Does the Planck unit system relate to a non-singular primordial state of the universe?

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Abstract

Recently, a new model for flat-metric expansion of the universe that eliminates several problems arising in the expansion theory of standard cosmology was presented. In the original version of this dark source flux (DSF) model, Big Bang is manifested by a mathematical singularity with infinite initial matter density and infinite initial expansion rate. However, an integration constant (a time shift) with extremely small value was for simplicity set equal to zero in this theory. A closer analysis reveals that if this constant is assigned a very small nonzero value, Big Bang will not have started from a mathematical singularity, but from a primordial state of extremely high, *yet limited* density and expansion rate. This primordial state constitutes a non-singular Planck epoch of extremely short duration. It turns out that all primordial state parameters assume values of the order of Planck units. Thus, *the Planck unit system may have found an attractive physical significance: it relates to the primordial Planck state of the universe where the three fundamental theories of physics merge.*

There is a well known, puzzling ratio (of the order 10^{120}) between ground state ('vacuum') density values based on quantum field theory on one hand, and experimental values derived from ΛCDM (or DSF) on the other. This discrepancy has been called the worst theoretical prediction in the history of science. The present article offers a possible explanation to this issue.

Keywords: Planck units, Planck epoch, primordial state, dark source flux, dark energy, Big Bang, expansion of the universe

1. Background

In a previous article by Schweitz [1] it is demonstrated that in the *flat-metric, uniform universe approximation*, a new set of initial assumptions – consistent with earlier and recent observations – results in a simple, rigorous expansion theory, free-standing from General Relativity, readily and consistently explaining the observed expansion features of the universe, both qualitatively *and* quantitatively. The commonly accepted idea that dark energy is a physical manifestation of space is adopted. The basic hypothesis is that the universe is inflated by a uniformly distributed source flux of dark energy – a dark source flux (DSF) – generating the observed volume expansion. This source flux makes possible a concise mathematical formulation of the metric expansion in terms of one single variable (cosmic time t) and two measurable universal constants (H_g and ρ_g as defined below).

The expansion is described in terms of the following parameters: the Hubble parameter $H(t)$ expressing the rate of expansion (s^{-1}); the total mass density $\rho(t)$ (kg m^{-3}); the source flux $s(t)$ expressing the infusion of dark energy mass per units of volume and time (kg m^{-3}s^{-1}); and the scale factor $a(t)$ (dimensionless). These expansion parameters are hyperbolic functions in the DSF model:

$$H(t) = H_\mathrm{g} \coth(3H_\mathrm{g}t/2), \quad (1)$$

$$\rho(t) = \rho_\mathrm{g} \coth^2(3H_\mathrm{g}t/2), \quad (2)$$

$$s(t) = 3H_\mathrm{g}\rho_\mathrm{g} \coth(3H_\mathrm{g}t/2), \quad (3)$$

$$a(t) = \sinh^{2/3}(3H_\mathrm{g}t/2). \quad (4)$$

The three first parameters display Big Bang singularities at $t = 0$ and their ultimate values are: $H(\infty) = H_\mathrm{g}$, $\rho(\infty) = \rho_\mathrm{g}$ and $s(\infty) = s_\mathrm{g} = 3H_\mathrm{g}\rho_\mathrm{g}$, respectively. The scale factor function $a(t)$ increases from zero at $t = 0$ to infinity at $t = \infty$, and an arbitrary normalization constant is for simplicity set to unity in Eq. (4) (usually it is chosen so as to make $a(t_0)$ equal unity at our present cosmic time t_0). The ultimate density ρ_g is the dark energy density, which is constant over time and included in the total density $\rho(t)$. The expansion constants are evaluated from a measured Hubble constant and an estimated age of the universe (subscript 0 indicates present-day values; subscript g indicates ultimate values):

Input: $H_0 = 2.40 \pm 0.12\ 10^{-18}$ s^{-1} [2]
$t_0 = 14.46 \pm 0.80$ Gyr [3]
Output: $H_\mathrm{g} = 2.16 \pm 0.11\ 10^{-18}$ s^{-1} ($H_\mathrm{g} = 0.90\ H_0$)
$\rho_0 = 1.03 \pm 0.11\ 10^{-26}$ kg m^{-3}
$\rho_\mathrm{g} = 0.84 \pm 0.10\ 10^{-26}$ kg m^{-3} ($\rho_\mathrm{g} = 0.81\ \rho_0$)
$s_0 = 6.02 \pm 0.81\ 10^{-44}$ kg m^{-3} s^{-1}
$s_\mathrm{g} = 5.42 \pm 0.73\ 10^{-44}$ kg m^{-3} s^{-1} ($s_\mathrm{g} = 0.90\ s_0$)

The four expansion functions given by Eqs (1) – (4) are plotted in Figs 1 - 4, using the ground state values H_g and ρ_g listed above. Note that we are today ($t_0 \approx 14$ Gyr) close to the ultimate ground state.

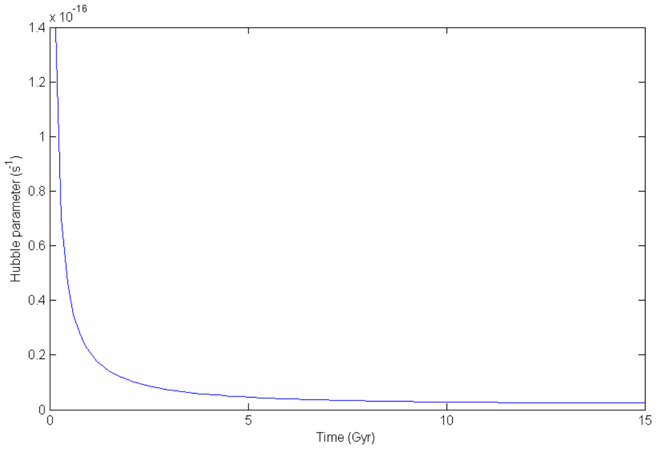

Fig. 1. Hubble parameter H (10^{-16} s^{-1}) versus cosmic time t (Gyr).

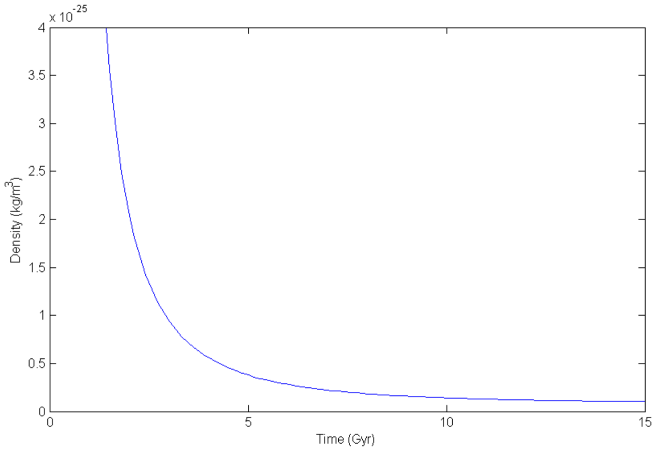

Fig. 2. Total density ρ (10^{-25} kg m^{-3}) versus cosmic time t (Gyr).

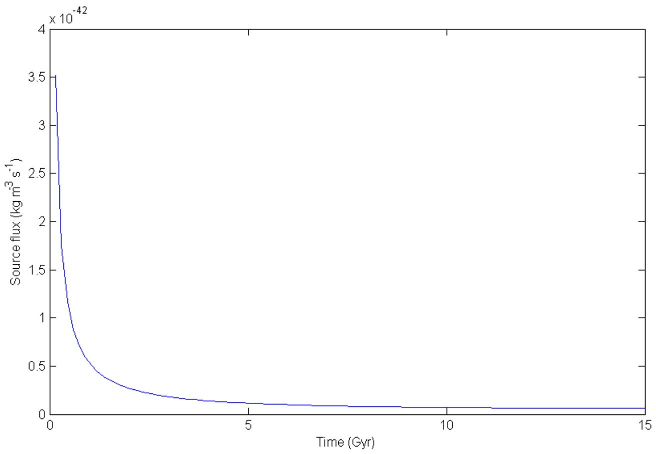

Fig. 3. Dark source flux s (10^{-42} kg m^{-3}s^{-1}) versus cosmic time t (Gyr)

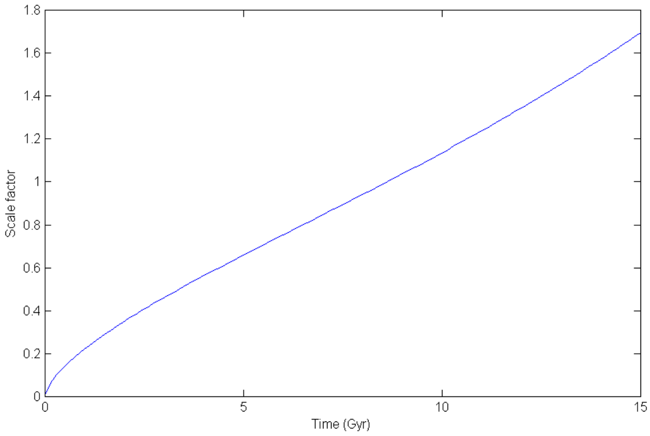

Fig. 4. Scale factor a versus cosmic time t (Gyr).

2. Primordial singularity (unlimited Big Bang)

Expand the expressions (1) – (4) in Maclaurin series about $t = 0$. Let τ be a non-zero t value small enough to make all terms of the Maclaurin series, except the first one, negligible. Then the *primordial singularity* is defined by the expansion functions below:

$$H(\tau) = \frac{2}{3\tau} \tag{5}$$

$$\rho(\tau) = \frac{1}{6\pi G\tau^2} \tag{6}$$

$$s(\tau) = \frac{2\rho_{\mathrm{g}}}{\tau} \tag{7}$$

$$a(\tau) = \left(3H_{\mathrm{g}}\tau / 2\right)^{2/3}. \tag{8}$$

3. Time shifted DSF theory (limited Big Bang)

The expansion functions (1) – (4) actually should include an integration constant, which for simplicity has been disregarded in Ref. $[1]$. It is easily shown that this integration constant can be expressed in terms of a shift in time Δt, i.e. the time parameter t in Eqs (1) – (4) should be replaced by $t + \Delta t$. A positive integration constant Δt corresponds to a shift Δt to the left along the time axes in Figs 1 - 4, meaning that all graphs will intersect the vertical axes at *limited, non-zero values*. For a very small value of Δt, the H, ρ and s graphs will intersect the vertical axes at very high yet limited primordial cut-off values: H_{p}, ρ_{p} and s_{p}, respectively. The a graph will intersect the vertical axis at a very small yet non-zero value a_{p}. It is also clear from the diagrams that the time shift Δt does not affect the ultimate levels of H_{g}, ρ_{g} and s_{g}, and that $H(t)$, $\rho(t)$ and $s(t)$ values are negligibly affected for $t \gg \Delta t$.

Hence this time shift transforms the mathematical singularity at $t = 0$ into a finite-density, initial state of a huge and spatially indeterminate universe. (*Note*: To a *local* observer whose range of vision is limited by the expanding Hubble horizon it would seem as if everything started from a small, initial kernel of non-zero spatial radius, reminding of Lemaître's 'primeval atom'.)

Assuming an extremely small Δt value we have $\tau = \Delta t$ and Eqs (5) – (8) yield:

$$H_{\mathrm{p}} = 2/(3\Delta t)\,. \qquad (9)$$

$$\rho_{\mathrm{p}} = 1/(6\pi G \Delta t^2) \qquad (10)$$

$$s_{\mathrm{p}} = 2\rho_{\mathrm{g}} / \Delta t \qquad (11)$$

$$a_{\mathrm{p}} = (3H_{\mathrm{g}}\Delta t / 2)^{2/3} \qquad (12)$$

In this primordial limit of the DSF model, s_{p} is the active agent while H_{p}, ρ_{p}, and a_{p} are reactive. It is seen that s_{p} is directly proportional to ρ_{g}. This means that the level of the ground state dark energy density ρ_{g} actually is determined by the primordial source flux (Eq. (11)):

$$\rho_{\mathrm{g}} = s_{\mathrm{p}}\Delta t / 2\,. \qquad (13)$$

The primordial dark source flux s_{p} determines ρ_{g} via Eq. (13), which in turn determines H_{g} via the dynamic balance criterion: $\rho_{\mathrm{g}} = 3H_{\mathrm{g}}^2/(8\pi G)$ (see Ref. [1]) and thus determines $H(t)$, $\rho(t)$, $s(t)$, and $a(t)$ via Eqs (1) – (4).

Thus, in the time-shifted DSF model, the creation and evolution processes are completely determined by the primordial dark source flux s_{p}.

4. Non-singular primordial Planck state

The Planck unit system is based on dimensional considerations linking together the fundamental constants of Nature of the three great basic theories of physics: classical Newtonian theory (G); theory of relativity (c); and quantum theory ($\hbar$). Although elegant in theory, the Planck unit system hitherto lacks commonly accepted physical significance.

Let the circumflex symbol above a letter ($\hat{x}$) denote a Planck unit. Assuming that Δt relates to the primordial Planck epoch, and that the primordial values defined by Eqs (9) – (12) are Planck epoch values, a natural conjecture is that Δt is of the order of one Planck time unit: $\Delta t = \hat{t} = (\hbar G / c^5)^{1/2}$ = 5.39 10^{-44} sec.

We can now express H_{p} and ρ_{p} in terms of Planck units. From Eqs (9) and (10) we obtain:

$$H_{\mathrm{p}} = \frac{2}{3\Delta t} = \frac{2}{3}\left(\frac{c^5}{\hbar G}\right)^{1/2} = \frac{2}{3\hat{t}} = 1.24\ 10^{43}\ \mathrm{s}^{-1}. \qquad (14)$$

$$\rho_{\mathrm{p}} = \frac{1}{6\pi}\left(\frac{c^5}{\hbar G^2}\right) = \frac{1}{6\pi}\hat{\rho} = 0.274\ 10^{96}\ \mathrm{kg\ m}^{-3}. \qquad (15)$$

On a global scale, the size of the universe is indeterminate even in the primordial Planck epoch. However, using Hubble's law it is possible to associate a *primordial Hubble sphere radius* r_p with the Planck scale parameters discussed above:

$$r_\mathrm{p} = c / H_\mathrm{p} = \frac{3}{2}\left(\frac{\hbar G}{c^3}\right)^{1/2} = \frac{3}{2}\hat{r} = 2.43\ 10^{-35}\ \text{m}. \tag{16}$$

It is important to realize that $r_\mathrm{p} = 3\hat{r}/2$ neither is the radius of the entire primordial universe, nor is the Hubble sphere thus defined a co-expanding volume (the Hubble radius is not co-expanding with the metric). From the primordial Hubble volume $V_\mathrm{p} = 4\pi r_\mathrm{p}^3/3$ and the density ρ_p the mass content of the primordial Hubble sphere can be calculated:

$$M_\mathrm{p} = V_\mathrm{p}\rho_\mathrm{p} = \frac{3}{4}\left(\frac{\hbar c}{G}\right)^{1/2} = \frac{3}{4}\hat{M} = 1.64\ 10^{-8}\,\text{kg} \tag{17}$$

The small mass M_p contained in the primordial Hubble sphere is a vanishingly small fraction of the total mass of the entire primordial universe, which is indeterminate but enormous.

If our conjecture is correct, the Planck unit system may have found an attractive physical significance: it relates to the primordial Planck state of the universe where the three fundamental theories of physics merge.

In summary, the primordial Planck state parameters, based on the time-shifted DSF theory *and* the conjecture $\Delta t = \hat{t}$, are:

H_p = 1.24 10^{43} s^{-1} $= 2/(3\hat{t})$
ρ_p = 0.274 10^{96} kg m^{-3} $= \hat{\rho}/(6\pi)$
r_p = 2.43 10^{-35} m $= 3\hat{r}/2$
$M_\mathrm{p} = 1.65\ 10^{-8}\,\text{kg} = 3\hat{M}/4$
s_p = 3.12 10^{17} kg m^{-3} s^{-1}
a_p = 0.312 10^{-40}
κ = 7.79 10^5 m

where κ is the conversion factor between length and (our choice of) scale factor ($r = \kappa a$).

5. "Worst theoretical prediction in history" explained?

One observation of interest concerns Heisenberg's uncertainty relation. The lower limit of this relation (the 'Kennard bound') usually is expressed: $\Delta E \Delta t = \hbar/2$. It is well known that the Planck units for energy and time satisfy: $\hat{E}\hat{t} = \hbar$, which is twice the lower Heisenberg limit. Our primordial values $E_\mathrm{p} = M_\mathrm{p}c^2 = 3\hat{M}c^2/4$ and $\Delta t = \hat{t}$ satisfy: $E_\mathrm{p}\Delta t = 3\hbar/4$, i.e. 1.5 times the lower limit. The close vicinity to the Heisenberg limit suggests that the primordial universe actually was in a *quantum ground state*, whereas the universe with increasing age turns into non-quantized ground states rising high above the lower Heisenberg limit.

This would explain the well known, puzzling ratio of the order 10^{120} between Λ values (or, equivalently, dark energy density values) based on quantum field theory on one hand, and experimental values derived from ΛCDM (or DSF) on the other. The ratio ρ_p / ρ_g derived in this article is very close to the order 10^{120}, suggesting that the extremely high Λ value derived from quantum field theory may relate to a *primordial quantum ground state* density ρ_p (as indicated by the Heisenberg limit), whereas the ultimate state density ρ_g, on the other hand, does not relate to any quantum state at all; it is a *non-quantized ground state* density.

Thus, the discrepancy 10^{120}*, which has been called the worst theoretical prediction in the history of science, may have found an explanation here.*

6. Conclusions

If an integration constant appearing in the DSF theory is assumed to equal a time shift of one Planck time unit, the Big Bang singularity turns into a non-singular primordial Planck state with primordial state parameters of the order of corresponding Planck units. This lends an attractive physical significance to the Planck unit system, which hitherto has been lacking.

The primordial state parameters for energy and time very nearly satisfy the lower limit of Heisenberg's uncertainty relation (the Kennard bound), suggesting that the primordial state was a quantum ground state. This would explain the well known and puzzling factor of 10^{120} between quantum theoretical and experimental dark energy density values.

These findings support the validity of the DSF model.

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