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论文题目：宇宙大尺度结构的统计研究

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中　文　摘　要

论文介绍了宇宙大尺度结构研究中的统计分析方法及其应用。全文共分四章。

第一章介绍了宇宙学大尺度结构形成理论的一些基本背景。分四个部分：理论、观测、数值模拟和统计分析来讨论；他们是相互独立而又紧密联系在一起的。 从第一章，我们可以知道：（1）、宇宙大尺度结构是如何在原初微扰的基础上通过引力不稳定作用下逐步演化的；（2）、目前有关大尺度结构的观测项目如星系红移巡天等，及获得的观测结果；（3）、利用数值模拟进行宇宙学研究以及取得的成果；（4）、如何构造统计分析方法，从观测样本获取宇宙学基本信息。其中数值模拟和统计分析是连接观测和理论的桥梁。

第二章详细介绍了一个具体数值模拟－－LAMOST 红移巡天样本构造－－所需要的环节。本章讨论了数值模拟中宇宙学模型参数的选取，模拟的实施，星系偏袒效应，以及各种观测效应等。并对构造的星系样本作了统计评估。

第三章中我们建立了基于离散小波变换（DWT）的多分辨分析方法。由于 DWT 分析的正交完备性（包括不同尺度间，不同位置间的正交），以及在相空间的局域性，可以对大尺度结构进行多尺度分解。其中大于一维的 DWT 分解和传统 Fourier 分析不同，它不具备旋转不变性，而只有指标轮换不变性。因此一些和表象模有关的效应如：径向选择效应、红移畸变效应等，可以利用 DWT 模的特点来考虑。在第二节，我们探讨了 DWT 分析的一些特点，并给出了测量星系功率谱方法。作为 DWT 功率谱的具体应用，在第三节对实际观测的 LCRS 样本作分析，其中考虑了各种观测效应的影响，结果显示 DWT 功率谱给出了 LCRS 样本所含宇宙信息的适切估计。DWT 可以自动给出正交的尺度分解，而且在 DWT 表象的功率谱红移畸变效应由对应的速度谱决定；我们在第四节讨论了宇宙速度场的 DWT 分析。DWT 对速度显示了很好的对数正态分布，它受一些非线性成团理论的支持。在第五节我们讨论 DWT 表象的红移畸变效应。由于 DWT 表象的红移畸变效应和模的形状有关，我们可以利用非对角 DWT 功率谱构造 β 因子的测量方法。另外，DWT 分析可以给出红移方向选择函数的估计，即从星系分布中直接得到选择函数；我们还考虑了它对红移畸变效应的影响。从数值模拟样本的检验结果可知，DWT 功率谱可以给出有效的红移畸变参数的估计，而不需要假设宇宙学模型；还可以进一步给出 DWT 表象的速度弥散；重构实空间功率谱。

第四章包括两部分内容。一个是试图从星系－星系的弱引力透镜效应来研究对应的透镜星系所

处暗晕的物理特性，包括其质量，半径，分布等。我们在 McKay et al. (2002) 分析 Sloan Digital Sky Survey 的星系－星系弱引力透镜效应基础上，利用数值模拟样本，较详细地探讨了透镜星系和暗晕的关系，分析了其质光比等。第二部分给出了不同光度星系在暗晕中分布的研究。我们建立了一种条件光度函数 $\Phi(L|M)dL$ 的模型，它给出了质量为 M 暗晕内, 光度为 $L \pm dL/2$ 范围的星系数目。在这个模型中我们同时考虑了星系光度函数、星系成团效应、Tully-Fisher (TF)关系的限制。根据模型预言和观测结果的比较，我们可以给出宇宙学和星系形成的强限制。而且可以解除最近基于弱引力透镜效应和星系团丰度研究给出的功率谱归一化 σ_8 值和物质密度 Ω_0 之间的耦合关系。对于平直 ΛCDM 宇宙学模型，根据最近的弱引力透镜给出的 σ_8 值，条件光度函数模型给出了最佳值为 $\Omega_0 \sim 0.3$；当 $\Omega_0 \leq 0.2$ 时，星系相关长度过大；而 $\Omega_0 \geq 0.4$ 则给出了太高的质光比，和观测的 TF 关系不符合。对参数为 $\Omega_0=0.3$ 和 $\Omega_\Lambda=0.7$ 的 ΛCDM 调和宇宙学模型，拟合结果给出的质光比相对 TF 关系稍高。我们讨论了一些可以解决这个问题的方案，如稍微改变 σ_8 和 Hubble 参数，假设宇宙中是以温暗物质为主；或者目前的观测结果有一定的误差，可能存在暗星系等。最后我们还给出了本地宇宙的星系光度分布的一些统计，如：得出约 50% 的光是由质量小于 $2\times10^{12}M_{\odot}/h$ 的暗晕提供的。

最后有关小波变换的一些基本数学运算，小波表象一些变量的计算，以及 NFW 密度轮廓的二维投影等在附录中给出。

关键词：宇宙学、大尺度结构、星系、统计

The statistical research on the large-scale structure

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ABSTRACT

This thesis mainly focuses on the statistical study of the large-scale structure in the universe, which is done during my PhD research. The thesis contents include four chapters.

First, we introduce the background of the large-scale structure formation in Chapter 1. There are four closely related subjects in the research of large-scale structure: the structure formation theories, the observations, the numerical simulations and the statistical analyses. The four sections in this chapter are obviously associated with these topics. I hope they will give you some clues of the research background and uptodate status.

In Chapter 2, we present the simulations associated with the LAMOST project. The model parameters of simulations and the simulation procedures are discussed briefly. Bias model is employed in constructing the mock catalogues for different types of galaxies. To mimic the LAMOST redshift survey samples, several observational effects are imposed to the catalogues, which are tested for their clustering properties.

We study the large-scale structure based on the multiresolution analysis of the discrete wavelet transformation (DWT) in Chapter 3. Besides the technical advantages of the computational feasibility for data sets with large volume and complex geometry, the DWT scale-by-scale decomposition provides a physical insight into the covariance matrix of the cosmic mass field. The method of measuring galaxy DWT power spectrum is presented in Section 3.2. This DWT estimator is optimized in the sense that the spatial resolution is adaptive automatically to the perturbation wavelength to be studied. The DWT power spectrum estimator for 3-dimensional samples has been studied in Section 3.3, in which we analyzed the Las Campanas redshift survey (LCRS) samples. The DWT estimator for higher than 1-dimensional samples provides two types of spectra with respect to diagonal and off-diagonal modes, respectively. The two types of modes have different spatial invariance, and therefore, the diagonal and off-diagonal DWT power spectra are very flexible to deal with configuration-related problems in the power spectrum detection. We established the algorithm to detect the redshift distortions using diagonal and off-diagonal DWT power spectra in Section 3.5. The β factor can be estimated without the assumption of cosmic models. After this, the DWT pairwise velocity dispersion can be measured and the real space DWT power spectrum can be recovered. While in Section 3.4, we analyzed the velocity field using DWT decomposition. The Probability Distribution of the DWT pairwise velocity shows a pure lognormal form, which is supported by some nonlinear evolution models.

The main contents of Chapter 4 can be divided into two parts. First we try to understand the weak galaxy-galaxy lensing shear measurements, from which to infer the mass and profile of the halos. Based on the recent galaxy-galaxy lensing measurements of Sloan Digital Sky Survey (McKay et al., 2002) and using the high resolution GIF simulations, we discussed the relation between the galaxies and their host halos in detail, and estimated the halo virial mass and the mass-to-light ratios. In the second part, we present a conditional luminosity function $\Phi(L|M)dL$, which gives the number of galaxies with luminosities in the range $L \pm dL/2$ that reside in a halo of mass M, to link the distribution of galaxies to that of dark matter haloes. Starting from the number density of dark matter haloes predicted by current models of structure formation, we seek the form of $\Phi(L|M)$ that reproduces the galaxy luminosity function and the luminosity dependence of the galaxy clustering strength. We test the models of $\Phi(L|M)$ by comparing the resulting mass-to-light ratios with constraints from the Tully-Fisher (TF) relation and from galaxy clusters. A comparison between model predictions and current observations yields a number of stringent constraints on both galaxy formation and cosmology. In particular, this method can break the degeneracy between Ω_0 and the power-spectrum normalization σ_8, inherent in current weak-lensing and cluster-abundance studies. For flat ΛCDM cosmogonies with σ_8 normalized by recent weak gravitational lensing observations, the best results are obtained for $\Omega_0 \sim 0.3$; $\Omega_0 \leq 0.2$ leads to too large galaxy correlation lengths, while $\Omega_0 \geq 0.4$ gives too high mass-to-light ratios to match the observed TF relation. The best-fit model for the ΛCDM concordance cosmology with $\Omega_0=0.3$ and $\Omega_\Lambda=0.7$ predicts mass-to-light ratios that are slightly too high to match the TF relation. We discuss a number of possible effects that might remedy this problem, such as small modifications of σ_8 and the Hubble parameter with respect to the concordance values, the assumption that the universe is dominated by warm dark matter, systematic errors in current observational data, and the existence of dark galaxies. We use the conditional luminosity function derived from the present data to predict several statistics about the distribution of galaxy light in the local Universe. We show that roughly 50 percent of all light is produced in haloes less massive than $2\times10^{12} M_\odot/h$. We also derive the probability distribution $\Phi(L|M)\, dM$ that a galaxy of luminosity L resides in a halo with virial masses in the range $M \pm dM/2$.

Some numerical staffs concerning the DWT and the two dimensional projection of NFW profile are presented in the Appendix.

Keywords：Cosmology, the large-scale structure, galaxy, statistics