

The observational characteristics of the
inhomogeneous matter distribution in the Universe

By
Tao Hong

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Abstract

On large-scales, the distribution of matter in the Universe appears to be homogeneous and isotropic, allowing the use of the Friedmann-Robertson-Walker metric of General Relativity. However, due to the action of gravity on perturbations in the density field, the assumption breaks at the current epoch at scales $\lesssim 100 h^{-1}\text{Mpc}$. Conversely, the precise nature of the inhomogeneities in the matter distribution are a direct consequence of the cosmological model and can significantly improve our understanding of these models, allowing potentially tight constraints on cosmological parameters. Correspondingly, modern large-area surveys can provide the huge data samples that can facilitate such precision measurements. In this thesis, we will focus on two main observational characteristics of the inhomogeneous matter distribution: Baryon Acoustic Oscillations (BAO) and peculiar velocities of galaxies.

BAOs are overdensities in the baryon distribution field at a scale of $\sim 105 h^{-1}\text{Mpc}$, represented as ‘bumps’ in the 2-point correlation functions at the same scale. The BAO signal was “frozen” at this scale, and thus can be used as a standard ruler to study the cosmological model. The BAO signal has been previously detected using galaxy samples, with only a weak signature in samples of galaxy clusters.

Because of the gravitational effects of the inhomogeneous matter field, the motion of galaxies deviates from the prediction of uniform Hubble flow, giving rise to so-called ‘peculiar velocities’. By averaging peculiar velocities over thousands of galaxies, we can measure the bulk flow of these galaxies, which is again a strong constraint on the cosmological model. Most of the previous studies have been in agreement on the direction of the bulk flow. Unfortunately, debate on the amplitude is still ongoing.

In Chapter 1, we briefly review the history of the studies on the matter distribution field, before introducing the theory and observational status of BAO and peculiar velocity studies, respectively.

In Chapter 2, we calculate the correlation function of 13,904 galaxy clusters of $z \leq 0.4$ selected from the cluster catalog of Wen, Han & Liu. The correlation function can be fitted with a power-law model $\xi(r) = (r/R_0)^{-\gamma}$ on scales of $10 \leq r \leq 50 \text{ h}^{-1}\text{Mpc}$, with a larger correlation length of $R_0 = 18.84 \pm 0.27 \text{ h}^{-1}\text{Mpc}$ for clusters with a richness of $R \geq 15$ and a smaller length of $R_0 = 16.15 \pm 0.13 \text{ h}^{-1}\text{Mpc}$ for clusters with a richness of $R \geq 5$. A consistent power law index of $\gamma = 2.1$ is found for all cluster richness. A pronounced baryon acoustic oscillations (BAO) peak is detected at $r \sim 110 \text{ h}^{-1}\text{Mpc}$ with a significance of $\sim 1.9\sigma$. By analyzing the correlation function in the range of $20 \leq r \leq 200 \text{ h}^{-1}\text{Mpc}$, we find the constraints on distance parameters are $D_v(0.276) = 1077 \pm 55(1\sigma) \text{ Mpc}$ and $h = 0.73 \pm 0.04(1\sigma)$, which are consistent with the WMAP 7-year cosmology. However, the BAO signal from the cluster sample is stronger than expected and leads to a rather low matter density $\Omega_m h^2 = 0.093 \pm 0.0077(1\sigma)$, which deviates from the WMAP 7-year result by more than 3σ .

The 2MASS Tully-Fisher Survey (2MTF) measures Tully-Fisher distances for all bright inclined spirals in the local Universe using high-quality HI widths and 2MASS near-Infrared photometry. Compared with previous peculiar velocity surveys, 2MTF is significantly more complete at low Galactic latitude ($|b| < 15^\circ$) because of its near-infrared selection. It therefore provides a more reliable map of peculiar velocities in the local Universe. In Chapter 3, we introduce the selection criteria and other basic information for the 2MTF survey, then describe the 2MTF observations in the southern hemisphere. For $\delta \leq -40^\circ$, we observed 303 galaxies using the 64-m Parkes radio telescope. All target galaxies were selected from the 2MASS Redshift Survey (2MRS) with $K_s < 11.25 \text{ mag}$, $cz < 10,000 \text{ km s}^{-1}$ and axis ratio $b/a < 0.5$. After data reduction, we obtain 152 high signal-to-noise HI spectra, from which we extract 148 high-accuracy ($< 5\%$ error) velocity widths and derive reliable rotation velocities. In Chapter 4, we analyse the whole 2MTF data sample. We calculate the redshift-independent distances and peculiar velocities for 2,018 spiral galaxies. A χ^2 minimization method was adopted to analyze the peculiar velocity field in three near-infrared wavebands, using a Gaussian filter. We combine information from the three wavebands, to provide a bulk flow measurement of $V = 260.6 \pm 50.5 \text{ km s}^{-1}$, $V = 214.7 \pm 25.8$

km s⁻¹, and $V = 284.5 \pm 34.1$ km s⁻¹ at depths of 20 h⁻¹Mpc, 30 h⁻¹Mpc and 40 h⁻¹Mpc respectively. Each of these bulk flow vectors points in a direction similar to those found by previous measurements. At each of the three depths, the bulk flow magnitude is consistent with predictions made by the Λ CDM model at the 1σ level.

In Chapter 5, conclusions for the work in Chapters 2 to 4 are presented, and some ideas for the future work are proposed.

Keywords: cosmology: observations — large-scale structure of universe — galaxies: distances and redshifts — galaxies: clusters: general — surveys — radio lines: galaxies