SURP Computing Project – Clara Chung

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This exercise will explore the matter power spectrum $P_m(k)$, which indicates the amount of fluctuation in the fractional matter density field, δ, on a given scale corresponding to a wavenumber k.

1 Exploring Theoretical Matter Power Spectra

1. Install the `camb` package—the easiest implementation is the python wrapper.

2. Start by making a plot of $P_m(k)$ at $z = 0$ for some standard parameters which you obtain by running CAMB from python (feel free to borrow lines from the CAMB jupyter notebook tutorial for this). (Please make sure that 'nonlinear growth' is turned on for this standard curve. Below, you will explore turning this off). Is it most useful to use linear or log scaling for each of the x and y axes?

3. Explore the impact on the theoretical $P_m(k)$ of changing some parameters; in each of the following cases make a plot showing a few curves indicating what happens when you change the following properties (keep the original, standard curve in all of your plots). Make sure to put in a legend showing the values of the parameters that you changed in each case. Also, note in words what you observe.
   - Changing the physical matter density $\Omega_m h^2$
   - Changing the neutrino density $\Omega_\nu h^2$ while compensating by a corresponding change in the cold dark matter density $\Omega_c h^2$
   - Turning on/off nonlinear growth
   - Comparing the $z = 0$ curve with earlier times (higher z)

4. The "dimensionless" power spectrum $\Delta^2(k) \equiv k^3 P_m(k)/(2\pi^2)$ gives a more direct measure of the density fluctuation on a given scale k. Make a plot of $\Delta^2(k)$ for your standard parameters. At what k value does $\Delta^2 = 1$?

5. If the cosmic density field is smoothed within spheres of radius R (typically written in units of $h^{-1}\,\mathrm{Mpc}$) then the variance of the resulting field will be

$$\sigma_R^2 = \int_0^\infty \frac{dk}{k} \left[\frac{3j_1(kR)}{(kR)} \right] \Delta^2(k). \tag{1}$$

   Here $j(x) = \sin(x)/x - \cos(x)$, and the $[3j_1(kR)/(kR)]$ factor comes from evaluating the Fourier transform of a hard sphere in 3d. Make a plot of this latter factor (as a function of k) for $R = 8\,h^{-1}\,\mathrm{Mpc}$ and $200\,h^{-1}\,\mathrm{Mpc}$. One use of σ_R is that for values of R at which σ_R is close to or larger than 1, we expect nonlinear growth to have a significant effect.

6. Write a routine that computes σ_R for a given R and $P_m(k)$. For your standard $P_m(k)$ compute σ_8 and σ_{200}, which correspond to the variances if the matter field is smoothed in spheres of these radii. Now, for each curve you generated in step 3, compute these two values and add them to the legends of your plots.

2 Generating and Analyzing Simulations of Clustering

1. Install `nbodykit` in your CITA user directory or on your own computer, consulting
http://nbodykit.readthedocs.io/en/latest/getting-started/install.html
for instructions. (When I did this, I first set up a local copy of `Anaconda`, and then installed `nbodykit` into a custom environment, as they recommend.)

2. Read through the `nbodykit` documentation, located at http://nbodykit.readthedocs.io/en/latest, to familiarize yourself with catalogs, meshes, and other useful concepts and data structures.

3. You will work with Gaussian random fields in this problem. They are easy to generate within `nbodykit`, and the way you measure the power spectrum of a Gaussian realization is similar to what you would do with a full N-body simulation.

   (a) Generate 10 realizations of a Gaussian random field in a box with side length $L = 1000h\,\mathrm{Mpc}^{-1}$ and on a 256^3 mesh. For the input power spectrum, use a `LinearPower` object (which corresponds to having nonlinear growth turned off in CAMB) at redshift $z = 0$, with the same cosmological parameters you used in Part 1. Measure the power spectrum of each realization, and make a plot of the mean and standard deviation of the 10 measured spectra as a function of wavenumber k.

   (b) Do the same thing, but using the "Halofit" matter power spectrum as input (this corresponds to having nonlinear growth turned on in CAMB). Explain the differences between the power spectra you measure in this case and what you got from using the linear power spectrum as input.

   (c) Repeat parts (a) and (b) at $z = 5$ instead of $z = 0$, now only making a plot of the mean measured power spectra using the linear or Halofit power spectrum as input. Explain the differences you see between the $z = 0$ and $z = 5$ measurements.

4. In this problem, you will generate realizations of particles whose density has a certain power spectrum. It has been found both in observations of galaxy clustering and in N-body simulations that after gravitational evolution, the nonlinear density field has roughly lognormal statistics, so `nbodykit` has routines to generate particle distributions with these statistics. While not suitable for precision work, they are useful for exploring issues related to measuring statistics from a set of discrete particles.

   (a) Using the same input linear power spectrum, redshift, and box size as Problem 3a, generate 10 lognormal catalogs with $\bar{n} = 3 \times 10^{-3} h^3\,\mathrm{Mpc}^{-3}$. Measure their power spectra, using the CIC option to assign mass to the grid and making sure that the associated window function is deconvolved (which flag controls this?), and make a plot of the mean over the 10 catalogs. On the same plot, show what happens to the mean if you turn off the window function deconvolution. Also show what happens if you use the NGP or TSC mass assignment schemes. How much of a difference do these schemes make in the measured power spectrum?

   (b) What happens to the measured power spectrum when you change $\bar{n}$ to 1×10^{-3}, 5×10^{-4}, and $1 \times 10^{-4} h^3\,\mathrm{Mpc}^{-3}$? Plot the mean measured power spectrum over 10 lognormal catalogs in each case. Explain the behavior you observe at higher values of k. (Feel free to consult other references to learn about what's going on.)