Possible explosion mechanism in a complete cosmological model

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A hypothesis of a very rapid expansion ("explosion") of a finite universe immediately after its quantum-mechanical birth is discussed. An estimate is found for the expansion coefficient. It depends exponentially on the total number of different fields in nature.

When applied to cosmology, the general theory of relativity leads to a singular state of the universe in the past, as we know quite well.[1] In order of magnitude, the quantum-mechanical size fo the singularity is determined by Planck scales, which we adopt as a unit here: $8\pi G/3 = \hbar = c = 1$. We consider a closed model, in which there can be a quantum-mechanical birth of the universe[2,3] (a so-called complete cosmological model).

We introduce the singularities

$$\epsilon = NT^4 = 1/4t^2 ; \qquad a = a_1 \sqrt{t}, \tag{1}$$

where ϵ is the energy density, T is the temperature, $N \gg 1$ is the effective number of

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different fields in nature (along with some numerical factors; this effective number is a large parameter of the problem), and a is the radius of curvature and the size of the space. An extrapolation of modern observational data leads to the exceedingly large value $a_1 \gtrsim 10^{30}$ (instead of the natural value $a_1 \sim 1$).[3,6] This is one of the cosmological puzzles: For some reason, our universe is too large or too flat. Some very different models, of an "inflationary" universe, have been developed in resent years in an effort to explain this feature.[3–6] All of these models contain, in some form or other, a "cosmological constant" ($\epsilon \to C \approx \text{const}$). In the present letter we are proposing yet another model for a rapid expansion of the universe, but this one is based on a different mechanism.

To analyze the various expansion regimes, it is convenient to work from the functional dependence $\epsilon(t)$ in the basic Einstein equation, which can be written in the following form near a singularity [the metric is $ds^2 = dt^2 - a^2(t) dl^2$)]:

$$\dot{a}/a \approx \sqrt{\epsilon}. \tag{2}$$

The classical Friedmann power-law solutions correspond to a very special ("critical") functional dependence $\epsilon(t)$ in (1), for which the expansion occurs most slowly. If $\epsilon(t)$ decreases even more slowly, e.g., in accordance with $\epsilon \sim t^{-q}$, where $q < 2$, the expansion becomes exponential: $\ln a \sim t^{1 - q/2}$. In particular, the familiar inflationary regime corresponds to $q = 0$. Our purpose in the present letter is to call attention to the circumstance that a rapid expansion of the universe is possible even if the decrease in $\epsilon(t)$ is faster than the critical decrease. Let us assume, for example, $q > 2$; we then have $\ln a \sim -A/t^{q/2-1}$. If we furthermore have $A \gg 1$, the expansion will be of the nature of an explosion.

Under what physical conditions might such an explosion have occurred? It seems that it would have been possible in the case of a rapid quantum-mechanical birth (occurring over a time $t_0 \sim 1$) of the universe, which would set an absolute beginning of time ($t = 0$). The basic hypothesis is that under these conditions the effective temperature of all the fields or, more precisely, the average energy per degree of freedom (per oscillator) of the vacuum of these fields is regulated by a fundamental quantum-mechanical law—the uncertainty principle:

$$\tilde{T} = \alpha/t; \qquad \epsilon = N\alpha^4/t^4, \tag{3}$$

where $\alpha \sim 1$ is a numerical factor which must be found from the exact theory. If this hypothesis is valid in even a small time interval, then we have

$$\ln \frac{a(t)}{a_0} = \frac{\alpha^2 \sqrt{N}}{t_0} \left(1 - \frac{t_0}{t}\right), \tag{4}$$

where the initial values $a_0 \sim t_0 \sim 1$ are determined by the conditions of the quantum-mechanical birth of the universe. The circumstance that the expansion coefficient during the explosion (a/a_0) turns out to be very large ($N \gg 1$) is not the only very interesting feature of this regime; in addition, this coefficient has a definite value. We wish to emphasize that the duration of this explosion is very short, on the order of the Planck time.

Although expressions for ϵ of the type in (3) have been discussed previously in several papers,[7,8] the discussion has been restricted to an anisotropic and furthermore inconsistent metric; i.e., the inverse effect of the rapidly decreasing $\epsilon(t)$ on the metric has been ignored. On the other hand, in a consistent de Sitter metric[4,5] the expressions which have been used for ϵ have been the asymptotic expressions found by turning on a perturbation adiabatically. These expressions may not be valid near a quantum-mechanical singularity (the birth of the universe). We note in this connection that there are two distinct physical mechanisms for the appearance of a vacuum energy density in a time-varying metric: an essentially classical excitation of field oscillators by a nonadiabatic perturbation[7,8] and a shift of the average energy of the oscillators due to quantum-mechanical fluctuations (a time-varying Casimir effect). Either of these mechanisms would operate effectively only for oscillators with a frequency $\omega \lesssim \widetilde{T}$; hence we find "thermodynamic" estimate (3). The region of the excited modes; $\kappa = a\omega \lesssim a\widetilde{T} \sim \dot{a}$ (κ are eigenvalues), increases rapidly with the time in explosion regime (4), so the process is definitely a nonequilibrium process. The same comment applies to an exponential inflation. In a Friedmann regime, in contrast, $\dot{a}$ decreases, and the expansion process becomes adiabatic.

Perhaps the most serious difficulty with this hypothesis is that if an explosion does occur, then it would occur immediately after the quantum-mechanical birth of the universe, at which point the use of the classical Einstein equations would be questionable. One can nevertheless hope that such a rapid process as (4) would be relatively insensitive to various corrections and isntabilities, either quantum or classical.

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