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## Homework - 2

1. Assume our universe would be only filled with radiation with equation of state  $w = \frac{1}{3}$ . What would its age be? What about a universe that is dominated by curvature with  $K = -1$ ?

Let us derive the Friedmann equations from classical mechanics and thermodynamics:

2. For a test particle of mass  $m$  at a radius  $a(t)$  from the origin, Newton's second law yields

$$F = m\ddot{a}(t) = -\frac{GMm}{a(t)^2}. \quad (1)$$

Here  $M$  is the total mass of all matter contained inside the sphere of radius  $a(t)$ . Multiply both side by  $\dot{a}(t)$  and integrate. Calculate  $M$ , assuming a uniform mass distribution  $\rho$  inside the sphere. Choose the constant of integration such that you find the first Friedmann equation

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 + \frac{K}{a(t)^2} = \frac{8\pi G}{3}\rho. \quad (2)$$

3. Derive the continuity equation from the first law of thermodynamics

$$dE = -pdV + TdS. \quad (3)$$

If the particle interactions in a fluid are small, then we may neglect the heat transfer and set  $TdS = 0$ . Look at a volume  $V = a(t)^3$  and derive the continuity equation.

4. Use your results from 2. and 3. to derive the second Friedmann equation

$$\frac{\ddot{a}(t)}{a(t)} = -\frac{4\pi G}{3}(\rho(t) + 3p(t)). \quad (4)$$