Lecture 12: Large Scale Structure and Galaxy Clustering Notes

Course: Introduction to Astronomy and Astrophysics I

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1 Large Scale Structure (LSS)

1.1 Overview of Cosmic Structure

The universe shows hierarchical organization at different scales:

- Local Group ($\sim$ 1 Mpc)
- Clusters ($\sim$ few Mpc)
- Superclusters ($\sim$ 10-100 Mpc)
- Voids and filaments (cosmic web)

1.2 Major Sky Surveys

Key redshift surveys that mapped LSS:

- CfA Survey (1985) - First major redshift survey
- Las Campanas Redshift Survey (LCRS)
- 2dF Galaxy Redshift Survey (2dFGRS)
- Sloan Digital Sky Survey (SDSS) - Most comprehensive to date

Multi-wavelength surveys:

- X-ray: ROSAT all sky survey
- UV: GALEX
- Near-IR: 2MASS
- Mid-IR: WISE
- Far-IR: IRAS, COBE/WMAP/Planck
- Radio: NVSS, FIRST, TGSS

2 Quantifying Large Scale Structure

2.1 Two-Point Correlation Function

The two-point correlation function $\xi(r)$ measures the excess probability of finding galaxy pairs at separation r compared to a random distribution:

- Power law form: $\xi(r) = (r/r_0)^{-\gamma}$
- Typical values: $r_0 \approx 5h^{-1}$ Mpc, $\gamma \approx 1.8$
- Varies with galaxy properties and environment

2.2 Estimation Methods

Two common estimators for $\xi(r)$:

1. Simple estimator:
$$\xi(\mathbf{r}) = \frac{\langle DD \rangle}{\langle RR \rangle} - 1$$
2. Landy-Szalay estimator:
$$\xi(\mathbf{r}) = \frac{\langle DD \rangle - 2\langle RD \rangle + \langle RR \rangle}{\langle RR \rangle}$$

Where:

- $\langle DD \rangle$ = data-data pairs
- $\langle RR \rangle$ = random-random pairs
- $\langle RD \rangle$ = random-data pairs

2.3 Power Spectrum Analysis

The power spectrum $P(k)$ is the Fourier transform of $\xi(r)$:

- $\delta(\mathbf{k})$ is the Fourier transform of density contrast $\delta(\mathbf{x})$
- $P(\mathbf{k}) = |\delta(\mathbf{k})|^2$
- Useful for comparing observations with theoretical models

3 Galaxy Clustering Properties

3.1 Dependence on Galaxy Properties

Clustering strength varies with:

- Luminosity (brighter galaxies cluster more strongly)

- Color (red galaxies show stronger clustering than blue)
- Mass (more massive galaxies cluster more strongly)
- Environment (stronger clustering in dense regions)

3.2 Biasing

- Galaxies are biased tracers of underlying dark matter distribution
- Rare objects show stronger clustering (Kaiser effect)
- Bias increases with galaxy mass and luminosity

4 Further Reading

Key references:

- Peebles (1980) "The Large-Scale Structure of the Universe"
- Kaiser (1984) ApJ, 284, L9 - Biasing in rich clusters
- Landy & Szalay (1993) ApJ, 412, 64 - Correlation function estimator
- York et al. (2000) AJ, 120, 1579 - SDSS description
- Colless et al. (2001) MNRAS, 328, 1039 - 2dFGRS

Online resources:

- SDSS website: `http://www.sdss.org`
- 2dFGRS website: `http://www.2dfgrs.net`
- Galaxy clustering tutorial: `http://www.astro.ljmu.ac.uk/~ikb/research/galaxy-correlations/`