Extra-Galactic Astronomy I (Cosmology)

Project 6: Halo Abundance Matching

Total marks: 30

1 Background

One of the most striking observations in extra-galactic astronomy is the fact that the clustering strength of galaxies, as measured by the spatial 2-point correlation function, monotonically increases as a function of galaxy luminosity. In this project, we will explore one of the simplest arguments to explain this trend, namely, that galaxy luminosity must be approximately monotonic in halo mass. You will be given galaxy luminosities from the SDSS catalog and halo masses and positions from an N-body simulation. You will perform 'abundance matching and assign luminosities from SDSS to the simulated haloes assuming a perfectly monotonic relation between luminosity and halo mass. You will then compute the 2-point correlation function of this 'mock galaxy catalog after selecting objects by luminosity, and demonstrate that the clustering strength increases with increasing luminosity.

2 Data

2.1 Galaxies

The plain text file `yangDR7_centrals.txt` is drawn from SDSS data and contains two columns, with the first corresponding to absolute magnitudes M_r and the second to colours $(g-r)$ of so-called 'central' galaxies. Each row gives the properties of one galaxy. The galaxies were observed in a comoving volume of $\sim (191h^{-1}\mathrm{Mpc})^3$.

2.2 Haloes

The plain text file `out_1.parents` contains several columns giving various properties (see the file header for details) of dark matter haloes identified in an N-body simulation of comoving volume $(300h^{-1}\mathrm{Mpc})^3$. You will only need the columns 'm200b' containing the halo mass in $h^{-1}M_\odot$ and the coordinates 'x', 'y' and 'z' of the haloes in $h^{-1}\mathrm{Mpc}$.

3 What to do

3.1 HAM

Using the two files, you should set up a numerical, *strictly monotonic* relation between galaxy luminosity and halo mass, such that bright galaxies live in massive haloes and faint galaxies in low-mass haloes. Using this monotonic relation, create a 'mock' galaxy catalog in which each object has a luminosity, dark matter mass and 3-dimensional position. The luminosities will be assigned from the galaxy catalog and the other properties from the halo catalog. (*Caution!*: The galaxy and halo catalogs have different volumes, and you must account for this difference.)

3.2 Clustering

Set up code to take 3-d positions of a set of objects and calculate their 2-point correlation function using the estimator $\xi(r) = DD(r)/RR(r) - 1$, where $DD(r)$ is the number of pairs of objects in the **data** that have separations in the range $(r, r + \mathrm{d}r)$, normalised by the total number of pairs in the data set, and $RR(r)$ is the same quantity calculated for a set of points randomly thrown down in the same volume. For RR you may use the analytical result (valid for separations $r < L/2$ in a cubic periodic box of side L): $RR = 4\pi r^3 \mathrm{d}\ln r$, where we assume logarithmic binning in separation. For DD you may use a brute-force pair-counting code, but you should also try to explore more efficient techniques. (*Caution!*: You will be working with halo positions from a cubic periodic box, so your code for DD must account for this.) Test your code by showing that $\xi(r)$ is consistent with zero if the data points are themselves randomly thrown down in a cubic volume (assuming periodic boundary conditions).

3.3 Luminosity dependent clustering

Apply your $\xi(r)$ estimator in the range $0.2 < r/(h^{-1}\mathrm{Mpc}) < 75$ for different subsets of your mock galaxy catalog, corresponding to increasingly bright samples satisfying $M_r < -20$, $M_r < -21$ and $M_r < -22$. Show that the clustering strength at large r increases as a function of luminosity. Can you explain this behaviour? Can you explain the behaviour of the measurements at small r?