BOSS UPDATE ON GALAXY CLUSTERING

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The Baryon Oscillation Spectroscopic Survey Data Release 11 (BOSS, DR11) has measured with unprecedented accuracy the scale of the Baryon Acoustic Oscillation peak (BAO) from galaxy clustering at $z \simeq 0.32$ and $z \simeq 0.57$, thus providing the best estimate to date of the cosmic distance scale at these redshifts, with errors that are respectively less than 2% and 1%. The error analysis of the data has been made possible by the use of a large number of mock galaxy catalogues, created using the PTHalos methodology. These mocks were crucial for providing the covariance matrices and understanding the systematics of the observations.

1 The CMASS and LOWZ DR11 galaxy samples

BOSS[1] is a spectroscopic survey that uses imaging data from SDSS-III[2] to map the positions of 1.35 million galaxies over a quarter of the sky. It targets two distinct galaxy samples: the LOWZ sample, a low redshift sample $0.2 \lesssim z \lesssim 0.45$ with galaxies selected following an algorithm close to that designed for Luminous Red Galaxies (LRG) in SDSSS-I/II, and the CMASS sample, a high redshift sample $0.4 \lesssim z \lesssim 0.7$ that targets galaxies with roughly a constant stellar mass.

The BOSS LOWZ and CMASS Data Release 11 (DR11) galaxy samples cover respectively an area of 7,998 and 8,976 square degrees, which is splitted into a Northern Galacic Cap (5,793 and 6,769 square degrees respectively) and a Southern Galactic Cap (2,205 and 2,207 square degrees). The volume of these samples more than doubles what was available in the DR9.

For the clustering analysis the BOSS galaxy working group have used 690,286 galaxies for CMASS and 313,780 for LOWZ; these include those targeted galaxies that have good spectroscopic redshifts and pass the redshift cuts, as well as the SDSS-II spectroscopic known galaxies that also pass the sample cuts.[3,4]

2 Measuring the Cosmic Distance and the BAO peak scale

The two-point correlation function measured from the CMASS sample using the Landy-Szalay estimator, is shown in the top panel of Figure 2. The BAO peak feature is clearly seen, and is detected with a significance of over 7 sigma. The position of the peak, commonly used as a "standard ruler", is given by the distance the sound waves travel before the coupling between baryons and radiation breaks down, r_d, which is 148.28 Mpc in our fiducial flat ΛCDM cosmology with $\Omega_m = 0.274$, $h = 0.7$, and $\Omega_b h^2 = 0.0224$.

We have measured the cosmic distance $D_V(z) \equiv \left[cz(1+z)^2 D_A(z)^2 H^{-1}(z)\right]^{1/3}$ by fitting the averaged correlation function ξ as a function of the distance in redshift space s:

$$\xi^{\rm fit}(s) = B^2 \xi^{\rm mod}(\alpha s) + \frac{a_1}{s^2} + \frac{a_2}{s} + a_3 \tag{1}$$

where $\xi^{\rm mod}$ is the model, $H(z)$ the Hubble distance at redshift z and D_A the angular distance. B is a multiplicative constant allowing for an unknown large scale bias and a_1, a_2, a_3 the coefficients of a polynomial that helps marginalize over the broadband signal. The parameter α rescales the correlation function and gives a measure of the cosmic distance, $D_V(z) r_{d,\rm fid} = \alpha D_V^{\rm fid}(z) r_d$, We find $D_V = (1264 \pm 25{\rm Mpc})(r_d/r_{d,fid})$ for the LOWZ sample and $D_V = (2056 \pm 20{\rm Mpc})(r_d/r_{d,fid})$ for the CMASS sample. These measurements have taken advantage of the reconstruction technique [5] that extrapolates the galaxy positions back in time to recover a more linear acoustic fetature, and incorporate as well the information from the power spectrum. The CMASS measurement, at 1.0 per cent accuracy, includes also anisotropic information, and is the most precise distance constraint ever obtained from a galaxy survey.[3] Complementary cosmological measurements have been made for $H(z)$, D_A and D_V using Redshift Space Distortions.[6,7,8,9]

3 Mock Galaxy Catalogues

Mock galaxy catalogues are essential to obtaining statistical errors and covariance matrices, calibrating the pipelines, testing the systematics, and linking theoretical predictions to the observed measurements. Mock galaxy catalogues (600 for CMASS and 1000 for LOWZ) have been created using the PTHalos methodology, with the basic steps summarised as follows[10]:

- Given a set of cosmological parameters, and an initial linear power spectrum, create a dark matter particle field based 2nd-Order Lagrangian Perturbation Theory (2LPT). This step is very fast (orders of magnitude faster than an N-Body run) and consequently allows for the creation of a large number of mock catalogues.

- Identify halos using a Friends-of-Friends (FoF) halo-finder with an appropriately chosen linking length ℓ, which is derived by comparing the spherical collapse of structures in 2LPT versus full (spherical) Eulerian dynamics. We argue that for LOWZ and CMASS ℓ should be respectively 0.39 and 0.38 times the comoving interparticle distance.[10,11] After the dark matter halos are identified we use Halo Abundance Matching technique to reassign the masses of the halos such as to recover the theoretical (or the N-Body) mass function of our chosen cosmological parameters.

- Populate halos with galaxies using a Halo Occupation Distribution (HOD) algorithm calibrated to fit the observational data. For CMASS we have used the DR9 correlation function with $30 < r < 80$ Mpc/h and for LOWZ the DR10 power spectrum with $0.02 < k < 0.15$ h/Mpc. and allowed a redshift dependence for the HOD.

- Apply the survey angular mask and (if necessary) the galaxy redshift distribution. The mock catalogues also take into account the completeness of the survey as a function of the position of the sky. The mock include galaxy close-pair corrections, which happen when two targeted galaxies are very close together in angular separation: one of these might not be observed due to the fact that two spectroscopic fibers in the focal plane cannot be placed closer than the equivalent of 62 arc seconds.

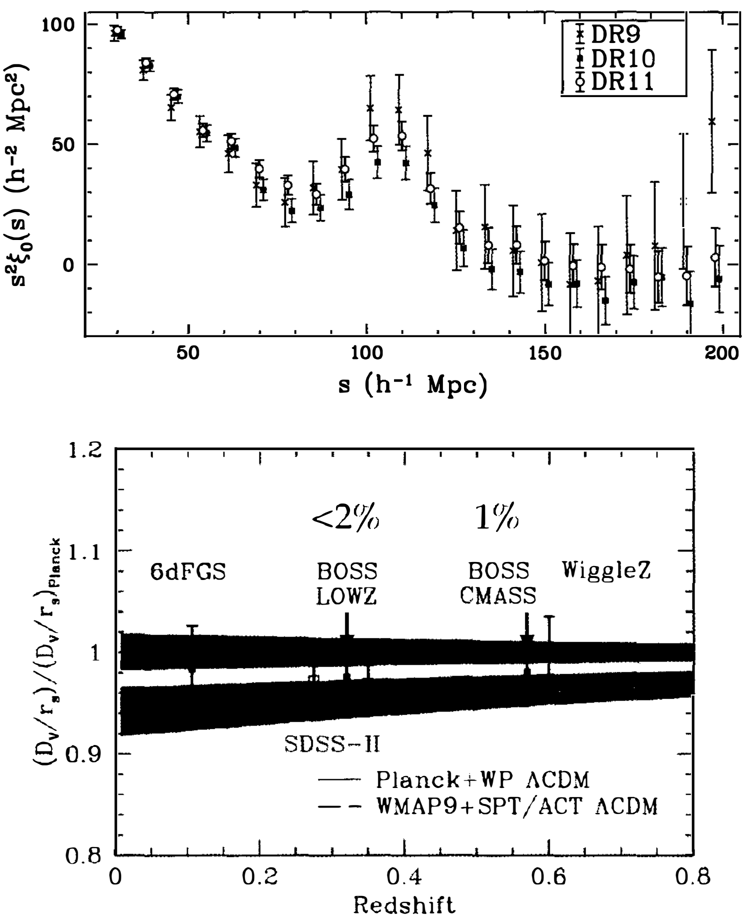

Figure 1 – Top: Two point correlation function of the CMASS DR9, DR10 and DR11 galaxy samples. The position of the BAO peak is clearly seen and can be accurately measured. The covariance matrix for these measurements have been obtained from the PTHalos mocks galaxy catalogues. Bottom: The cosmic distance scale derived from the BAO measurement for the LOWZ DR11 ($z \simeq 0.32$) and CMASS DR11 ($z \simeq 0.57$) galaxy samples. Results are compared with other measurements from 6dF, SDSS-II and WiggleZ. The volume observed partially overlaps between measurements at the same redshift, thus they are not statistically independent. The bands give the 1-sigma range of values allowed by Planck + WMAP Polarization and by WMAP + SPT/ACT data. Top and bottom panels correspond to figures 10 and 22 in Anderson et al. 2014 [3], where an extended explanation can be found.

The PTHalos mock galaxy catalogues have been crucial for the error analysis of the BOSS galaxy clustering data, including a) estimating the systematic and statistical errors of α, and (thus, through D_V) of the cosmological parameters;[3,14] b) determining the optimal number of bins for the anallysis;[13] c) obtaining the correlation between the power spectrum and the correlation function estimator of α and thus allowing for a combined measurement;[3,14] d) understanding the improvement of the errors from the reconstruction technique; and e) determining the best way to correct for the systematic effects of observations.[12] The most important of the latter is the correlation between the number of galaxies in a region of the sky and the number of stars in that region. This local signal leaks into our measurement of the galaxy clustering correlation. It changes the correlation function by more than one sigma at the BAO scale[8], and it needs to be corrected. This is especially relevant for studies involving the full shape of the correlation function, as the position of the BAO peak is more robust to changes in the broad shape of $\xi(s)$.

Finally, an accurate estimation of the cosmic distance measurement error, requires correcting for the error in the inverse covariance matrix caused by the finite number of mocks available. A correction is required for the inversion of the covariance matrix, and for the derived parameter error. Furthermore the parameter error corrections depend on the way in which the parameter error is determined, and are different if this is calculated from the distribution of recovered values from the mocks, or the likelihood surface.[13] For the cosmoic distance measurement of the LOWZ and CMASS galaxy samples, we achieve an accuracy of less than 2% and 1% respectively, the latter being the most precise distance constraint ever obtained from a galaxy survey.[3]

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