GR6014 Final Project:

Due on Friday, December 13, 2024

You have a choice between the following two projects. Both of these require a computer, although (1) does not require writing any of your own code. They also require a fair amount of background reading, including material not (yet) covered in class, so please start early! You are encouraged to work in groups, but you must write up and turn in your own solutions. You are welcome to propose your own alternative project – come discuss it with me, then.

Project 1: Find the best–fit cosmological model yourself.

In this project, you will use the power spectrum of the CMB temperature anisotropies, measured by the *Wilkinson Microwave Anisotropy Probe (WMAP)* experiment, and fit cosmologies models to it.

First, visit *WMAP*'s data website, https://lambda.gsfc.nasa.gov/product/map/current. Download the nine–year (DR5) temperature ("Combined TT") data, and read its description. Then, visit the CAMB website http://camb.info, and read the description of this public Boltzmann code. Download and compile the code, and use it to produce the temperature "TT" CMB power spectra, i.e., plot $\ell(1+\ell)C_\ell/2\pi$ for various cosmologies. Assume that there are no neutrinos ($\Omega_\nu = 0$), and that the present-day matter density $\Omega_{\mathrm{m},0} = 0.26$ and Hubble constant $H_0 = 72$ km/s/Mpc have been measured in other experiments. Find the best fitting value of Ω_Λ, and estimate its uncertainty, given the uncertainties in the WMAP measurements of C_ℓ. The WMAP team's results are published in Hinshaw, G. et al. 2013, ApJS, vol. 208, article id. 19, 25 pp. (2013). (arXiv:1212.5226). Use these results as a guide in choosing the default values of the other parameters (which you may keep fixed).
For extra credit: examine the dependence of C_ℓ on other parameters, such as the baryon density (Ω_b), neutrinos (Ω_ν) and/or the normalization of the power spectrum (σ_8), and compute the constraints on these parameters - either when they are allowed to vary individually, or all of them simultaneously.

Project 2: Cosmology in a future galaxy cluster survey.

In this project, you will estimate how well the cosmological parameters can be determined by counting galaxy clusters in a large survey. For this, you will need to predict the number of clusters per unit redshift and solid angle, $d^2N/dzd\Omega$.

Assuming that galaxy clusters can be identified with collapsed dark matter halos, use the Press–Schechter mass function (see, for example, Peebles, eq. 25.40) for this purpose. For simplicity, you may use a fitting formula for the power spectrum (e.g. the one given in Peebles, eq. 25.22). Assume a flat universe, and for the growth–function of linear perturbations, you may use the fitting formula in Carroll, Press & Turner, 1992, Annual Reviews of Astronomy & Astrophysics, 30, 499. For the comoving volume element, $d^2V/dzd\Omega$, you may use the simplified expressions (which are 1–D elliptical integrals and easy to compute numerically), in Eisenstein (1997, http://xxx.arxiv.org/pdf/astro-ph/9709054).

With the above, compute the total number $N_{\rm tot}$ of clusters in a hypothetical survey that detects all dark matter halos with a mass above 2×10^{14} $\mathrm{M}_\odot$, in $4,000$ square degrees of the sky (this is similar to the capability of the South Pole Telescope). Use Planck's best fitting results (i.e. from their final data release: Table 2 in https://arxiv.org/abs/1807.06209), to choose the values of the other parameters, except, for simplicity, round off the densities to $\Omega_m = 0.31$, $\Omega_\Lambda = 0.69$, adding up to a flat universe.

Next, compute $N_{\rm tot}$ as a function of $\Omega_{\rm m}$, for a few values of $\Omega_{\rm m}$ above and below $\Omega_{\rm m} = 0.31$. For simplicity, keep all parameters fixed, except adjust Ω_Λ to keep the universe flat. Assuming the uncertainty in the number of clusters is simply the Poisson error, $\sqrt{N_{\rm tot}}$, estimate the accuracy to which Ω_m could be determined by this counting method.

Make a plot of dN/dz, the number of clusters per unit redshift, and identify the redshift where most of the clusters are located. Is the dependence of $N_{\rm tot}$ on Ω_m at this redshift coming mostly from the cosmic volume factor or from the growth function?

For extra credit: Also examine how $N_{\rm tot}$ depends on the normalization of the power spectrum, σ_8, and compute the *joint* constraint on $\Omega_{\rm m}$ and σ_8. Does the direction of the degeneracy between $\Omega_{\rm m}$ and σ_8 make sense?