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THE CONCEPTS OF "BEGINNING" AND "CREATION" IN COSMOLOGY*

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The paper is inspired by the arguments raised recently by Grünbaum criticizing the current approaches of many cosmologists to the problem of spacetime singularity, matter creation and the origin of the universe. While agreeing with him that the currently favored cosmological ideas do not indicate the biblical notion of divine creation *ex nihilo*, I present my viewpoint on the same issues, which differs considerably from Grünbaum's. First I show that the symmetry principle which leads to the conservation law of energy is violated when the time axis is terminated at $t = 0$. Next I discuss why this epoch ($t = 0$) is more a mathematical artifact whose supposed significance may disappear when one goes beyond the classical relativistic cosmology. This is illustrated by the example of quantum cosmology.

1. Introduction. Recently Grünbaum (1989, 1990) has criticized several authors including myself (e.g., Bondi 1961; Lovell 1961, 1986; Maddox 1989; Narlikar 1977, 1988) for confusing the concept of "creation" of the universe with a finite temporal limit. For example, he writes:

> The physical cosmologist Jayant Narlikar is instructively articulate in his confusion of the question of the origin of the universe with the pseudo problem of its creation. And having conflated these two different questions he feels entitled to complain that "most cosmologists turn a blind eye" to the latter. (Grünbaum 1989, 374)

Grünbaum has been critical of the general practice in physics and philosophy of science of the use of the words "creation" and "annihilation" which he considers misleading. He argues that "the word 'creation' suggests a creating agency as well as a *process* in which something new is being produced" (Grünbaum 1989, 384).

In this paper I venture to present a somewhat different point of view of "creation" in the context of the big bang and steady state cosmologies. It is this point of view that led to my following statement concerning the origin of the universe that was criticized by Grünbaum above:

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> The most fundamental question in cosmology is: "Where did the matter we see around us originate in the first place?" This point has never been dealt with in the big bang cosmologies in which, at $t = 0$, there occurs a sudden and fantastic violation of the law of conservation of matter and energy. After $t = 0$ there is no such violation. By ignoring the primary creation event most cosmologists turn a blind eye to the above question. (Narlikar 1977, 136–137)

I will contrast the situations in the two cosmologies within my framework. While I agree with Grünbaum when he is critical of "miracles" invoked to explain "the origin of the universe" or "creation of matter" I will argue that as a physical theory, the classical big bang cosmology is less than complete on the issue of origin of the universe.

Finally I will discuss what new ideas on this issue are being contributed by quantum cosmology. As in the rest of physics, one would expect quantum theory to resolve, or at least throw new light on, some of the conundrums of classical theory.

2. Symmetries and Conservation Laws. First of all, I agree with Grünbaum's criticism of the words "creation" and "annihilation" in the context that these are used by particle physicists. In the reactions

$$\gamma + \gamma \rightarrow e^+ + e^-$$

$$e^+ + e^- \rightarrow \gamma + \gamma$$

the law of conservation of energy and momentum is preserved and in that sense nothing new is being created. Taking cue from this example I may term an event as a "creation event" if it involves a breakdown of the above conservation law. In using the word "creation" I may still be open to Grünbaum's criticism of the word in the philosophical context. However, I will go by the dictionary meaning "bring into existence" (see Pocket Oxford Dictionary). Likewise the conservation law also breaks down at an "annihilation" event. So I should begin with a discussion of this law.

In the classical relativistic cosmology we assume the spacetime to be a four-dimensional manifold (for a mathematical definition and properties of a manifold see, for example, Hawking and Ellis 1973) in which the equations of general relativity (Einstein 1915) are valid. These equations are to be derived from the principle of stationary action first stated by Hilbert (1915):

$$\delta A = 0. \tag{1}$$

Now, according to a theorem of Noether (see for example Bjorken and Drell 1965 for a discussion) the symmetries in the basic Langrangian that goes into the action functional $\mathscr{A}$ translate into conservation laws for corresponding physical quantities. Thus, in special relativity, the spatial translation invariance results in the global law of conservation of momentum while the temporal translation invariance results in the global law of conservation of energy. Likewise, rotational invariance implies the conservation of angular momentum.

It therefore follows that the global law of conservation of matter is intimately linked with time translation. If there were a finite end to the time axis, then necessarily the law would break down at the end. This is the reason why we may associate a creation or annihilation event with the end.

Now we look at Grünbaum's statement:

> But let us note that even an unrestricted conservation principle does not rule out a cosmological model featuring a first moment of time, that is a model featuring *an instant that has no temporal predecessor*. Why not? Because the conservation of matter or energy requires only that *at all existing times*, the amount of matter-energy has to be the same. Such conservation does *not* require that every instant have a temporal predecessor. (1989, 380)

Clearly the claim is at variance with the way the law is *deduced* in theoretical physics from a global symmetry principle. However, it may be argued that in a curved spacetime the global symmetry does not operate. In that case we can reword the argument in terms of *local* symmetry principles.

The global translational invariance of special relativity is replaced in general relativity by the coordinate covariance *locally*. Thus the Langrangian is a scalar quantity, whose value does not depend on any one set of coordinates x^i ($i = 0, 1, 2, 3$; x^o time-like, say) or the corresponding metric tensor g_{ik}. What is the corresponding conservation law? This is the local law of conservation of the energy-momentum tensor T_{ik}, given by the vanishing of its covariant divergence

$$T^{ik}_{;k} = 0. \qquad (2)$$

Now, to derive this result from (1) it is necessary to consider a small spacetime 4-volume *surrounding* the point P (x^i) where (2) is to hold. The procedure involves the use of coordinate covariance and the application of Green's theorem to this volume, which is eventually made vanishingly small (see, for example, Landau and Lifshitz 1975).

The crux of the argument is that this procedure *cannot* be carried out if P is a boundary point of the manifold. Green's theorem cannot be applied to the boundary point. Again this issue is relevant to the case of the big bang cosmology. It is worthwhile therefore examining the logical framework of this model, *as a solution of Einstein's field equations derived from the Hilbert action.*

3. The Big Bang Cosmology. The Friedman models are the standard models of Big Bang Cosmology (BBC). To obtain these models, certain global symmetrics are imposed on the spacetime manifold, symmetries that are usually stated under the names "the Weyl Postulate" (WP) and "the Cosmological Principle" (CP)—see Bondi (1961) for a discussion. The WP provides the justification for a "cosmic time" t and a set of comoving space coordinates $x^{\mu}(\mu = 1, 2, 3.)$. The 3-bundle of worldlines singles out a *special class of observers*, each specified by x^{μ} = constant and each having the proper time measured by the universal time coordinate t. The cosmological principle then implies that the universe is homogeneous and isotropic on the hypersurface t = constant. Thus no particular fundamental observer à la Weyl has any special status. The universe looks homogeneous and isotropic when viewed by all these special observers.

Had there been no such special class of observers, the concept of time t would make no sense. For, locally, at any point Lorentz invariance holds and one unique time coordinate has no special status just as Newton's absolute time has no special place in local physics. Nevertheless of all the inertial observers at P, only one, the Weyl observer, has a special cosmic status with his clock measuring the time t. An observer at P in uniform motion relative to the fundamental observer will not see the universe isotropic as the Weyl observer would. The fact that the microwave background radiation shows a dipole anisotropy is interpreted in terms of the Earth's motion relative to the local rest frame of the Weyl fundamental observer.

The worldlines of the above 3-bundle do not interact at any point except in the singular situation when they all might pass through the same spacetime point. This is the instant of singularity often labelled $t = 0$.

My purpose in elaborating on these basic assumptions is to review the two cases of BBC discussed by Grünbaum (1989, 389–391).

> *Case (i)*: This features a cosmic time interval $t \geq 0$ for the universe. The Weyl geodesics are supposed to diverge from a single world point at $t = 0$.

Grünbaum writes:

> To suggest or to assume tacitly that such prior instants existed after all is simply incompatible with the physical correctness of this model and thus implicitly denies its soundness. (Ibid., 389)

I agree with this comment in the sense that if the model is defined for $t \geq 0$, it is improper to extend the time axis to $t < 0$ and argue about what the model does over that interval. Nevertheless, within the framework of section 2 this model faces the following problems.

The conservation law of energy-momentum requires time translation in the global sense and a closed surface in the local sense. Both cannot be provided in a time interval that includes $t = 0$. Thus the conservation law is undefinable at $t = 0$. This circumstance is in itself a drawback of the model. Notice that we have not invoked any instants prior to $t = 0$ to arrive at this conclusion.

The second problem comes from the way this solution is obtained. Using the framework of WP and CP the field equations are solved. They lead to a singularity at $t = 0$. Having arrived at this conclusion the time axis is terminated at $t = 0$, that is, it is asserted that only the instants $t \geq 0$ are in existence. Had the energy conditions of Hawking and Ellis (1973) been violated as happens, for example, in the C-field cosmology of Hoyle and Narlikar (1964), the singularity may not have existed. In that case the time axis would have been extended all the way through $-\infty$. In other words, whether $t = 0$ exists as the initial point of the time axis or not is decided only after solving the field equations.

A more satisfactory interpretation seems to me to regard the time axis as from $-\infty$ to $+\infty$, *whatever the solution*, and consider the singularity as a *defect* of the classical gravity theory. Later we will see that quantum cosmology divests $t = 0$ of its special significance.

> *Case (ii)*: This differs from case (i) by the deletion of the $t = 0$ instant from the actual time span. This gets round my first objection to the case (i) model and is more satisfactory for the following reason.

It is characteristic of the causality principle in physics that one studies the evolution of a physical system given its initial conditions and the laws of evolution. Thus, stellar physicists like to work out the life history of a massive star from its birth in a molecular cloud to its "death" as a supernova. Galactic physicists are trying to piece together a theory of galaxy formation from some primordial fluctuations.

These problems of "origins" have always been difficult to solve, but successive attempts by physicists indicate that they consider such problems as worthwhile challenges in the overall framework of science. Not surprisingly, these problems, as their solutions progress, require us to shift the initial conditions further and further back in time. For example, the primordial nucleosynthesis of light nuclei assumes the existence of electrons, protons, neutrons, neutrinos and photons at, say, $t = 0.01$s. The next step is to understand how these particles were made. So we push our investigations through the epoch of grand unified theories (GUTs) at say $t \sim 10^{-36}$s. The process, even if it succeeds, would again require us to understand the state of the universe at the GUTs epoch in terms of something that existed earlier. This may lead to the Planck epoch of $t \sim 10^{-43}$s when quantum gravity was important. And so on. . . .

Whether or not this picture of the BBC is correct, the process described above forms a chain in which the assumed initial condition at a given epoch is sought to be understood in terms of something that existed *earlier*. With an open time interval $0 < t$, this process could continue indefinitely with a succession of earlier epochs in a way that Zeno would have approved:

$$t_1 > t_2 > t_3. \ . \ . \ . > t_n > . \ . \ . \ . > 0. \tag{3}$$

A closed interval terminating at $t = 0$ with the conditions specified there and with no further backward steps allowed is therefore entirely alien to the above-mentioned spirit of enquiry.

However, even in case (ii) the question is: Why is $t = 0$ the limit point of the sequence (3)? Is it just because of singularity? In that case, if with some future new physics the singularity is avoided, do we cross the $t = 0$ barrier? Again I feel that the instant $t = 0$ is an artifact that would go away in a more complete theory.

I agree with Grünbaum's arguments that the $t = 0$ instant does not warrant "miracles" or "divine intervention". I would go further (and here I depart from his thesis) and argue that this instant has been given an undue importance on the time axis, an importance that comes from a specific theory of gravity we happen to use: a theory that is essentially inadequate in handling the situation at $t = 0$. My criticism (quoted in section 1) was intended to highlight this inadequacy.

4. Continuous Creation and the SSC. The Steady State Cosmology was put forward along two different lines of reasoning. One was the notion of the Perfect Cosmological Principle (PCP) of Bondi and Gold (1948) and the other was the notion of creation of matter of Hoyle (1948). The Bondi-Gold approach was a purely deductive one, starting with a global principle. The PCP is "perfect" because it improves on the CP by bringing time on an equal footing with space and by satisfying the Popperian criterion of vulnerability of predictions to observational tests. The continuous creation of matter is thus a deduction of the PCP and as Bondi and Gold have emphasized, the SSC stands disproved purely by null observations of this phenomenon. Thus there is no compelling demand in this approach either to conform to the law of conservation of matter or to come up with a physical theory of creation of matter.

In his discussion of the SSC, Grünbaum (1989) has used the Bondi-

Gold version. This is also the main point of criticism of the theory by astronomers and physicists who always wish to reconcile any observations with the law of conservation of matter and energy. This is how the idea of "miracle" came up to highlight the "nonscientific" approach to creation of matter. However, whether or not one likes the PCP approach, one has to acknowledge that within its own deductive logic it is entirely self-consistent and complete. And it makes clearcut predictions which, despite a heavy input of highly sophisticated physics, the BBC has not yet succeeded in making. It is also worth stressing that the SSC received its major setback (considered fatal by many) by the *observation* of microwave background and not by any theoretical inconsistency.

By contrast with the Bondi-Gold deductive approach Hoyle adopted the more conventional framework of field theory and general relativity to describe continuous creation. Later in 1960, M. H. L. Pryce proposed a variation on Hoyle's method in which all the field equations of the theory were derivable from an action principle (private communication). I will take this variation for discussion.

Thus, equation (1), the starting point of general relativity, still stands. There is no departure from Einstein's field equations and, consequently, no violation of the law of conservation of energy-momentum. In fact, as I mentioned earlier in this article, *any* set of field equations derived from the action principle will automatically guarantee this conservation law. *How then is matter creation achieved apparently ex nihilo*?

The trick lies in introducing a new scalar field C of *negative* energy and *negative* stresses. There is an exchange of energy-momentum between ordinary matter and the C-field. This exchange plays three mutually complementary roles:

(i) When new matter appears, energy and momentum are taken *out* of the C-field reservoir. This *increases* the negative energy density and stresses of the C-field. (A conventional positive energy field *diminishes* in strength and would soon be depleted away through matter creation.) The C-field energy density and stresses are, however, maintained at their steady equilibrium values because of the expansion of the universe. So the phenomenon of matter creation is within the framework of physics, requiring neither the miracle of *ex nihilo* creation nor the alternative loophole of finite time boundary at $t = 0$.

(ii) How and why does the expansion proceed the way it does? Unlike the BBC which has the initial explosion as "given" at $t = 0$, the SSC has the correct dynamical framework within the set of Einstein equations. Because of the negative energy density of the C-field, there is repulsion in space leading to expansion. Thus the most fundamental observation of cosmology, namely, the expansion of the universe is brought into the framework of physics in the SSC whereas in the BBC it is relegated to the aftermath of the mysterious even at $t = 0$.

(iii) The quantum physicist is worried by the concept of negative energy: Would it not lead to a cascading of states down the energy ladder? The worry is justified when one talks about the quantum field theory in flat Minkowski spacetime but not when there is a dynamical interaction between energy and spacetime geometry. In a negative energy situation, as we saw above, the space expands and momentum falls. Thus the phase space is able to accommodate more states and no cascading occurs in the steady state. Or, to put it the other way around, if cascading starts, the amplification of negative energy accelerates the expansion and puts a brake on it.

In the 1960s considerable work (e.g., Hoyle and Narlikar 1964, 1966a,b,c) was done on the physical properties of the C-field. The idea of negative stresses causing expansion of space in the C-field cosmology was viewed skeptically by physicists just as the concept of baryon nonconservation was considered anathema in the 1960s. Within two decades these objections changed to favorites. For example, the bubble universe of the C-field cosmology (Hoyle and Narlikar 1966a) and the inflationary universe of the 1980s have much in common. Ironically, these changes came too late for the survival for the SSC, which received a heavy blow through the discovery of the microwave background. More ironically still, today the extraordinary smoothness of this background is proving an embarassment for the BBC while the SSC is on the verge of finding a physical theory of its origin (Arp et al. 1990).

Although the PCP has certain attractive features like simplicity and predictivity, the C-field approach to creation has practical advantages, for example:

(i) It is readily assimilated in the mainstream of field theory,

(ii) It allows one to discuss creation/annihilation not only in cosmology but also in local environments like white holes/black holes (Narlikar 1974),

(iii) It is amenable to discussions of uniqueness, stability and observable features of its solutions.

And, finally, it offers a reasonable solution to the fundamental problem of origin of matter in the universe.

5. Quantum Cosmology. Grünbaum has extended his argument to quantum cosmology although he does not find that the problem of "creation" is not resolved thereby:

> We are now ready to see that despite the replacement of the classical big bang theory by quantum cosmology, the philosophical issues with which we have been concerned, as well as their resolution, remain essentially the same. (1989, 391)

The approaches to quantum cosmology are many: Grünbaum has referred to Weisskopf (1989) and Hawking (1988). I give briefly the point of view that is based on quantum conformal fluctuations (Narlikar and Padmanabhan 1986). This may be contrasted with the above viewpoint.

The equations of relativity (on which the BBC is based) are derived from (1). The classical action principle is valid provided $|\mathscr{A}| \gg \hbar$ and thus (1) is suspect when $\mathscr{A}$ is comparable to $\hbar$. For the Hilbert action this happens close to $t = 0$ in a spacetime region of characteristic dimensions given by the spacetime curvature. If we continue our trust in the BBC all the way through $t = 0$ we find that $|\mathscr{A}| \leq \hbar$ when t is less than the Planck time

$$t_P = \sqrt{G\hbar/c^5}. \tag{4}$$

If we believe that, as in the rest of physics, quantum considerations take over when $|\mathscr{A}| \leq \hbar$, then our trust in BBC all the way to $t = 0$ is not justified. We need a theory of quantum gravity instead of classical general relativity to extrapolate our model to epochs earlier than t_P.

In conformal fluctuations the metric of spacetime changes by a scale factor that can vary with space and time. Such fluctuations leave unchanged the ratios of infinitesimal-lengths at any point. The angles also remain the same. By using a path-integral formalism the effects of such fluctuations can be computed exactly within the framework of quantum mechanics.

Thus corresponding to a classical big bang solution there exist infinite (uncountably so) conformal transforms of that spacetime. The path amplitude attaches probability to each of them. A subclass of these are singular at $t = 0$ while the rest are nonsingular. *Theory shows that the probability measure of singular solutions is zero.* In other words the probability that the present universe had a singular state at $t = 0$ is zero.

The summary of such attempts is the conclusion that there is nothing sacrosanct about $t = 0$: The singularity is highly unlikely in terms of quantum fluctuations and the history of the universe could very well exist prior to $t = 0$. It may well be that because of the quantum uncertainty over the time section $|t| < t_P$, the state of the universe for $t > t_P$ cannot be uniquely predicted from the knowledge available at $t < -t_P$. Within this framework it is not unlikely that an empty Minkowski universe at $t < -t_P$ goes into a Friedman universe at $t > t_P$. This is the closest one could come to creation "ex nihilo". However, here the appearance of matter and energy is controlled by the uncertainty principle which is respectable physics.

6. Conclusion. To summarize then, it is not a symptom of "confusion" to ask what existed prior to the big bang event at $t = 0$. It is a reflection on the incompleteness of the classical BBC. There exist ways of making a more complete physical theory that justifies and answers this question. Instead, terminating the backward time axis at $t = 0$ may raise conceptual problems that are more intractable than those which this hypothesis is made to solve. An appeal to quantum cosmology makes the status of the epoch $t = 0$ an ordinary one in the sense that the probability of a singular epoch is made vanishingly small. Thus the epoch is not associated with a "miracle"; it is not even a special epoch when we go beyond the classical relativistic cosmology. I can do no better than reproduce what I said in Narlikar (1988) concerning $t = 0$:

> Most physicists would agree that the singular situation at $t = 0$ reflects an incomplete understanding of how gravity operates when matter is in an extremely dense state. General Relativity cannot therefore be relied on to describe the universe at $t = 0$. Opinions differ, however, as to what the 'correct picture might be'. (P. 67)

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