LECTURE 9: BAO, RSD AND THE AP EFFECT (I)

GONG-BO ZHAO

1. Galaxy 2-point correlation function and power spectrum

The correlation function and power spectrum are tools to quantify the clustering of galaxies.

In cosmology, the 2-point galaxy correlation function is defined as a measure of the excess probability, relative to a Poisson distribution, of finding two galaxies at the volume elements dV_1 and dV_2 separated by a vector distance $\mathbf{r}$:

$$dP = n[1 + \xi(\mathbf{r})]dV \tag{1}$$

is the conditional probability that a galaxy lies at dV at distance r given that there is a galaxy at the origin of r, where n is the mean number density over the whole sample volume.

In practice, we are interested in $\xi(s, \mu)$, where s is the separation between two galaxies, and μ is the cosine of the angle between the vector $\mathbf{r}$ and the separation vector $\mathbf{s}$. Then $\xi(s, \mu)$ can be decomposed using Legendre polynomials,

$$\xi(s, \mu) = \sum_{\ell=0}^{\ell_{\max}} \xi_\ell(s)\mathcal{L}_\ell(\mu) \tag{2}$$

The galaxy power spectrum is a 3D Fourier transformation of the correlation function, namely,

$$P(k, \mu) = \int \xi(s, \mu)e^{i\mathbf{k}\cdot\mathbf{s}}d^3\mathbf{s} \tag{3}$$

and similarly we can define the power spectrum multipoles as,

$$P(k, \mu) = \sum_{\ell=0}^{\ell_{\max}} P_\ell(k)\mathcal{L}_\ell(\mu) \tag{4}$$

Date: March 24, 2020.

2. Baryonic Acoustic Oscillations

BAO is a specific three-dimensional clustering pattern of galaxies due to interactions between photons and baryons in the early Universe [1]. Back in the early cosmic epochs, photons scattered with electrons and electrons interacted with protons, making photons and protons (baryonic matter) "glued" together. There are two opposite forces exerting on this tightly coupled plasma: the pressure of photons and gravity acting on baryons. Similar to what happens to a vibrating spring vertically fixed on the ground, the photon-baryon plasma underwent "Baryonic Oscillations", propagating waves in the same way as the sound does. Therefore, this physical process is called Baryonic Acoustic Oscillations (BAO). The effect of the BAO is to push galaxies apart until at a specific time, called the cosmic recombination, when the temperature of the Universe becomes so low that no more photon-baryon interaction can happen. Since then, the separation among galaxies is "frozen" at a characteristic scale, which is about 150 Mpc depending on the energy content of the Universe, making it a "standard ruler" to be used to infer the expansion history of the Universe, thus BAO is one of the key probes for the nature of dark energy. Observationally, BAO was first detected in 2005 [1].

The sound horizon:

$$s = \int_0^{t_{\rm rec.}} c_s(1+z)dt = \int_{z_{\rm rec.}}^{\infty} \frac{c_s dz}{H(z)} \sim 150 \text{ Mpc} \tag{5}$$

where

$$c_s = \frac{1}{\sqrt{3(1+R)}} \tag{6}$$

and

$$R \equiv \frac{3\rho_b}{4\rho_\gamma} \tag{7}$$

3. The Alcock-Paczynski (AP) effect

The Alcock-Paczynski (AP) effect [3] is another kind of geometric distortion similar to the RSD, but due to completely different physics. Remember in cosmology we use redshifts to get distances, thus this process is cosmology-dependent. If we use a wrong cosmology to get the distances, which we inevitably do, we get wrong distances on both radial and transverse directions. The errors we get on these two directions are different, thus a distortion is caused. This effect can be used to probe the geometry of the Universe through measurements of D_A and H.

[1] `http://w.astro.berkeley.edu/~mwhite/bao/`

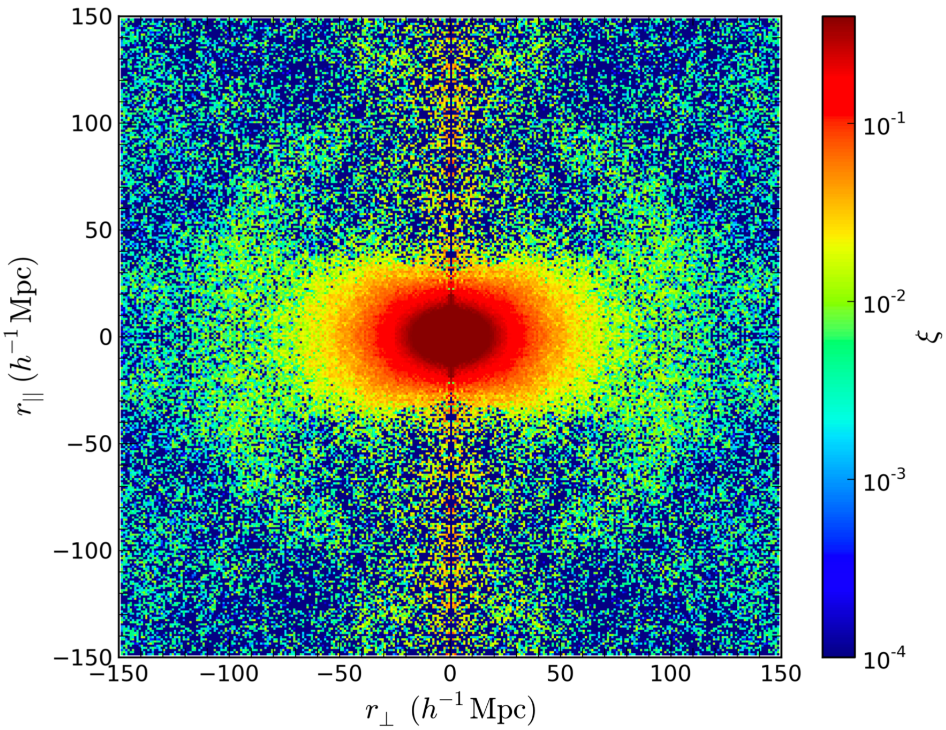

Figure 1. The 2D correlation function measured from the BOSS galaxies [4].

References

[1] D. J. Eisenstein *et al.* [SDSS Collaboration], Astrophys. J. **633**, 560 (2005) doi:10.1086/466512 [astro-ph/0501171].
[2] N. Kaiser, Mon. Not. Roy. Astron. Soc. **227**, 1 (1987).
[3] C. Alcock and B. Paczynski, Nature **281**, 358 (1979). doi:10.1038/281358a0
[4] L. Samushia *et al.*, Mon. Not. Roy. Astron. Soc. **439**, no. 4, 3504 (2014) doi:10.1093/mnras/stu197 [arXiv:1312.4899 [astro-ph.CO]].