Problems Class V

Dr. James Mullaney

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Equations and constants

The Friedmann Equation:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3c^2}\varepsilon - \frac{\kappa c^2}{R_0^2}\frac{1}{a^2}$$

The Fluid Equation:

$$\dot{\varepsilon} + 3\frac{\dot{a}}{a}(\varepsilon + P) = 0$$

Cosmological parameter values in The Benchmark Model:

$$\Omega_{M,0} = 0.31, \ \Omega_{D,0} = 0.69, \ \Omega_{R,0} = 9 \times 10^{-5}, \ H_0 = 67.7 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

Parsec in SI units: $1 \text{ pc} = 3.09 \times 10^{16} \text{ m}$

1. At what redshift did the Universe transition from being radiation-dominated to being matter dominated?

2. What was the temperature of the Universe when the above transition occured?

3. In the Benchmark Model, the above transition occured when the Universe was 50,000 years old. Assuming that the Universe was strongly radiation-dominated at even higher redshifts, calculate the temperature of the Universe 5 minutes after the Big Bang.

4. Assuming (incorrectly) that protons and neutrons remain in equilibrium throughout, calculate the ratio of protons to neutrons when the Universe was 5 minutes old.

5. What was the horizon distance when the Universe was 5 minutes old?