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IS THERE AN ARROW OF TIME AFTER ALL?

MILAN M. ĆIRKOVIĆ
Astronomska Opservatorija, Volgina 7, 11000 Belgrade, SERBIA;
Dept. of Physics & Astronomy, SUNY at Stony Brook,
Stony Brook, NY 11794-3800, USA
E-mail: mcirkovic@aob.bg.ac.yu

Abstract. In recent attempts at building an atemporal ("tenseless") picture of the physical world, insufficient attention is devoted to the cosmological arrow of time. According to new empirical findings, and particularly the epoch-making discovery of a large effective vacuum energy density, the existing discussions of the topic need reassessing. In particular, the necessity of a new treatment of asymmetric temporal boundary conditions in an open universe is hereby put forward. Some errors implicit in the earlier treatment of the problem of the cosmological arrow of time are briefly discussed.

1. 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. Only in the course of the last century, since 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. Although this simple point has been put forward by many authors (e.g. Gold 1962; Penrose 1979; Hawking 1985; Price 1996), it has somewhat remained 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 (i.e. Hoyle and Narlikar 1972, 1974). Another, which I 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 the light of great difficulties encountered—even after the great cosmological controversy of the 1950-ies has left only evolutionary Friedmann models on the battlefield—by observational cosmologists in determination of the three fundamental cosmological parameters, H_0, Ω and Λ.

Hereby, I would like to defend the following thesis:

1) The recently observationally confirmed positive cosmological constant breaks any conceivable time-reversal global symmetry.

In addition, two complementary philosophical theses can be put forward, but their discussion is beyond the scope of this paper and will be the subject of a subsequent work:

2) The existence of life, and particularly intelligent observers has basically the same effect of breaking the global symmetry. Therefore, the introduction of an additional arrow of time, which we can call the anthropic arrow (or arrow of technologization) may be a useful concept.

3) A reductionist 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.

2. OPEN UNIVERSE AND THE COSMOLOGICAL CONSTANT

In a recent very important study of 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. Central point of atemporal description of the initial (and possibly) the final conditions in cosmology is what Price calls the "basic dilemma":

> *...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.*

However, smoothness or simplicity of the early universe does not seem intractable from the point of view of a general theory of nonlinear dynamics (Devlin 1991; Treumann 1993). 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 final state through entropy production are actively investigated in contemporary astrophysics and cosmology.[1]

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;

[1] 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).

Barrow 1999) the low initial entropy from anthropic constraints; even more to the point, it could well be done in each particular instance without the ontological enlargement (i.e. postulating the multiverse), if one is willing to follow in bold steps of Dyson (1979), and break the taboo by introducing a teleological discourse. This step immediately breaks the symmetry, since "known physics" which should, from the reductionist point of view, include the complexity of biological and even psychological structures, is (to say the least) ambiguous with respect to temporal orientation. This point does not seem to have been recognized in contemporary literature on the subject. However, another form of breaking of the temporal symmetry has obtained (and justly so) very much publicity during the last two years.

Recent observational confirmation of the large vacuum energy density (commonly known as "cosmological constant")[2] will undoubtedly have great impact on our way of thinking about the time, as well as on almost any aspect of physical eschatology. The three most significant consequences of a cosmological constant roughly corresponding to the 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; Ćirković and Bostrom 1999), it will enter a de Sitter (quasi-exponential) expansion phase.
- Event horizons (Rindler 1956; Harrison 1991; 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,

$$T \to T_\Lambda = \frac{\hbar c}{k}\sqrt{\frac{\Lambda}{12\pi^2}} \approx 3.3\times10^{-30} h\sqrt{\frac{\Lambda}{0.7}}\ \mathrm{K}, \tag{1}$$

where k is the Boltzmann constant.

The extremely low temperature in Eq. (1) will, eventually, become higher than 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 (for the maximal amount of information which can be processed by a physical system using energy E and working at 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 hypothesis (Ćirković and Bostrom 2000) seems frustrated by the realization that the temperature in Eq. (1) is the **minimal** possible temperature, and

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[2] 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 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).

therefore the integration of the Brillouen inequality 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 1999). 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 of the emergence of intelligent observers, what are the relations between the two breaks? Of course, the answer may be given only **with respect** to the entire timespan of intelligence in a universe (which can be thought of as a generalization of relationist view of time; see Schuster 1961; Newton-Smith 1980).

Parenthetically, the presence of vacuum energy as indicated by the recent cosmological supernovae experiments has some interesting consequences for the 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 & Nakao 1994; Adams, Mbonye & 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). Therefore, it seems that the basic dilemma is resolved in a way which you consider less appealing, that is, through physical boundary conditions which are asymmetric completely independently of human cognizance. In a sense, the true cosmological arrow of time is established only after the existence of the cosmological constant is confirmed.

3. 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 comes, with 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 & Dabrowski 1995). Although there are some exceptions to this, we shall not consider them further here. What is interesting is the fact that the ultimate "Theory of everything" will have to give the explanation of the sign of the cosmological constant in terms of the "first principles", in order to explain the cosmological asymmetry. Since the same ultimate theory is (naturally) expected to account for the CP violation, it is quite plausible to think that the same set of fundamental processes is responsible for both asymmetries, thus unifying micro- and macrocosmos in the most remarkable way, confirming Bronstein's (1933) farsighted intuition.

From a historical perspective, therefore, it seems that apart from 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 has 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 somewhat 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.

In this respect we see another instance of violating inherent symmetry of (macro)physical laws. The phenomenon of life, and particularly intelligent life, if regarded as transcedental, 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, as most practicing physicists and philosophers tend to do. Instead, one may follow the leads of Schrödinger (1944) and Stapp (1985), or even better, 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 (e.g. Guthrie 1969). While here is certainly impossible to go into depths of such a rich and insufficiently studied worldview (which, ultimately, includes the transition, or **translation** between syntaxical and semantical structures in epistemological sense), 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. What does seem clear is that melioristic cosmos in which complexity increases as more and more advanced form of life and intelligence arise is incompatible with the time-symmetric worldview, as personified by the Gold (1962) universe, or indeed any similar simple scheme.

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