Ph 444 Problem Set 7

Due: Friday, November 19, 2010

1. Ryden problem 9.3 (Imagine that at the time of recombination, the baryonic portion of the universe consisted entirely of ^{4}He...) A slightly tricky point here is what to use for n_{baryon} when calculating $\eta = n_{baryon}/n_\gamma$. To keep η numerically equal to that for the case with pure hydrogen, use $n_{baryon} = 4(n_{He} + n_{He^+})$.

2. Ryden problem 9.5 (We know from observations that the intergalactic medium is currently ionized...)

3. The program CMBFAST was developed by U. Zeljak and M. Zaldarriaga to predict the anisotropies of the CMB given the properties of the inhomogeneities of the universe at the surface of last scattering and the other parameters that describe the universe. It is the program used by most professionals for this purpose. It integrates over the sources of radiation along each line of sight, taking into account the geometry and expansion of the universe. The output is the power-spectrum of intensity fluctuations in the CMB (the C_l's) as a function of the multipole order l. Also predicted is the polarization of the CMB, though we will not consider polarization in this assignment.

A web interface to run CMBFAST is available at
http://lambda.gsfc.nasa.gov/toolbox/tb_cmbfast_form.cfm
and this page is linked to the class home page. The interface allows you to set the parameters of the universe and run CMBFAST. It outputs plots and tables of the predicted power spectrum. The spectrum for the intensity fluctuations is C_l^{TT}. For this exercise, use Output Request = CMB Only, Sky Map Output = None, L Max = 1500, K eta max = 3000, Include 5th dimension = No, Peebles recombination, Scalar/Tensor = Scalar alone, and Initial Conditions = Isentropic (adiabatic).

Run CMBFAST with the parameter settings: $\Omega_b = 0.0456$, $\Omega_{cdm} = 0.228$, $\Omega_\Lambda = 0.726$, $\Omega_{hdm} = 0.0$, $H_0 = 70$, $T_{cmb} = 2.725$, $Y_{He} = 0.24$ (helium mass fraction), N_ν (massless) = 3.04 (number of massless neutrino types), N_ν (massive) = 0.0 (number of massive neutrino types), $g^*_{massive} = 0$, Optical Depth to lss = 0.084 (optical depth to the surface of last scattering due to reionization), # of Spectral Indices = 1, and Spectral Indices = 0.99 (this specifies the power-law index for the spectrum of density fluctuations in the early universe). Save the output file of Scalar C_l's on your computer (save the file using a name that will let you determine which model this is as you will be saving other files for other models). Plot the C_l's versus l and describe the spectrum. The l's are in the first column of the saved file and the C_l's are in the second. (NOTE! The C_l's are normalized in such a way that if you want to compare these values to the plots, you MUST multiple the results in column 2 by the square of the average temperature of the CMB measured in MICROKELVINS). Compare this spectrum to that actually measured by WMAP (see the link on the class web page).

4. Make two more runs of CMBFAST with $\Omega_\Lambda = 0.4$. For one keep Ω_{cdm} unchanged and for the other change it to keep the total Ω equal to one. Plot the resulting two spectra and the standard one on a single plot. Describe the changes and explain the change in the location of the first peak using your results from the first numerical assignment. Do these results confirm the assertion in the text that the location of the first peak is primarily dependent on the curvature of the universe?