

## Ay 127 – Spring 2009 – Homework #4

Distributed on May 15, due by 5 pm on May 22 (Return to the TA directly)

*The honor system applies as follows:* You can discuss the problems among yourselves, how to go about them, but not derive the solutions jointly – everyone should work out their own solutions.

### 1. Cosmic IR Background [36 points, 12 each]

The observed energy density of the cosmic far-infrared background (CIRB) is  $u_{\text{CIRB}} \approx 7 \times 10^{-15}$  erg  $\text{cm}^{-3}$ . Assume that the background is generated by a population of obscured starbursts with a mean luminosity  $\langle L \rangle \approx 10^{12} L_{\odot}$ , with all energy emerging in the mid/far IR, with a mean redshift  $\langle z \rangle \approx 3$ , each lasting on average  $\Delta t \approx 3 \times 10^7$  yr.

- How many such starbursts should there be in the entire observable universe, in order to account for the CIRB?
- Estimate the comoving number density of their progeny at  $z \sim 0$ , and compare it with the estimated comoving number density of normal galaxies today. (Hint: estimate the total comoving volume of the observable universe first; an order-of-magnitude estimate is OK.)
- Assuming the yield of nuclear reactions of 7 MeV/nucleon, how much helium was generated by these starbursts? How much metals, assuming the ratio of helium to metals production by mass  $\Delta Y/\Delta Z = 5$ ? If each of these starbursts was in a galaxy with a baryonic mass  $M \approx 10^{11} M_{\odot}$ , what is the mean metallicity of the resulting stars?

### 2. All Galaxies in the Universe [36 points, 12 each]

- From deep galaxy counts, it is estimated that there are  $\sim 40$  billion galaxies within the observable universe (not including probable multitudes of dwarf galaxies). Assuming that the mean age of these galaxies is  $\sim 10$  Gyr, and that each one goes through an AGN episode once, with a mean duration of  $\sim 10^8$  yr, estimate the projected surface density of quasars on the sky (in  $\text{deg}^{-2}$ ).
- If the volume number density of quasars at  $z \sim 0$  is  $\sim 100 \text{ Gpc}^{-3}$ , and the normalization of the galaxy luminosity function is  $\varphi_* \sim 0.01 \text{ Mpc}^{-3}$ , what is the probability of a galaxy containing a quasar at  $z \sim 0$ ? Their comoving density was  $\sim 1000$  times higher at  $z \sim 2$ , the peak of the quasar era. Compare these numbers with the average probability evaluated in (a).
- Using the same assumptions about the galaxy luminosity function, and assuming the look-back time to the onset of galaxy formation of  $\sim 10$  Gyr, estimate the number of  $L \sim L_*$  (i.e., non-dwarf) galaxies in the entire observable universe. State your assumptions. Compare this with the total observed number of galaxies over the entire sky. Discuss the differences, if there are any.

### 3. Galaxy Counts [24 points, 3 each]

Sketch and explain the effect on galaxy counts as a function of magnitude, of:

- The expansion of the universe (including the k-corrections)
- Cosmological parameters
- Galaxy luminosity evolution
- Galaxy merging (i.e., density evolution)
- What is the logarithmic at the bright end and why?
- How can the effects of luminosity evolution and merging be separated?

Everyone gets 4 bonus points!