

Birla Institute of Technology and Science, Pilani-Hyderabad Campus
28th Jan (Tuesday), 2020
Qualifying Examination
(Open Book)

Course Title: COSMOLOGY
9.30AM -12.30PM

Total Marks: 75
Time: 3 hour

Instructions

- (i) Answer all questions. Marks for each question are given at the end of the question.
- (ii) Start a new question in a new page and answer all its parts in the same place.
- (iii) Write all the steps clearly and give explanations for the complete credit.

1. The Friedman equation is

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8}{3}\pi G\rho(t) - \frac{kc^2}{a^2R^2} + \frac{\Lambda}{3}$$

Here, the density $\rho(t)$ is the sum of the density of radiation, $\rho_r = \epsilon_r/c^2$ and the density of matter, ρ_m .

- (a) Express this in terms of ρ_{r0} and ρ_{m0} , the present day densities of radiation and matter. [6]
 - (b) Express it in terms of Ω_r , Ω_m and $\Omega_\Lambda = \Lambda/3H^2$, the density parameters at time t . [6]
 - (c) Express it in terms of present-day values Ω_{r0} , Ω_{m0} and $\Omega_{\Lambda0}$. [6]
2. Solve the Friedman equation for the case where the only contribution to the energy density of the universe comes from something which has equation of state $p = w\rho$ where w is a constant whose value is greater than -1. Use the boundary condition that $a = 0$ at $t = 0$. [10]

Find the relationship between the age of the universe t_0 and the current Hubble constant H_0 in this model. [5]

3. In a universe which contains matter and is positively curved (i.e. $\Omega_{m0} > 1, k > 0, \Omega_{r0} = 0, \Lambda = 0$) the Friedman equation can be written

$$\dot{a}^2 = H_0^2 \left(\frac{\Omega_0}{a} - (\Omega_0 - 1) \right)$$

where for convenience we have dropped the 'm' from the suffix since there is no other contribution to Ω .

- (a) Find an expression for the maximum possible value of a in this universe. Calculate a_{max} for the case $\Omega_0 = 1.1$. What is the maximum possible value of Ω_0 for which $a_{max} > 1$ (i.e. 'the universe has not already collapsed')? [5]
- (b) Show by differentiation that the parametric equations

$$a(\theta) = \frac{\Omega_0}{2(\Omega_0 - 1)}(1 - \cos\theta)$$

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