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A NOTE ON SINGULARITIES AND THE ARROW OF TIME

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SUMMARY: An interesting thought experiment claiming to highlight the connection between singularities and the global arrow of time is re-analyzed, and a further specification suggested. Against the criticism of Price (1996), it is proposed that the original Penrose (1979) interpretation is still valid. Some ramifications of the result of our understanding of the cosmological arrow of time are sketched.

The problem of the origin of temporal asymmetry ("the arrow of time") in time-symmetric physics is one of the greatest challenges the physics and philosophy of the XX century passed on to the new millenium. One of the basic trends in the modern philosophy of space and time has been the attempt to complete the project begun with the rise of B-theories of time by constructing a truly atemporal ("tenseless") picture of the physical world (e.g. Grünbaum 1973). In a recent important and thought-provoking study, Huw Price (1996) has offered so far the most comprehensive attempt of building such a description. He excellently shows the dependence of various local arrows of time on the global, cosmological arrow, as well as irrelevancy of most attempts to derive the arrow of time on a local basis involving the temporal double standard. However, his treatment of the cosmological arrow is not entirely satisfactory, as we shall show on the example of the Penrose's thought experiment described and commented upon in the Chapter IV of his book. This example is characteristic for the somewhat ambiguous approach often encountered in contemporary physics and philosophy when arguments related to the various anthropic principles are considered. Specifically, we shall show that Price's criticism of the conclusion of Penrose is either wrong, or-and more probably-simply *non sequitur* for the discussion of the cosmological arrow of time.

The background of the issue considered in this note is the (un)famous question of the "naturalness" of orderly singularities of the (actual) big bang type. In order to account properly for the cosmological arrow of time arising from the time-symmetric physics, Gold (1962) suggested a highly regular nature of **all** global singularities. In particular, since recollapsing world-models were in vogue among the adherents to the general class of Friedmann models (as opposed to the steady state proponents), Gold suggested a time-symmetric recollapsing model in which the total entropy of the universe reaches the maximum at the point of maximal spatial extent, and subsequently decreases all the way back to the final singularity which is of regular type-actually indistinguishable from the initial one. Consequently, the arrow of time in the second half of the Gold universe will be reversed when compared to the present one, and we shall witness a "counter-clock world" (to borrow a fine expression from the title of a novel by Philip K. Dick) of shattered glasses restoring, the dead coming to life again, etc. This time reversal will naturally come about in such a model, since after the universal contraction sets in, the final conditions for all matter will play the same role as initial conditions at the big bang play for matter today (causing, as demonstrated by Price, those asymmetries conventionally denoted as thermodynamical and radiative arrows of time).

However, what is happening without the "big crunch"? The overwhelming empirical evidence today suggests that the recollapse will **not** take place in the actual universe. While this is not in itself the cause for not investigating properties of the Gold universe (such counterfactual research can very often bring invaluable new insights in the functioning of the real world, as the very history of XX-century cosmology clearly shows; see Kragh 1996), this certainly is an obstacle for building a complete atemporal description based on the structure of cosmological temporal boundary conditions in the manner of Price (1996). However, as suggested by Penrose (1979) in his seminal discussion of connection between the arrow of time and singularities, the conditions similar to those around the big crunch could be "simulated" by a local gravitational collapse, presumably the one occuring in formation of stellar-mass black holes.

Penrose considers the fate of an astronaut falling in the black hole, and conducting experiments prior to his fatal encounter with the central singularity. If the black hole is large enough, he will have a reasonable amount of time in the internal region for experimenting and pondering on their results. His experiments, as well as his entire condition, will be in a sense dictated by the future boundary conditions at the singularity. In accordance with the Gold view, this is the same as determining of results of his experiments and his entire state by the initial conditions at the big bang singularity prior to his crossing the event horizon. Therefore, the arrow of time should suddenly reverse upon his crossing the horizon, and he will experience all the miracles of the "counterclock world". Penrose finds this absurd, and it is hard to avoid concurring. The event horizon is a geometrical construction-there is, we know now, after a long and painful history of the problems, no physical discontinuity there; why should entropy behave so differently? Apart from rejecting the existence of black holes entirely, Penrose suggests that a natural way out of the difficulties is simply to reject the Gold view for the origin of time asymmetry. He finds this as a further instance of necessity of finding a new time-asymmetry **law** (after the pioneering discussion of this option by Bronstein 1933).

When discussing Penrose argument Price (1996, p. 102) writes:

> *Consider Penrose's argument. He is presumably a product of a billion years of cosmological evolution, which created the conditions for biology to begin on our planet. So he is the sort of a physical structure that could only exist at this kind of temporal distance from a suitable big bang. What counts as suitable? The relevant point is that low entropy doesn't seem to be enough; for one thing, the 'bang' will need to be massive enough to produce the cosmological structure on which life depends. ... This means that Penrose's astronaut is not going to encounter any time-reversed humanoids inside the black hole... He need not be a 'natural' product of the hole's singularity.*

I have quoted this argument in detail, since there seem to be several interesting things about it. First, it includes an explicit anthropic justification; since Dicke (1961) and Carter (1974) we-slowly-began getting accustomed to the fact that it is impossible to separate the observed large-scale properties of the universe from the particular conditions imposed on them by our own existence. Price actually endorses what Carter has christened the weak anthropic principle (WAP): the astronaut-in a sense contrary to the Archimedean tradition Price lauds in the entire study-could **not** come "from nowhere" in order to be a truly objective observer of the physical world in action. He could only come from rather large, but still well defined region of spacetime in which astronauts (and any other form of intelligent observers) can exist. While there is certainly nothing wrong about WAP-based as it stands, it is interesting to speculate whether (i) that means that the entire point (i.e. time's arrow in proximity of a singularity) depends on such things as the "naturalness" of the life's origin[1], and (ii) the argument is dependent on the particular cosmological model chosen. To illustrate the second point, let us consider the classical steady state universe of Bondi and Gold (1948)[2]. There is no *a priori* reason to believe that local gravitational collapse will not occur in this theory, and that consequently, a "final" (i.e. unchangeable on long timescales, although not truly final, that is in the $t \to \infty$ limit) state of very massive stars will be black holes singularities. However, there is obviously no such thing as the initial singularity in the steady state universe, and the very contingency of the thermodynamical on the cosmological arrow of time is absent in this case. The astronaut approaching a black hole is in strongly asymmetric situation: he has a (black hole) singularity in his future, but not in his past. It is doubtful, to say the least, whether the Gold conjecture of orderly nature of singularities were applicable here.

[1] For instance, if Sir Fred Hoyle's estimate of chances for spontaneous assembly of life on Earth is as small as 1 in 10^{40000} (Hoyle 1982), this will immediately have impact in the sense of either "increasing" the required big bang, or invalidating the entire argument by regarding it as a miracle. (Of course, this is not a problem for Hoyle himself, who does not believe in big bang in the first place, but it remains the problem for the standard cosmology.)

[2] There is a reason to be more cautious when considering Hoyle's (1948) version of the steady state theory. It is an explicit field theory, and although it is not altogether clear, some remarks of Hoyle and later Narlikar indicate that there is a way to halt gravitational collapse in that theory so as to avoid singularities altogether.

One may remark here that the steady state universe is not non-singular in the strict sense. Namely, worldlines of all particles making up the astronaut's body are incomplete, in the sense that they all have ultimately popped up out of nowhere (or from the field of negative energy density in the McCrea's relativistic field formulation), and formally it can be seen from the Hawking-Ellis criterion which can be written as (Hawking and Ellis 1973)

$$\int_{t_0}^{0} R(t)dt = -\infty, \qquad (1)$$

where $R(t)$ is the usual cosmological scale factor, and t_0 ($\geq -\infty$) is the lower limit of the length of the timelike geodesics normal to the hypersurfaces of homogeneity and isotropy. For $R(t) = \exp(Ht)$ characterizing the steady state theory this criterion is not satisfied, and it is intuitively understandable, since an ephemeral micro-singularity occurs whenever a particle is created in the spacetime. However, to invoke this aspect of singularity in explaining the arrow of time in the particular case under consideration, entails a strange assumption that trillions and trillions of particles composing our astronaut (which have passed through various physical processes since their creation, like being processed in stars, scattered through the interstellar medium, etc.) originated in highly correlated creation events. Since the latter are so rare (because the creation is so slow if the theory is to be in accordance with terrestrial experiments), they are likely to have been occuring separated by parsecs and millions or billions of years. There is nothing in the known laws of physics capable of inducing such bizarre collective behaviour.

Moreover, if one does not appreciate these difficulties, one can always see the dependence on the cosmological model in considering those *prima facie* viable cosmologies like the bouncing universes or the static models of Ellis et al. (1978) or Phillips (1994a,b), in which either there is no global singularity, or the singularity is co-present with the universe and our astronaut. In all these situations, the position of the astronaut is strongly asymmetric in the sense described above. In particular, it can not be said for him that he is a "product" of a singularity possessing such-and-such properties.

However, the problems with the Price's counterargument are highlighted if we accept the standard notions of the Friedmann-type big bang, but modify the **final conditions** of the thought experiment in the following way[3]. It has been shown several times in a nascent discipline of physical eschatology, that the fate of matter in galaxies is to be either expelled in the intergalactic space, or to coalesce with the central supermassive black hole (Tipler 1986; Adams and Laughlin 1997). Eventually, such galactic black holes will coalesce whenever they are gravitationally bound to a larger system, and on timescales very short in comparison to the timescales of their eventual evaporation. Therefore, it is natural to expect that in the ever-expanding universe, the entire Local Supercluster will end up as a giant black hole, containing about 1014 Solar masses (larger fraction of the mass of the supercluster will disperse and eventually evaporate through proton decay and CDM-particle annihilation). It should be immediately emphasized that although we do not know how wide the spectrum of initial density perturbations is, we know that sufficiently large overdensities (such corresponding, for instance, to rich galaxy clusters or superclusters) will eventually end up in giant black holes if the universe continues to expand[4]. Now, superclusters are supposed to be the largest entities bound by gravity against the Hubble expansion; as such, they represent fairly isolated structures in the observable universe (Oort 1983, and references therein).

With this in mind let us modify Penrose's thought experiment in the following way. Let our astronaut be a simple guy from the present (or near-future) epoch in possession of the photon rocket, enabling him to achieve velocities arbitrarily close to c. He goes and travels for some time around the universe achieving 99.9999...% of the light velocity, thus rapidly travelling forward in time. Let him travel in time until the huge black hole forms from the remnants of the Local Supercluster, and **only then** does he repeat the Penrose's experiment. Now, the conditions are somewhat different and the entire situation seems immune from the objections of Price. The black hole now contains all entropy which was produced during the cosmological evolution, and *eo ipso* chemical, biological and even technological evolutions (the last one enabling the existence of his photon rocket). It contains also all information on the complexity formed during the billions of years of cosmic time, complexity embodied in intelligent observers (and, unfortunately, they presumably contain all remnants of the intelligent observers themselves). Our astronaut, on the other hand, shares the entropic history of the black hole. As long as there is no reason to believe that (**if** life and conscience are naturally arising phenomena) matter outside of the Local Supercluster has any impact on this, we have effectively accepted the horn of the "Adam's (from Milton's *The Paradise Lost*) dilemma" and created a sufficiently large big bang/crunch. Local big crunch is now truly 'generic' to the observer (astronaut) involved. He **is** a "natural" product of the black hole singularity now. Do we expect that the miracles of "counter-clock world" will now happen? Will his rocket travel be regarded in fact as time travel into the past? Will he encounter beings with time-reversed metabolism and mental processes? While

[3] There should not be any problem with this in an atemporal picture, since the postulate underlying the entire effort is the symmetry between initial and final conditions, as far as the physical world is concerned.

[4] It is not necessary that the universe continues to expand to infinity for the discussed situation to occur. If the universe is topologically closed, with zero cosmological constant, but with $\Omega - 1 = \varepsilon$ much smaller than 10^{-5} (which can occur in some of the inflationary universe), the duration of expanding phase of such an ultimately recollapsing universe is so long, that all physical processes proceed as in the ever-expanding models.

one can not know for sure, we find more acceptable to hold with the Penrose's original conclusion-that such things will not happen anymore in this case than in the case of "external" (in the sense of spacetime histories), small black hole. But the argumentation should be modified. Appeal to the mixing model does not seem to help, since if we cover the left half of Fig, 4.1 of Price (1996) with a piece of paper and move it toward the right-hand side of the page, we see that as we approach "the other" singularity, the two models are indistinguishable-and we are dealing exactly with situations close to singularity (in a spatial sense, if the emphasis is necessary).

However, the original discussion of Penrose is not completely innocent, in the sense that one can interpret the situation in a different way than the inventor of this ingenious thought-experiment does. It becomes a *non sequitur* for the debate of the cosmological arrow of time if one somehow shows that the common premise of both Penrose's and Price's discourses, namely that the local and global gravitational collapse are not comparable at all. In a sense, one can give credit to Price here for pointing that a massive black hole is not "big enough" for comparison with the global big crunch. However, it may as well be more than size. If we accept a Machian picture of gravitation and cosmology, which has so profoundly influenced Einstein, local gravitational properties are determined by the distribution of all other gravitating bodies in the universe (Raine 1981, and references therein). The conclusion that the global singularity in this picture is generically incomparable with anything local seems natural enough in this picture. In our opinion, the realization that the power spectrum of density perturbations may extend to very large scales, and that entire visible universe may be only an atypical region within much larger, and presumably inhomogeneous whole (e.g. Harwit 1995). Therefore, even the notation of Fig. 12.4 in Penrose (1979) is misleading, because the same symbol is used for both global and local singularities, which is not *a priori* warranted. In this light, it is more natural to conclude that Price's objection is simply a *non sequitur*, the local singularities being unable to create an arrow of time at all.

Therefore, one may conclude that there are two possible ways for accounting for the presumable absence of miracles when approach to any local black hole is considered. The miracles will not happen because local gravitational collapse is something entirely different from the global one and incapable of causing the arrow of time even locally ("Machian view") or because the Gold view makes no physical sense ("Bronstein-Penrose" view)-or because of both. Note that by the first option, we may retain the Gold view of global singularities as places of low entropy dictating the arrow of time in subsequent local processes throughout the universe. By the second (and the third, of course), we need some novel explanation of the low entropy initial conditions, the explanation that the stronger versions of the anthropic principle may ultimately offer.

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БЕЛЕШКА О СИНГУЛАРНОСТИМА И СТРЕЛИ ВРЕМЕНА

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Претходно саопштење

У овом раду поново се анализира један занимљиви мисаони експеримент који претендује да расветли везу између сингуларности и глобалне стреле времена. Предложена је додатна спецификација поставке самог експеримента. Против критике Прајса (Price 1996), сугерише се исправност оригиналне Пенроузове (Penrose 1979) интерпретације овог експеримента. Неке последице које овај резултат има по наше разумевање космолошке стреле времена су овде скициране.