Homework 8

Due **March 25 at 10:45am via Canvas**

Please show all work, writing solutions/explanations clearly, or no credit will be given. You are encouraged to work together, but everyone must turn in independent solutions: do not copy from others or from any other sources.

1. A fascinating bit of cosmological history is that of Gamow's prediction of the Cosmic Microwave Background (CMB) in 1948. (Unfortunately, his prediction was premature; by the time the CMB was actually discovered in the 1960s, his prediction had fallen into obscurity.) Let's see if we can reproduce Gamow's line of argument. Gamow knew that nucleosynthesis must have taken place at a temperature $T_{\rm nuc} \approx 10^9$ K, and that the age of the universe is currently $t_0 \approx 10$ Gyr. Let us further assume that the universe is flat and contains only radiation.

   (a) What was the energy density ε at the time of nucleosynthesis?

   (b) What was the Hubble parameter at the time of nucleosynthesis?

   (c) What was the time $t_{\rm nuc}$ at which nucleosynthesis took place?

   (d) What is the current temperature T_0 of the radiation filling the universe?

   (e) If the universe switched from being radiation-dominated to being matter-dominated at a redshift $z_{\rm rm} > 0$, will this increase or decrease T_0 for fixed values of $T_{\rm nuc}$ and t_0? Explain your answer.

2. Suppose the difference in rest energy of the neutron and proton were $Q_n = (m_n - m_p)c^2 = 0.129$ MeV instead of $Q_n = 1.29$ MeV, with all other physical parameters unchanged. Estimate $Y_{\rm max}$, the maximum possible mass fraction in ^{4}He, assuming that all available neutrons are incorporated into ^{4}He nuclei.

3. The total luminosity of our galaxy is $L \approx 4 \times 10^{10}$ $L_\odot$. Suppose that luminosity has been constant for the past 11 Gyr. How much energy has our galaxy emitted in the form of starlight during that time? Most stars are powered by the fusion of H into ^{4}He, with the release of 28.4 MeV for every He nucleus formed. How many He nuclei have been created within stars in our galaxy over the past 11 Gyr, assuming that H$\rightarrow^4$He fusion is the only significant energy source? If the total mass-to-light ratio of our galaxy is 100 $M_\odot/L_\odot$ and the baryon-to-dark matter ratio is consistent with that of the universe as a whole, by what amount has the helium fraction Y of our galaxy been increased over its primordial value $Y_p = 0.24$?

4. **Presentation Prep**: Settle on a paper(s) for your presentation and *get it approved* by me (verbally or via email). This is mostly for your benefit, so you know your presentation is based on appropriate source material.