Cosmic Temperature Decline in the Course of the Evolution of the Universe

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Abstract

At the early stage of the Universe-evolution there were no stars and no galaxies, but only a uniform hot plasma consisting of free electrons and free nuclei. The Universe temperature was determined by the Stefan-Boltzmann law of thermodynamics and the general relativistic cosmological theory. At the present time one has the background cosmic radiation with the temperature of 2.73K. We calculate how much of the early Universe energy has gone to matter and other forms of energy, so as to leave us with a background radiation of only 2.73K.
I. INTRODUCTION

At the early stage of the Universe-evolution there were no stars and no galaxies, but only a uniform hot plasma consisting of free electrons and free nuclei. At very early times, the violent thermal collisions would have prevented the existence of any kind of nucleus, and the matter in the Universe must have been in the form of free electrons, protons and neutrons. The temperature of the Universe is related to its evolution and, at the early stage, is given by a well-known formula which shows that $T \propto t^{-1/2}$. The question raised here is how to relate this temperature at the very early stage of the Universe to the present time cosmic background temperature 2.73K. Obviously part of the energy that the Universe had at the early stage has gone to the matter, and the background radiation temperature represents the other part. In the following it is shown that the ratio of energy that goes to matter to that of the background radiation is about 13. In other words, if the Universe today would have no matter, the background cosmic temperature would be about 35K ($13 \times 2.73\text{K}$).

II. TEMPERATURE FORMULA IN THE ABSENCE OF GRAVITY

Our starting point is the familiar thermodynamical formula that relates the temperature to the cosmic time with respect to the Big Bang [1,2]:

$$T = \left( \frac{45h^3}{32\pi^3k^4G} \right)^{1/4} t^{-1/2}. \quad (1)$$

In this equation $k$ is Boltzmann’s constant and $G$ is Newton’s gravitational constant. Our aim is to transform this temperature to the present time. This can be done by using the cosmological transformation [3]

$$T = \frac{T_0}{\left(1 - \tilde{t}^2/\tau^2\right)^{1/2}}, \quad (2)$$

where $T_0$ is the present time background temperature, $T_0 = 2.73\text{K}$, $\tilde{t}$ is the cosmic time measured with respect to us now, and $\tau$ is the Hubble time in the absence of gravity,
\( \tau = 12.486 \text{Gyr} \) [4,5]. Since we are looking for temperatures \( T \) at very early times, we can use the approximation \( \tilde{t} \approx \tau \), thus

\[
1 - \frac{\tilde{t}^2}{\tau^2} = \left(1 + \frac{\tilde{t}}{\tau}\right) \left(1 - \frac{\tilde{t}}{\tau}\right) \approx 2 \left(1 - \frac{\tilde{t}}{\tau}\right) = \frac{2}{\tau} \left(\tau - \tilde{t}\right) = \frac{2t}{\tau},
\]

where \( t \) is the cosmic time with respect to the Big Bang. Using this result in Eq. (2) we obtain

\[
T = T_0 \left(\frac{\tau}{2}\right)^{1/2} t^{-1/2},
\]

with the same dependence on time as in Eq. (1).

### III. COMPARISON

As is seen, both equations (1) and (4) show that the temperature \( T \) depends on \( t^{-1/2} \). The coefficients appearing before the \( t^{-1/2} \), however, are not identical. A simple calculation shows

\[
\left(\frac{45\bar{h}^3}{32\pi^3 k^4 G}\right)^{1/4} = 1.52 \times 10^{10} \text{K s}^{1/2}
\]

for the coefficient appearing in Eq. (1), and

\[
T_0 \left(\frac{\tau}{2}\right)^{1/2} = 1.16 \times 10^9 \text{K s}^{1/2},
\]

for that appearing in Eq. (4). In the above equations we have used

\[
\bar{h} = 1.05 \times 10^{-34} \text{Js},
\]

\[
k = 1.38 \times 10^{-23} \text{J/K},
\]

\[
G = 6.67 \times 10^{-11} \text{m}^3/\text{s}^2 \text{Kg},
\]

\[
T_0 = 2.73 \text{K},
\]

\[
\tau = 12.486 \text{Gyr}.
\]

Accordingly we can write for the temperatures in both cases

\[
T \approx 1.5 \times 10^{10} \text{K s}^{1/2} t^{-1/2},
\]
and

\[ T \approx 1.2 \times 10^9 K s^{1/2} t^{-1/2}. \]  \hspace{1cm} (9)

The ratio between them is approximately 13.

**IV. CONCLUSION**

It thus appears that the dominant part of the plasma energy of the early Universe has gone to the creation of matter appearing now in the Universe, and only a small fraction of it was left for the background cosmic radiation.
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