regard to the new empirical findings, and particularly to the epochal discovery of large effective vacuum energy density, the existing discussions of the topic need to be reassessed. In particular, the necessity of a new treatment of asymmetric temporal boundary conditions in an open universe is hereby put forward. Some errors and uncertainties implicit in the recent treatment of the problem of the cosmological arrow of time in the brilliant recent monograph of Prof. Price are briefly discussed. In addition, we discuss relevancy of the high level of complexity observable in living and intelligent beings in the universe for the question of time-reversal symmetry.

1. INTRODUCTION: THE ATEMPORAL UNIVERSE

The puzzle of apparent temporal asymmetry of the physical world arguably governed by series of simple time-symmetrical processes has been considered by philosophers and cosmologists from the time of pre-Socratics. One particularly interesting instance of such early insight is the cyclical cosmological model of Empedocles of Acragas in which physical and biological processes unfold in the same direction in each great cosmic cycle, which is supported by a primitive sort of absolutist (or substantivalist) theory of time (e.g. O'Brien 1969). Only at the end of the XIX and in the course of the XX centuries-in the aftermath of the great discoveries of Ludwig Boltzmann, and subsequent elucidations by Eddington, Jeans, Tolman and others-it has gradually become clear that the problem of irreversibility of physical processes encountered in everyday life is inseparably linked to the global initial conditions of the world we live in, that is, to cosmology. This cosmological connection surfaced for the first time in the famous debate between Boltzmann and Zermello in 1896/97 (Steckline 1983). Although this simple point has been put forward by many authors (e.g. Gold 1962; Penrose 1979; Hawking 1985; Zeh 1992), it has regrettably remained somewhat outside of the mainstream of cosmological thought, for at least two reasons. One is unhappy association of some attempts to deduce the thermodynamical and radiative arrows of time from the cosmological one, with the discredited steady state theory defended mainly by Hoyle and Narlikar (1964, 1974). Another, which we shall try to highlight in this note is too narrow cosmological framework to which the idea has been applied. In other words, the problem has been set in several versions, each too special to appeal to most of cosmologists, naturally very cautious with respect to determination which **exact** cosmological model describes the empirical reality. This is understandable, particularly in light of great difficulties encountered-even after the great cosmological controversy of the

1950-ies has left only evolutionary Friedmann models on the battlefield (Kragh 1996)-by observational cosmologists in determination of the three fundamental cosmological parameters, H_0, Ω and Λ[1]. What certainly remains to be done before any attempt of explaining away the various arrows of time and *eo ipso* formulating an atemporal worldview is to determine various internal relations between these different arrows (Freundlich 1973). Incidentally, this is in direct opposition to the professed aims of Hoyle, Narlikar and Hogarth who in 1960-ies have hoped to determine the realistic cosmological model **from** the empirically perceived macroscopic arrow of time.

In accordance with the perceived superiority of so-called B-theories of time (e.g. Grünbaum 1973), the attempts have been made by several philosophers of science to put forward a coherent atemporal view of the physical universe. In a recent very important study of Prof. Huw Price, *Time's Arrow and the Archimedes' Point* (Price 1996), the most comprehensive discussion to this day of implications of an atemporal worldview for physics can be found. The case for underlying temporal symmetry of physical processes-leading to situations in which directionality is determined exclusively by a set of special initial conditions-has been superbly highlighted in cases of thermodynamical and electromagnetic arrows of time. It has been shown (Chapters 2 and 3) that in these cases one really deals with local symmetry which **looks** asymmetric for the very special boundary conditions in that part of the spacetime manifold which is conventionally called beginning of the universe. That is, local physical courts are unable to decide on the directionality of time *per se*, and the decision lies with the supreme court of cosmology. These results (significant in their own right) could, in principle, be splendidly synthesized in the global picture if one somehow could demonstrate the equity of what is conventionally called initial and final conditions for the entire universe. Price makes an attempt to answer this task by invoking a special case: the temporally symmetric universe proposed by Thomas Gold in 1962, in which the master arrow of time is the cosmological expansion arrow. In the Gold universe, contraction is accompanied by change in the direction of the local entropy increase. By showing that some of the objections to the Gold model encountered in cosmological literature so far are fallacious or ambiguous, Price attempts to defend the globally symmetric cosmological picture in accordance with his overall aim of building a tenseless "view from nowhen".

However, more attention ought to be devoted to the physical processes underlying the conventional notions of symmetry and asymmetry in cosmology. The Gold model of the recollapsing universe, favored by Price, does not, in our view, represent a solid enough platform on which the discussion of initial and final conditions in cosmology can mature. Therefore, we would like to defend the following two main theses in the rest of the present study:

(I) The recently observationally confirmed cosmological constant gives a physical reason for perpetuity of the universal expansion, thus making obsolete the recollapsing models in general and the Gold model in particular.

(II) The existence of life and intelligent observers has basically the same effect of breaking the global symmetry. Therefore, the introduction of an additional arrow of time, which we call the anthropic arrow may be a useful concept. This is incompatible with the "view from nowhen" viewpoint put forward by Price.

Along these lines, we shall criticize some of the theses put forward by Price in his monograph, in particular in his account of the state of affairs in cosmology in the Chapter 4. Although the thesis (II) is not prima facie relevant to his discourse, it should be emphasized that a true Archimedean point should, *ultimo facie*, be able to account not only for the phenomenon of life and intelligence as such, but also the particular kind of life and intelligence we observe around us on Earth. In addition, Price's discourse contains a number of places (e.g. considerations of the asymmetry of agency) in which "anthropocentrism" is invoked to do the explanatory work, i.e. to suggest why we should prefer some not-so-obvious conjectures over

[1] While the detailed elaboration of the meaning of these parameters would include a bigger part of the contemporary cosmological discourse, we may briefly sketch it here for the purposes of understanding several points in the further course of the present study. The Hubble constant H0 measures the present-day (hence the index 0) expansion rate; it is the proportionality constant in the Hubble law expressing linear (in the first approximation) relationship between velocity of a typical galaxy with respect to another galaxy and their mutual distance: $V = H_0 \times R$. Obviously, it has the dimensions of $(\text{time})^{-1}$, giving the reciprocal of the characteristic timescale for expansion. Unfortunately, the exact value of the Hubble constant represents a major riddle of modern cosmology. While it is certainly located in the range 50-80 km s^{-1} Mpc^{-1}, the exact value has not been determined yet, each particular value having its host of supporters, the middle value in the interval (65 km s^{-1} Mpc^{-1}) obtaining higher degree of support recently. The cosmological density parameter, Ω, is a dimensionless quantity expressing the ratio of the density of various matter fields to the critical density, necessary for gravitation to stop the expansion. It may be defined for various components (like normal matter, dark matter, vacuum energy, radiation, etc.) as $\Omega_i = \rho_i/\rho_{crit}$, where the index i denotes a particular component of the universe. Finally, Λ (or λ) is the traditional symbol used for denoting the cosmological constant, in its modern version understood as the residual vacuum energy of various quantum fields. It enters the Einstein equations of the gravitational field as a very weak, repuslive components of the gravitational force, unnoticeable in laboratory experiments, or indeed at any scales other than cosmological, because of its strange nature: it is a force linearly increasing with spatial separation. The history of this constant entering and exiting cosmology provides several of the most interesting chapters in the history of modern physics (see, for instance, the detailed review of Carroll, Press and Turner 1992). From about 1998 onward, most of cosmologists are convinced that it indeed exists and constitutes the single predominant component of the total energy budget of the universe, as will be discussed in further text.

some other conjectures. Recognition of an anthropic arrow obviates these instances. Cosmological preconditions for origination and development of systems as complex as living and intelligent beings are built in the (conventional) initial conditions of our universe, and are a legitimate target for cosmological discourse. In particular, the professed atemporal worldview should account for the local asymmetries introduced by existence and behaviour of such systems. That such an account is not likely to be coherent, as we shall attempt to show below, points out to a broader problem of incompatibility between the "view from nowhen" and the anthropic principles which can not be strictly treated here.

2. OPEN UNIVERSES AND THE COSMOLOGICAL CONSTANT

The central point of an atemporal description of the initial[2] (and implicitly) the final conditions in cosmology is what Price calls the "basic dilemma" (p. 82):

> ...a symmetric physics seems bound to lead to the conclusion either that both ends must be smooth (giving the Gold universe), or that neither end need be, in which case the smooth big bang remains unexplained. On the face of it, then, we seem to be presented with a choice between Gold's view, on the one hand, and the conclusion that the smooth big bang is inexplicable (at least by a time-symmetric physics), on the other.

The point to keep in mind here is that Price correctly points out that the property of-not yet well defined, but widely used by physicists and cosmologists-gravitational entropy is that it is larger in clumped than in smoothly distributed matter. This is, as Penrose (1989) points out in a particularly illustrative manner, equivalent to saying that low (gravitation) entropy states are simple, i.e. describable with small amount of information, in contradistinction to the high entropy states; this is another instance of the famous Shannon connection. Price argues that observed entropy gradient is explicable only with low-entropy initial conditions of the universe, and construes his argument in Chapter 4, as if this is external condition to be imposed on various cosmological models. However, smoothness or simplicity of the early universe and consequent restrictions of the entropy behaviour do not seem intractable from the general theory of nonlinear dynamics point of view (Devlin 1991; Treumann 1993). For instance, the study of Treumann, (1993) which demonstrates that the informational content of the universe right after the Planck epoch must be of the order of few bits, is independent of the entropy gradient whatsoever![3] In this respect, Treumann and other modern cosmologists are in much better position than Gold was in early 1960-ies, and that Price sees them being in (we shall return to this point below). If one could specify information content of the universe at any given epoch, it could be shown that the retrodiction to the initial state requires a very simple state. Although the prospects for giving exact laws of this complexity growth are still unclear, it seems plausible that in an atemporal view it is enough that the final state is **complex** enough to give a unique initial state. And the roads to such a final state through entropy production are actively investigated in contemporary astrophysics and cosmology.[4]

In contradistinction to the spirit of the "basic dilemma", it should be noted that there have been several attempts to derive (Clutton-Brock 1977; Tegmark and Rees 1998; Barrow 1999) the low initial entropy from anthropic constraints. For example, Tegmark and Rees (1998) discuss the anthropic selection effects plausibly underlying the magnitude of anisotropies of the early universe detected recently with the *COBE* satellite. This point is directly related to the Price's discourse, since these authors correctly identify amplitude of these fluctuations in microwave background radiation with the amplitude of gravitational potential fluctuations in the early universe when they enter the horizon. The observed fact that this number is of the order of $Q \sim 10^{-5}$ can not be derived from known physical theories, and-as Tegmark and Rees emphasize at the very beginning of their paper-one may either wait for some future fundamental theory from which Q could be computed or take the option (supported independently by various inflationary scenarios) that it is effectively a random number whose observed value will be constrained by the anthropic selection. What they persuasively demonstrate in the rest of their paper is that such constraints are effective in keeping the expected *observed* value in the approximate interval $10^{-6} \leq Q \leq 10^{-4}$. On the face of Price's analysis, one may take this result as a strong reason for giving credence to the anthropic approach in explanation of the entropy gradient (Price's "anthropic strategy").

However, what we would like to suggest here is that even in the case of the single universe and even if the measure of inhomogeneity may be uncomputable from any future "theory of everything", a similar form of anthropic reasoning still applies. In other words, the task of deriving the low-entropy

[2] While recognizing that in the true atemporal universe these labels are misplaced, we shall use the conventional notions of "initial" and "final" conditions, with the proviso that they should be understood in the traditional (or "anthropocentric", see below) and not necessarily literal sense.

[3] Except, of course, in the most obvious manner in which this gradient constitutes part of the weak anthropic principle constraints on all possible worlds.

[4] In linear regimes, the entropy production has been thoroughly investigated by Weinberg (1971). For non-linear regime of the structure formation, see, for example, Valageas and Silk (1999) and references cited therein, which all follow the seminal study of Press and Schechter (1974).

past could, in principle, be done in each particular instance without the ontological enlargement (i.e. postulating the multiverse in any form), if one is willing to follow in Dyson's (1979) steps (and break "one of the most entrenched taboos of the twentieth-century science") by analyzing the possible teleological requirement. This step necessarily breaks the Gold-like symmetry, since "known physics" which should, in principle, include the complexity of biological and even psychological structures, is (to say the least) ambiguous with respect to the temporal orientation. This reductionist point (by no means undisputed, but usable as a working hypothesis) can be called the Empedoclean view.[5] We shall return to this point in subsequent discussion, after we consider eminently **physical** reasons for rejecting the time-symmetric cosmology.

One of the small number of pieces of empirical data which should certainly be taken into consideration in any discussion of asymmetry of time is the fact that today we have overwhelming evidence to the effect that the universe will not recollapse; apart from that, there are also theoretical reasons why the closed universe is not an appealing option any more (as it may have been in the time of Einstein or Tolman).[6] The list of references even only pretending to be complete discussing the empirical evidence for

(1) $\Omega_{matter} < 1$, and

(2) $\Omega - \Lambda > 0$,

is certainly beyond the scope of the present manuscript; for the moment one may mention works of Bartlett and Blanchard (1996), Fan, Bahcall and Cen (1997), or Bertschinger (1998) and references therein in support of (1). Apart from that, observational discovery of the large positive cosmological constant-point (2), and several theoretical considerations preceding the empirical discoveries-offers exactly what Price mentions in the very next paragraph: a plausible reason for rejecting closed universes *in general* (Riess *et al.* 1998; Perlmutter *et al.* 1998, 1999). Now, one may argue that the argument is insufficient unless the complete quantum field theory (including quantum gravity) is attained, from which the vacuum energy density would be calculable "from the first principles". However, we find that remark to be rather peripheral; the theoretical fact that cosmological constant is a *natural* product of field theories and the observational fact that it seems to govern the universal expansion are enough to doubt whether any universe could be (except by a highly improbable and unappealing numerical conspiracy) closed. In the light of all this evidence, it is somewhat surprising why the closed universe is still so popular, in particular outside of cosmological circles; Price offers just a recent and highly sophisticated example of that trend. It may be speculated that there are aesthetical, sociological or even religious factors involved in that (as for instance in Tipler's Omega-point theory; see Tipler 1994), but the weighting of these extra-cosmological arguments is certainly beyond the scope of the present discussion.

The example of how difficult is to face these cosmological facts can be found in the chapter of Price's book dealing with cosmology. In defense of the Gold universe, he writes (p. 95):

> First of all, it might be though that the basic dilemma only arises if the universe eventually recollapses... In this case, an argument showing that all extremities are smooth and ordered would not imply Gold's view. Entropy would be free to go on increasing forever.
>
> This point is an interesting one, but it should not be overrated. For one thing, if we are interested in whether the Gold universe is a coherent possibility, the issue as to whether the actual universe recollapses is rather peripheral. The main issue is whether the Gold view makes sense in a recollapsing universe, not whether our universe happens to be a recollapsing universe. Of course, if we could show that a recollapsing universe is impossible, given the laws of physics as we know them, the situation would be rather different: we would have shown that the original puzzle concerns a case that physics allows us to ignore.

Here, we would like to argue that (i) this account is rather biased and misleading in the **very description** of the task ahead of us, and (ii) that the recent findings in cosmology do prove that "the original puzzle concerns a case that physics allows us to ignore". The problem with existing accounts, including Price's, is that they do not pay enough attention to this "rather different" situation, even when (as in the quotation above) pay lip- service to its relevance.

[5] As discussed in more detail in the forthcoming work, it was in the cosmology of Empedocles of Acragas that the idea of biological and even anthropological evolution as an inherent and inseparable aspect of the cosmological evolution of matter has been first put forward (see for instance his fragments B20 and B21 in the Diels' anthology). This "reductionist" view has been quite common among the pre-Socratic philosophers.

[6] Although we can not deal much with these theoretical issues here, we can direct the reader to the study of Barrow and Dabrowski (1995), as well as earlier discussions of Landsberg and Park and others discussing oscillating universes. In addition, closed universes could face conceptual as well as observational problems connected with the turn-around images of light sources, gravitational megalensing, and some other issues, which they could escape only if they are closed by a very, very small margin, $\Omega = 1 + \varepsilon$. Here, as well as in the entire text we use the common cosmological notation of dimensionless density fraction of energy component i as $\Omega_i \equiv \rho_i/\rho_0$, where ρ_0 is the critical density for the universe to recollapse. If the universe contains only matter fields, it will expand forever for $\Omega_{matter} \leq 1$ and recollapse to the big crunch for $\Omega_{matter} > 1$. According to the modern view, the total cosmological density $\Omega_{tot} = \Omega_{matter} + \Omega_\Lambda$, where Ω_Λ is the vacuum energy-density commonly known as the cosmological constant. As elaborated by Krauss and Turner (1999) cosmological constant introduces a degeneracy into the cosmological future, which indicates that even topologically closed $\Omega_{tot} > 1$ can expand forever in the presence of positive cosmological constant.

As to (i), one may find a host of examples in the Price's book that indicate different attitude toward interpretation of physical results in light of an atemporal worldview. For instance, when discussing macroscopic notion of entropy increase in the Chapter 2, Price has taken for granted that it is the Boltzmann kinetic theory or statistical mechanics in general that is governing the real world. Accordingly, there were no conditionals of the form "We are interested whether the world in which macrosystems are composed from a huge number of identical simple subsystems, etc. is a coherent model, not whether the real world can be described in such a way, and the issue whether actual entropy increases or not is rather peripheral", etc. On the contrary, everything has been discussed in the general tone of college textbooks, i.e. as pertaining to the unique physical world around us. Further instances where the topics studied do look objective enough can easily be found; for example, on the page 133, we read "...if our interest is in the time asymmetry of the objective world." [underlined by the present author] And, the frequent mention of occurrences **in the world** suggests the same, as in the following locution (p. 39):

> Our world exhibits a huge and apparently monotonic such departure toward what we call the past, the explanation of which is the major task revealed by thermodynamics.

All these examples suggest that what we are interested here in is not just the theoretical consistency of (sometimes very fanciful) theories like the one of Gold, but also whether any of such is applicable to the real world. In that context, the statement that very serious anti-collapse objection "should not be overrated" does not sound honest; apart from the very questionable assumption that what Price calls "a point" is close to becoming an observational fact, and it is unclear how a fact (and the central cosmological fact at that!) should or should not be "overrated". While it is, of course, legitimate to investigate physical details of a counterfactual world (and it can be argued that much of physics ultimately reduces to such investigations), it is somewhat misleading to present it as the most relevant case for building an atemporal picture of the real universe, or to leave the impression that when subtle arguments against Gold universe fail, its very real lack of viability in the real world is somehow obscured.

This immediately raises another issue that can be formulated as follows: why should we assume that the fact that Avogadro's number N_A is of the order of 10^{23} or Boltzmann constant of the order of $k \sim 10^{-16}$ (in cgs units) is *more fundamental* than the fact that the cosmological density fraction $\Omega_{matter} < 1$? It is obvious that we know N_A or Boltzmann constant **with greater precision** than Ω_{matter}. However, this can not make them *a priori* more fundamental. To state the contrary would be to invoke a flagrant anthropocentrism, and of an ignorance-type (see below). This issue is not limited to cosmology at all. It is rather well-known in physics that Newton's gravitational constant G is still very poorly known, at least when compared to the elementary charge or the fine-structure constant or the Planck constant. Does this mean it is **less fundamental** than the latter ones? The answer is certainly negative, even if we take into account all attempts to build what Eddington called "fundamental theory" in which all constants of nature could be derived from mathematical constants and simple integers. Still, the prejudice against cosmological parameters and double standards in this manner continue to be applied, and in our opinion, for chiefly psychological and sociological reasons into which one cannot enter here.

Much more important argument to the effect that the Gold universe should be seriously studied although it does not correspond to reality is given in the continuation of the same section wherein an assertion is made that (p. 96)

> the Gold universe is just a convenient way of thinking about a problem which arises independently. The intrinsic symmetry of a recollapsing universe ensures that without leaving the comfort of our ordinary temporal perspective, we are confronted with the question which the atemporal perspective requires us to ask about the big bang itself: How could such an event possibly have the properties it must have, in order to account for what we observe around us.

In other words, this amounts to using the Gold universe as a toy model when all its limitations are acknowledged. There are two sides of this issue also. The appeal of the Gold model as "a convenient way of thinking" is undermined by the very statement quoted above, about the possibility of entropy increasing **forever** in a realistic universe. In addition, as we shall discuss in slightly more detail below, considerations of black hole physics (which is the **local** physics) imply local irreversibility which does influence the evolution of matter on largest possible scales. Therefore, even if one may agree with Price that-at least the classical- cosmology is time-symmetric **in principle**, this is certainly not the end of the story. The other side of this argument for seriously considering the Gold universe is that it is hiding a subtle *non sequitur*, which becomes clear only later on in Price's book when the topic of backward causation is analyzed. Namely, arguing that the Gold universe is interesting for us because (pp. 109-110):

> ...suppose that an event B follows deterministically from an event A. In a Gold universe we may not be able to say that if A had not happened B would not have happened-not because there is some alternative earlier cause waiting in the wings if A fails to materialize (as happens in cases of what philosophers call preemptive causation, for example), but simply because B is guaranteed by *later* events.

There is nothing special concerning Gold universe here, in fact. This argument stands as it is for **any type of universe in which both temporal boundary conditions are specified in sufficient detail**. Is there anything in the abovequoted argument which invokes the fact that final state of the Gold universe is a low-entropy one? It seems that the answer to this question is negative. Why is, then, the recollapse relevant at all? If it is because the final state is simple to specify in such case, that can only be called an "argument from (human) laziness", and not a true physical argument. It is important to realize that the precise specification of the initial/final state is not a simple matter in physical terms in Gold universe either. For instance, the same relation of causally linked events can be found in Tipler's Omega-point theory, which is a recollapsing universe model with no entropy decrease in the contracting phase (Tipler 1994). Moreover, one may conjecture that exactly the same situation which Price describes represents a viable model for divine pre-destination in Tipler's theology-ladden theory. In an overall picture, there is no reason to expect the causation to be phenomenologically different in any type of block-universe (and, as Price implicitly admits when speaking about "convenient way of thinking", the Gold universe is only one among many model block-universes).[7]

As to the issue (ii), it has two main aspects. The first aspect is obvious lack of sufficient matter in the universe to make it recollapse, the situation which persisted for at least half a century in astrophysics and cosmology. In spite of invoking various forms of dark matter, there is still not a single observational indication that Ω_{matter} is larger than about 0.4. (And one should recall that for the recollapse to occur one needs $\Omega_{matter} > 1$ **plus** additional constraint that the cosmological constant has to be zero or smaller than a critical value determined by Ω_{matter} and the present-day Hubble constant, which will be discussed below.) However, that would not still constitute an insoluble problem, since a completely homogeneous distribution of any form of undetectable dark matter would not be observable, and although this possibility is contrived in the extreme, it could in the limit give sufficient mass to attain the closure density. The problem is that, in fact, the universe is not decellerating toward the stop of expansion and beginning of recollapse, or even toward ever-lasting, but also ever-slowing expansion, as it would be the case if only matter had been present; it is in fact **accelerating**.

Recent observational confirmation of a large vacuum energy density (commonly known as the "cosmological constant")[8] will undoubtedly have great impact on our way of thinking about the time, as well as on almost any aspect of physical eschatology.[9] The three most significant consequences of a cosmological constant corresponding to rough cosmological density fraction $\Omega_\Lambda \sim 0.7$ are as follows:

- The universe will expand at an ever-accelerating pace; at some point in time, which has already been reached (Kardashev 1997; Cirkovic and Bostrom 2000) will enter a de Sitter (quasi-exponential) expansion phase.
- Event horizons (Rindler 1956; Ellis and Rothman 1993) form in the de Sitter space, the size of which is determined exclusively by the magnitude of Λ.
- The temperature of ever-expanding universe will not go to zero as in open Friedmann cosmological models. Instead, in asymptotic limit when proper time $t \to \infty$, temperature will tend to a constant value (Gibbons and Hawking 1977),

$$T \to T_\Lambda = \frac{\hbar c}{k}\sqrt{\frac{\Lambda}{12\pi^2}} \simeq h\sqrt{\frac{\Omega_\Lambda}{0.7}}\ K, \tag{1}$$

where k is the Boltzmann constant.
The extremely low temperature in Eq. (1) will, eventually, become higher than the temperature of the microwave background radiation. In addition, it will become hotter than any other form of background remaining at these distant epochs. Without going into details (see Tipler 1986; Treumann 1993) we note that in the open universe energy consumption entering the Brillouen (1962) inequality

$$I \le I_{max} = \frac{1}{k\ln 2}\,\frac{\Delta E}{T}, \tag{2}$$

(I being the information-in bits-processed by investing the amount of energy ΔE in contact with the thermal reservoir of the temperature T) remains finite, but the possible divergence can be obtained in the $T \to 0$ limit. Such manner of satisfying the Final anthropic principle (or, as argued by Ćirković and Bostrom 2000, the final anthropic hypothesis) seems frustrated by the realization that the temperature

[7] The same reasoning applies on a smaller scale if we suppose the true block-universe and select some particular occurrences in absence of complete Laplacean specifications of physical state of the universe. How otherwise is one to understand the famous *dictum* of Collins and Hawking that "since it would seem that the existence of galaxies is a necessary condition for the development of intelligent life, the answer to the question 'why is the universe isotropic?' is 'because we are here'" (Collins and Hawking 1973)? This is certainly not an example of backward causation as usually considered in the philosophical discourse, of the kind, for instance defended by Price or Brown (1992). The bilking paradox does not apply here. However, the occurrence of galaxy formation processes in relation to the large-scale near-isotropy of the universe mimics the situation described by Price's example without invoking the particular Gold universe at any point.

[8] For observational findings see Perlmutter *et al.* (1998, 1999), Riess *et al.* (1998) and Lineweaver (1998). The methodology used in searches for distant Type Ia supernovae has been elaborated on by Branch and Tamman (1992). Impact on theoretical cosmology has not yet been investigated in detail, but some important lessons have been drawn by Kardashev (1997) and Krauss and Turner (1999), as well as in an earlier study of structure formation by Liddle *et al.* (1996). For the anthropic significance of the cosmological constant see Barrow and Tipler (1986), Weinberg (1987), Efstathiou (1995) and Martel, Shapiro and Weinberg (1998).

[9] Physical eschatology is a rather young branch of astrophysics, dealing with the **future** fate of astrophysical objects, as well as the universe itself. Landmark studies in physical eschatology are those of Rees (1969), Dyson (1979), Tipler (1986) and Adams and Laughlin (1997). Some relevant issues were discussed in the monograph of Barrow and Tipler (1986), as well as several popular-level books (Davies 1994; Adams and Laughlin 1999). Since the distinction between knowledge in classical cosmology and physichal eschatology depends on the distinction between past and future, several issues in the physics and philosophy of time are relevant to the assessment of eschatological results and *vice versa*.

in Eq. (1) is the **minimal** possible temperature, and therefore the integration of the right-hand side of Eq. (2) will give a finite result in any realistic case. A hibernation-type decrease in energy consumption (Dyson 1979) probably will not help due not only to finite asymptotic temperature but also to quantum effects (Krauss and Starkman 2000). The recourses left are connected with the topological structure: transferring to another unit of the global multiverse, or **creating** another such unit (Harrison 1995). In a sense, this offers a possibility of answering the question: if the cosmological constant breaks the temporal symmetry, and the same may be said for emergence of intelligent observers, what is the relation between the two breaks? Of course, the answer may be given only **with respect** to the entire time span of intelligence in a universe (which can be thought of as a generalization of relationist view of time; see Newton-Smith 1980). This time span is necessarily and obviously finite in the Gold universe, as will be discussed in the further text.

The Gold view includes such an exotic process as transforming black holes into white holes-something entirely different from Hawking evaporation, for several reasons: (i) it must exist in the purely classical picture of entropy growth and subsequent decrease, while the Hawking process is a quantum one (Penrose 1979), (ii) the rate of black hole formation is determined by stochastic processes of matter accretion, which during the history of galaxies are much more intense than the evaporation can ever be; these processes are expected to be proportional to mass, so massive black holes gain most mass, while holes are evaporating at rate inversely proportional to their mass. Therefore, this issue is not just another instance of statistical arguments blind to the direction of time-something more than just statistical chance of a particular configuration of particles is at stake when we consider spacetime with local event horizons.

Parenthetically, the presence of vacuum energy as indicated by the recent cosmological supernovae experiments has very interesting consequences for the **local** evolution of matter. For instance, it seems clear that the long-term evolution of black holes is substantially different when Λ is present (e.g. Hayward, Shiromizu and Nakao 1994; Adams, Mbonye and Laughlin 1999). If anything, the process of black hole accretion of matter and subsequent evaporation through Hawking radiation is made even *more* asymmetric than earlier (in this respect, the physical asymmetry has been emphasized by Paul Davies back in 1973; see also Davies 1974). Histories of local matter constituents are, therefore, determined by the values of fundamental coupling constants and cosmological parameters (which may be expected to be derivable in the future "theory of everything" but may for the moment be regarded as additional constants of nature), which are all boundary conditions. This is a physical background corresponding to the Price's corkscrew model, which has not been sufficiently elaborated in the literature as yet. Therefore, it seems that the basic dilemma is resolved in a way which Prof. Price considers less appealing, that is, through physical boundary conditions which are asymmetric independently of human cognizance. It is not cognizance as such which the asymmetry is related to, but the particular instatiation of **human** cognizance. It is an interesting question whether this can be generalized to statement that all possible universes **in which any cognizance is to be expected** are asymmetric through boundary conditions. Unfortunately, the nature of cognizance and its underlying physical principles are still too poorly known for this question to be answered with any degree of certainty.

3. INFORMATIONAL CONTENT OF THE UNIVERSE AND IRREVERSIBILITY

Further difficulty with the Gold universe which seems to has been overlooked is the fact that in that model there are actually **two** maximal values of entropy: (i) the value attained at the maximum of expansion, and (ii) maximal **conceivable** entropy taking the observed energy density of the universe into account. It seems obvious that the realized entropy peak (i) will in any case (except for a very improbable coincidence) be significantly smaller than (ii), no matter in which way we treat the gravitational entropy. The problem is that (ii) is essentially governed by local physics (maybe even local chemistry, biology, etc.), and (i) is the single-valued consequence of the cosmological parameters. Gold has not offered any plausible theoretical reason for thinking that there is any coupling between the two. This is similar to the local and global entropy maxima in Penrose (1979) picture, in particular in his Figure 12.6. Whether a local parcel of gas will reach thermodynamical equilibrium and eventually collapse into a black hole does not seem to have any bearing on the global value of Ω (and Λ). While this does not constitute an argument against the Gold picture, it certainly makes it less appealing from the physical point of view, when a deeper understanding is achieved.

This issue is tightly connected with the informational content of the universe (which is, *via* the Shannon connection, related to the entropy content). Layzer (1976) has discussed reasons for believing that

> under certain conditions, the cosmic expansion generates information as well as entropy and that the second law does not require the initial state of the Universe to have been highly structured, or indeed to have had any structure at all.

The alternative idea is expressed in the book of Davies (1974), stating that the "cosmic medium possesses an infinite reservoir of negative entropy". In view of Davies, local processes, and the local gravitational collapse in particular, are in contact with this reservoir, thus producing the observable gradient.

The important study of Treumann (1993) investigates the evolution of the informational content of the universe from the point of view of general nonlinear dynamics, taking into account newer developments, such as the rise of inflationary models in the

1980-ies and 1990-ies. Results of this study indicate that the universe in its early stages could be characterized by a very small amount of information I $\sim$ 10 bits. Obviously, the universe today needs much more information for the detailed description; estimates are around 10^{120} bits. The growth of information is connected with the growth of entropy, and a simple model of Treumann gives us a general picture of such growth in matter-dominated models. Of course, much further work is needed in order to establish the details of this picture, as well as to incorporate the effects of the cosmological constant (which become relevant only at late-conventionally-cosmological epochs). In a sense, such studies can be regarded as **independent confirmations** of the conclusions reached by Layzer, Zeh, Price and others who maintained that the basic puzzle concerning the arrow of time lies in special initial conditions for all physical processes.

Parenthetically, the idea that asymmetric physical *laws* are necessary for cosmology, has been with us for very long time, actually since the 1930-ies, from early work of Russian cosmologist Matvei Bronstein whose prescient cosmological insights have been repeatedly rediscovered during the last half-century. Before he was brutally murdered by Soviet communists in 1938, he wrote in the paper published in 1933:

> A physical theory upon which the solution of the cosmological problem can be based cannot be symmetrical with respect to the interchange of the past and the future.

It is true that this view has been vigorously put forward by Penrose (1979, 1989) in recent years, but actually it underlies most of the practical cosmological work, in particular since the victory of big bang models over their great steady state rival. Interestingly enough, Bronstein's considerations have also been founded on considerations of influence of non-zero vacuum energy on the universal dynamics.

Concluding our discussion of this issue, it should be stressed that relatively new findings concerning the large positive cosmological constant point essentially in the same direction as the previous cosmological lore, in spite of the picture Price and some other authors assume. The grounds for reintroducing the cosmological constant have existed for decades, as testified by the thoughtful review of Carroll, Press and Turner (1995) predating the discoveries of Perlmutter *et al.* In addition, the positive cosmological constant is an almost mandatory product of the quantum field theories which are considered so highly respectable in other cosmological application (for instance, in explaining the early inflation). The fact that this family of models was investigated to the lesser degree than the Einstein-de Sitter $\Omega_{matter} = 1$ model testifies, perhaps, more to the simplicity and lack of dilligence of theoretical cosmologists, as well as other elements of the sociology of science, than to the nature of the universe.

4. OTHER FORMS OF BREAKING THE TIME SYMMETRY

The discussion of the cosmologial constant sketched here points out that there is an easy way to break the symmetry of cosmological time. This solution comes, of course, at a price. Part of the price lies in the fact that it is necessary to account for the **sign** of Λ. Preceeding considerations apply only to the positive sign, in which case the universe is ever-expanding disregarding its topological structure. However, the negative Λ will just add to the total energy density, and if its magnitude is in a wide range of interesting values, it will cause recollapsing universe in which case we are faced with the Price's basic dilemma again (see also the illuminating discussion of such models in Barrow and Dabrowski 1995). Although there are some exceptions to this, we shall not consider them further here.

From a historical perspective, therefore, it seems that apart with the processes of unifying the various seemingly distinct empirical phenomena, we are dealing with attempts to unify the various arrows of time. While the connection of thermodynamical and cosmological arrows have been suggested by various authors, notably Gold and others during the last half century, and connection of electromagnetic arrow with the cosmological one first elucidated by Wheeler and Feynman (1945, 1949), later followed by Hogarth (1962), only with works such as Price's we get a comprehensive enough view. However, the prospect of this (inherently atemporal!) unification is marred by the explicit rejection of possibility that what is traditionally called psychological arrow of time can be explained in the same manner as the rest. When discussing the most common and everyday (and exactly for that reason hidden!) manifestation of the psychological arrow, namely the asymmetry of causation, Price writes (pp. 155, 160):

> Perhaps causal asymmetry isn't really in the world at all, but the *appearance that it is* a product of our own standpoint. Perhaps it is like the warmth that we see when we look at the world through rose-tinted spectacles... The great disadvantage of the approach may seem to be that it makes causal asymmetry an anthropocentric matter. My view is that we should acknowledge this consequence, but deny that it is a disadvantage. Its effect is merely to put causation in its proper metaphysical perspective, as something like a secondary quality.

In this respect we see another instance of violating the inherent symmetry of (macro)physical laws. The phenomenon of life, and particularly intelligent life, if regarded as transcendental, of course can not be analyzed in physical terms, but while such dualism permeates the modern scientific thought, from Descartes onward, and has certainly brought important fruits in natural sciences, it should not be regarded as divinely ordained truth. Instead, one may follow the leads of Schrdinger (1944) and Stapp (1985), or even more accurately, Empedocles, Anaxagoras and some other pre-Socratic thinkers, that the biological, psychological, and even sociological evolution is an inherent and inseparable part of the physical, i.e. cosmological evolution. While here is certainly impossible to go into depths of such a rich and insufficiently studied worldview, it is interesting to speculate whether the same sort of asymmetry creating the large cosmological constant and cosmological arrow of time is responsible for the appearance of life and intelligence in the physical world. This link is indicated by studies of Weinberg (1987) and Efstathiou (1995).

Therefore, one may reasonably ask whether the physical considerations are required at all when we are confronting the problem of temporal asymmetry? There is no extravagance in this, and one may use the analogy with the famous discovery of metastable level in ^{12}C nucleus by Fred Hoyle to understand the issue (Hoyle *et al.* 1953; Barrow and Tipler 1986; Hoyle 1994). In the same manner as the Hoyle's anthropic claim that there is a new resonant level in the carbon nucleus seemed at first preposterous to working nuclear physicists, but was later confirmed, we may hope that the anthropic principle gives us a similar shortcut for analysis of the directionality of time (although it may as well seem *prima facie* preposterous to both physicists and philosophers working on the problems of time). The existence and energy of such a level, which were correctly predicted by Hoyle, depend, of course, exclusively on the values of fundamental constants of nature-however, we cannot **for practical reasons** (as discussed by Barrow and Tipler) back-track the way in which the constants are fine-tuned for such a level to exist. This circumstance **does not** prevent anybody from reaching the conclusion that this is another instance of fine-tuning of the constants themselves, with all appropriate theleological (or ontological, in the sense of ensemble-of-worlds "explanations") luggage.

What does seem clear is that melioristic cosmos in which complexity increases as more and more advanced forms of life and intelligence arise is incompatible with the time-symmetric worldview, as personified by the Gold universe. Let us consider, for instance, a period immediately before and after the transition from expanding to recollapsing phase. This transition will, depending on the total energy density of such universe, occur in more or less distant astronomical future. There are two possibilities here. One is implied in the classical discussions of the future in closed universes, such as the study of Rees (1969). This scenario implies that universe is closed by a substantial margin, and that the recollapse will occur while most of astrophysical objects (stars, planets, comets, etc.) we perceive today still exist. We may expect that the universe will possess many places inhabited by advanced intelligent species which are condemned to devolution and eventual disappearance in the Gold universe. This is not only an obviously pessimistic picture, but the one bringing a strange element of predestination not only in the physical sphere, but in the domain of actions of intelligent observers also. Alternatively, if the universe is closed in such a way as to satisfy simultaneously inflationary conditions, than $\Omega - 1 \approx 10^{-5}$, and the lifetime of such a universe is so large that it is basically indistingushable from the final state of an open universe as far as the local physical processes are concerned. In other words, we can expect the expanding phase to last long enough for stars to vanish, protons to decay, and gravitational radiation causes all remaining matter to be in form of black holes and a dilute "soup" of electrons and positrons, as the "standard picture" of physical eschatology for an open universe suggests (Dyson 1979; Tipler 1986; Adams and Laughlin 1997). All that is assumed in absence of the active role of advanced intelligent life in such a model, in contradistinction to, for instance, Tipler's Omega-point theory, which is also based on the recollapsing universe (Tipler 1994). Now, the Gold alternative in this case is different only in the sense that life **may** become extinct **because of entropy increase** before the recollapse and the entropy decrease set in. In this case, the reversal of the thermodynamical arrow of time at the point of recollapse will mean simultaneous **increase in complexity**, which is the situation opposite to the one we encountered in the known history of the universe. After some point, however, there must be another turn when the complexity will begin to decrease again in later stages of contracting phase. Thus, the arrow of complexity makes **two** cycles while the thermodynamical arrow makes only one.

This demonstrates on a counterexample that the arrow of increase in complexity is not the same as the classical arrow of thermodynamics. One may as well imagine a counterfactual lifeless universe of low complexity which will still be subject to the increase of entropy in rather simple processes, such as shining of stars, formation of galaxies and black holes in galaxies, black holes' coalescence, etc. Although a large thermodynamical disequilibrium is a necessary condition for creation of life, and, subsequently, intelligent observers, there is no indication whatsoever that it is a sufficient condition. On the contrary, there are indications that much more is required, at least in a universe of realistic duration (e.g. Hoyle 1982).

In the same manner, this arrow of increase in complexity can not be reduced to any other classically discussed arrows, such as the arrow of radiation or psychological arrow. The relationship with the latter is rather a subtle one, and one is still too ignorant of psychological processes today to say more about it, but in general one should not conflate the two. An amusing illustration of this point can be read in the account of Penrose (1979):

> In the first place, there is something rather unreasonable about determining the behaviour of a system by specifying boundary conditions at all, whether in the past or future. The 'unreasonableness' is particularly apparent in the case of future boundary conditions. Suppose I throw my watch on a stone floor so that it shatters irreparably, and then wait for 10 minutes. The future boundary condition is a mess of cogs and springs, but with minutely organized velocities of such incredible accuracy that when reversed in direction (i.e. with the clock run backwards) they suddenly reassemble my watch after a 10-minute period of apparent motionlessness... I am not even convinced that 'entropy increase' is at all an appropriate concept for describing the shattering of my watch. Probably taking a bath increases the entropy enormously more - while, in the case of my watch, the proportional increase in entropy must be quite insignificant.

The message is that the issue of meaning and direction of entropy increase and reversibility for the very complex systems and their interaction with environment (like Penrose interacting with his bathroom!) is much less clear than for the simple examples commonly discussed in physics and astrophysics. The arrow of increasing complexity (which could be as well called the anthropic arrow, for the reason considered above) is tightly connected with several cosmological puzzles, notably the Davies-Tipler argument (manuscript in preparation), and the Olbers' "paradox". Unfortunately, the unclear situation in regard to the "laws of complexity" do not allow this issue to be quantitatively analyzed in detail, but the ongoing massive research activity in this direction will certainly change this situation.

5. SEARCHING WITHOUT END?

The investigation of the nature of apparent arrows of time is one more instance in which relevance of cosmological boundary conditions to local physics is clearly manifested. This agrees with the Machian tradition present from the very beginning of the modern cosmology. This tradition is still very much alive, and there have been attempts to encompass a much wider range of physical phenomena in it (Rosen 1981). However, to limit oneself to investigation of global singular states of the universes is too narrow a view for the realistic world-models. Therefore, a full attention must be paid to the final $t \to \infty$ non-singular state of the universe in either $\Omega < 1$ open matter-dominated universe or $\Omega \approx 1$ vacuum energy-dominated model. This would be in accordance with the consequent implementation of holism relevant to the contemporary philosophy of physics (e.g. Esfeld 1999).

However, if we are to treat final cosmological conditions on a par with the initial conditions, as the atemporal view suggests, we need to understand the former in all their possible complexity. Therefore, the inclusion of intelligent observers and products of their activity is not an option, but a compulsory step in any attempt at realistic description, as pointed out by Dyson (1979):

> It is impossible to calculate in detail the long-range future of the universe without including the effects of life and intelligence. It is impossible to calculate the capabilities of life and intelligence without touching, at least peripherally, philosophical questions. If we are to examine how intelligent life may be able to guide the physical development of the universe for its own purposes, we cannot altogether avoid considering what the values and purposes of intelligent life may be. But as soon as we mention the words value and purpose, we run into one of the most firmly entrenched taboos of twentieth-century science.

The future of the universe containing life and intelligence is **essentially** different from the past of the same universe in which there were no such forms of complex organization of matter. This is the same asymmetry which we have introduced under the name of the anthropic arrow. Now, there seems to be only two ways of thinking about this asymmetry: either to accept it as a **natural** product of physics, be it either symmetric (as we got accustomed to, and which the Archimedean point suggests to us) or asymmetric (with something like the Penrose's asymmetric boundary condition or new laws governing K^0 decay), or to regard it as something transcendent to physical world and **therefore** inexplicable. Both common sense and the history of science, as well as the success of various anthropic arguments in accounting for some of the features of the universe we perceive around us, indicate that we should accept the former possibility. On its face, a physical reductionist, or Empedoclean picture of continuity of cosmological, biological and anthropological evolution makes a good framework for unification of various arrows of time, and therefore presents the unique consequent approach to building a completely atemporal worldview. All this again points to a broader issue of ultimate incompatibility of the anthropic reasoning and the Archimedean point, which is beyond the scope of the present study.

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АНТРОПИЧКА СТРЕЛА ВРЕМЕНА И РЕАЛИСТИЧНИ СВЕТСКИ МОДЕЛИ: О ПРАЈСУ И БЕЗВРЕМЕНОМ КОСМОСУ

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Претходно саопштење

У савременим покушајима изградње атемпоралне (”безвремене”) слике физичког света недовољна пажња је посвећена процесима који узрокују космолошку стрелу времена. У светлу нових емпиријских налаза, а посебно епохалног открића велике ефективне густине енергије вакуума, постојеће дискусије ове теме треба да буду поново размотрене. Овде је нарочито истакнута неопходност новог третирања асиметричних временских граничних услова у отвореном универзуму. У овом раду укратко се дискутују неке грешке и неодређености имплицитне у скорашњем разматрању проблема космолошке стреле времена у брилантној монографији Проф. Хју Прајса. Поред тога, разматра се релевантност високог степена сложености који опажамо у живим и интелигентним бићима у универзуму за питање временске симетрије у физици.