PROBLEM SET #5 Due Date: Thursday April 23,2014

160 total points

1. FMC Q12.3 [20 pts]

2. Muons have a mass of $M=1.9\times10^{-28}$ kg. Using the relation between energy and temperature, calculate the threshold temperature for creation of muons in the early universe. [15 pts]

3. Nucleosynthesis [25 pts]

In recent years, a tremendous amount of effort has gone into measuring the abundance of Deuterium (D) in the Universe

a Why is this? Take a look at the abundance-density diagram from the "Where did the elements come from?" class notes and consider the effects of measurement uncertainty on any conclusions regarding the inferred baryon density. [5 pts]

b. Describe the way in which elements were (or are) created in the early universe. [10pts]

c What are the 2 most abundant elements? Explain why. [10pts]

4. The Cosmic history line [30 pts.]

Summarize in a 2-3 paragraphs the evidence that leads us to think that we live in a Universe where most of the matter is non baryonic. What fraction of the baryonic matter is in stars? What are the critical observations that drive us to these conclusions ?

5. Friedmann equation [20 pts.]

A. Recall that the expression for the critical density is $\Omega_{crit}=3H^2/(8\pi G)$. Calculate the present value of the critical density in kg. (Hint: the trick is to express H in MKS units). How does the critical density compare to the density of water or air ? [10 pts]

B. Using the definition of the Hubble parameter $H=(1/R)$ (dR/dt) (Hint: use FMC eq 11.11 and 11.20).derive the value of the critical density when the Universe was half its present age. If you have not had calculus please state so , try to give an answer which sounds reasonable . [10 pts]

6 A Hot Big Bang [20 pts.]

Today, there is much more energy density in matter than in radiation, but in the early stages of the Universe the situation was reversed.

A. Can you explain why we think radiation was dominant in the early universe? (Hint: recall how the radiation and matter densities change with redshift z) [10 pts] (see FMC fig 12.3 and pg 348)

B. The radiation density today is dominated by the Cosmic Microwave Background, which has about $411\text{x}10^6$ photons per m^3. The energy of one of these photons is $E=hc/\lambda$, where h is the Planck constant ($h=6.63\times10^{-34}$ m^2 kg s^{-1}), c is the speed of light ($c=3\times10^8$ m s^{-1}), and λ is the wavelength of light, in meters. The typical wavelength of a CMB photon is $1.1\ \text{x}10^{-3}$ m. How much energy does the CMB have in 1 cubic meter of space? (Hint: make sure all the units are compatible before plugging in numbers) [10 pts]

7 Cosmological Constant [20 pts.]

Summarize what the Cosmological Constant Λ is and its effect on the evolution of the universe,. Do you think Einstein was right in introducing the idea?

8. Age of the Universe[25 pts]

(a) Describe the evolution of the "radius" of the universe in the three kinds of Standard Models (i.e k = 0, -1, 1).[10 pts]

(b) The Hubble parameter today is H_0 = 72 km/s/Mpc. Calculate the Hubble time $t_H = 1/H_0$ in Gyr (billion years). [5 pts]

(c) Using diagrams as needed, discuss how the present age of the Universe t_0 relates the Hubble time, $t_H = 1/H_0$, in the three kinds of Standard Models (i.e k = 0, -1, 1) of the evolution of the Universe. [10 pts