Astro 448: Problem Set 4

Due Feb. 26

1. CMBFast:

Go to

http://www.sns.ias.edu/∼matiasz/CMBFAST/cmbfast.html,

download the CMBFast code for calculating CMB anisotropies, and compile it. The engine of the code is described in Seljak & Zaldarriaga, ApJ 469, 437 (1996) for future reference.

Run a "standard" ΛCDM model with: $\Omega_b = 0.05$, $\Omega_c = \Omega_m - \Omega_b = 0.30$, $\Omega_\Lambda = 0.65$, $H_0 = 65$ km s^{-1} Mpc^{-1}, $T_{\rm CMB} = 2.728$K, $Y_p = 0.24$, 3 species of massless neutrinos, scalar tilt $n_s = 1$, and no tensors.

1. Plot your result for the power spectrum $\ell(\ell+1)C_\ell/2\pi$ vs. ℓ.
2. Give the numerical value of ℓ at the first peak ℓ_1.

2. Degeneracies:

1. Calculate the comoving angular diameter distance d_A to $z = 1100$ in the above model. You may ignore the effect of radiation in the Friedmann equation. Express your result in comoving Mpc. Calculate d_A to $z = \infty$, how much difference does that make?
2. The observed peak from Boomerang and Maxima is at $\ell_1 = 206 \pm 6$. Assuming all else is fixed (in particular, the length of the "standard ruler" that defines the peak), what change in d_A would shift the peak to $\ell_1 = 206$.
3. Recalculate d_A to $z = 1100$ in a slightly closed universe assuming all other parameters except Ω_Λ are fixed. Numerically find the value of Ω_Λ that gives the desired value in part 2. Run CMBfast and check your answer.
4. Recalculate d_A to $z = 1100$ for dark energy models with $w > -1$ (and all other parameters the same as above) and numerically find the value of w that gives the desired value of d_A in part 2.
5. Rewrite CMBfast to check your answer for w (just kidding!).
6. Argue that it is OK to just think of the dark energy as modifying distances for degree scale anisotropies. For the value of w above, calculate the redshift at which the energy density in dark matter and dark energy are equal. Calculate the comoving horizon size η at that epoch. Calculate the comoving angular diameter distance to that epoch and give the angular scale of the horizon at that time as observed today. Recall that the interesting things in the growth of structure happen only on scales larger than this.

Note that these are only two ways of shifting ℓ_1, in particular the ones that preserve the morphology of the peaks. We can change ℓ_1 without adding any new parameters by altering the relative size of the sound horizon ("standard ruler") itself by upping the matter/radiation ratio or $\Omega_m h^2$. Extra credit: find a suitable model that is flat, has a cosmological constant, and for which $\ell_1 = 206$.