**Particle Astrophysics, 171.697**

**Problem Set 9**

**Due: First class of week 10**

1. Derive the Sachs-Wolfe formula for the large-angle ($\ell \lesssim 100$) CMB temperature power spectrum $C_\ell$ for a flat scale-invariant spectrum ($n_s = 1$) scalar power spectrum. Write your result in terms of the amplitude $\Delta^2_{\mathcal{R}}$ of the primordial curvature perturbation and also in terms of the inflaton potential $V$ and slow-roll parameter $\epsilon$.

2. Calculate the Silk damping length in terms of the baryon density $\Omega_b$, Hubble parameter $h$, and matter density $\Omega_m$.

3. The purpose of this problem is to explore the CMB temperature power spectrum for primordial density perturbations. You are asked to download, compile, and run either CAMB or CLASS, the two current publicly available CMB Boltzmann codes. Alternatively, you can simply run CAMB at
   `https://lambda.gsfc.nasa.gov/toolbox/tb_camb_form.cfm`
   which provides a simple user interface. Run and plot the power spectrum for the current Planck best-fit cosmological paramters. Then investigate the effect of small variation of each of the following parameters and try to understand either semi-analytically or at least qualitatively the change induced in $C_\ell$ by change in each of these parameters: the curvature $\Omega_K$ (the curvature); the cold-dark-matter density $\Omega_d$ (holding the cosmological geometry fixed to be flat); the baryon density $\Omega_b$; the scalar spectral index $n_s$; the Hubble parameter $h$; and the optical depth $\tau$ to reionization.