Early Universe
Review questions

1. What does it mean that Hubble's law is a linear relation? What is the significance of this linearity?

2. What is the Hubble time t_H? Under what condition is it equal to the age of the universe t_0? In a universe full of matter and energy, what would be the expected relative magnitude of these two quantities ($t_H > t_0$ or $t_H < t_0$)? What is the lower bound for t_0 deduced from the observation data on globular clusters?

3. What are "galaxy rotation curves?" What feature would we expect if the luminous matter were a good representation of the total mass distribution? What observational feature of the rotation curve told us that there were significant amounts of nonluminous matter associated with galaxies and clusters of galaxies?

4. What is baryonic matter? The bulk of baryonic matter resides in the intergalactic medium (IGM) and does not shine. Why don't we count it a part of dark matter?

5. What is luminosity distance? How is it related to the proper distance?

6. Describe the relation of the Friedmann equation and the Einstein equation, as well as give its Newtonian interpretation. Why can we use nonrelativistic Newtonian theory to interpret the general relativistic equation in cosmology? Also, in what sense is it only quasi-Newtonian?

7. In what sense can the critical density be understood as akin to the more familiar concept of escape velocity?

8. Why do we expect the energy density of radiation to scale as a^{-4}. Why should the energy of the universe be radiation-dominated in its earliest moments?

9. What is the equation of state parameter w for radiation? For nonrelativistic matter? If we know that the universe has a flat geometry, what is the time dependence of the scale factor $a(t)$ in a radiation-dominated universe (RDU)? In a matter-dominated universe (MDU)? How is the age of the universe t_0 related to the Hubble time t_H in a RDU, and in a MDU? Justify the approximation that the age of our universe is two-thirds of the Hubble time.

10. Give an argument for the scaling behavior of the radiation temperature: $t \sim a^{-1}$. Show that under such a scaling law, the spectrum distribution of the blackbody radiation is unchanged as the universe expands.

11. What is the condition (called the decoupling or Gamow condition) for any particular set of interacting particles being in thermal equilibrium during the various epochs of the expanding universe?

12. Estimate the effective number of degrees of freedom g_* in the Standard Model in the early Universe when the temperature was 50 GeV.