Ph 444 Problem Set 8

Due: Friday, November 21, 2014

1. Ryden problem 9.3
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 which is the case for pure hydrogen, use $n_{baryon} = 4(n_{He} + n_{He^+})$.

2. Ryden problem 9.5

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 first column of the data 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.

Recently, CMBFAST has been reincarnated as CAMB, a somewhat improved but slightly more complex version.

A web interface to run CAMB is available at

http://lambda.gsfc.nasa.gov/toolbox/tb_camb_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 CAMB. It outputs plots and tables of the predicted power spectrum. The spectrum for the intensity fluctuations is C_l^{TT}(the temperature WMAP data.) Most of the input parameters can utilize their default values, but the following should be input to the web page.

Run CAMB with the following parameter settings: Use Physical Parameters?=No, $\Omega_b = 0.0456$, $\Omega_{cdm} = 0.228$, $\Omega_\Lambda = 0.726$, $\Omega_{neutrino} = 0.0$, $H_0 = 70$, $T_{cmb} = 2.725$, $Y_{He} = 0.24$ (helium mass fraction), N_ν (massless) = 3.04 (number of massless neutrino types), N_ν (massive) = 0.0 (number of massive neutrino types),Use optical depth?=Yes, Optical Depth to lss = 0.084 (optical depth to the surface of last scattering due to reionization). 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. (A plot will be output by the program as well). The l's are in the first column of the saved file and the C_l's are in the second. Compare this spectrum to that actually measured by WMAP (see the link on the class web page).

4. Make two more runs of CAMB 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?