論文の内容の要旨

Building the model of redshift-space galaxy power spectrum based on machine learning and its application to SDSS data for cosmology inference

(機械学習を用いた赤方偏移空間銀河パワースペクトルのモデル構築 とSDSSデータの宇宙論推定への応用)

氏　名　小林　洋祐

The redshift-space power spectrum, characterizing the three-dimensional distribution of galaxies collected by wide-area spectroscopic surveys, is one of the most powerful probes of cosmological parameters. To obtain unbiased and stringent cosmological constraints, we need a sufficiently accurate theoretical template to meet the statistical precision expected by modern large-scale surveys. At the same time, we have to make a proper treatment on the uncertainty of the galaxy bias, i.e., the relationship between the spatial pattern of the observed galaxies and the underlying density field dominated by dark matter. A standard analysis method used in the literature is to use the analytic theoretical prediction based on the perturbation theory (PT) of the large-scale structure formation, with a set of nuisance parameters that model galaxy bias. However, the PT-based models cease to be accurate on smaller scales where the PT breaks down due to strong nonlinearities, and cannot extract cosmological information contained in such scales. To tackle this problem, in this dissertation, I present the achievements in three important steps: the construction of a theoretical template, the theoretical assessment of the cosmological parameter constraints, and the cosmological parameter inference from the real survey data.

For the theoretical template, we use an ensemble of high-resolution N-body simulations for 101 flat-geometry wCDM cosmology to construct an emulation software enabling fast, accurate computations of the redshift-space power spectrum of dark matter halos that is valid up to $k_{\rm max} \simeq 0.6\,h\,{\rm Mpc}^{-1}$, based on a feed-forward neural network. Galaxies, at least massive, early-type galaxies, tend to reside in dark matter halos with masses larger than $10^{12}\,h^{-1}\,M_{\odot}$, which our emulator can handle. The emulated redshift-space halo power spectrum includes various nonlinear effects relevant for the clustering of the observed galaxies, that are difficult to accurately model with an analytic method such as the PT. Aided by simple recipes to connect the simulated halos to the observed galaxies, our emulator has the flexibility to express the complex galaxy formation physics and its variety among galaxy samples based on different selection criteria. The emulator-based method enables us to compute the redshift-space galaxy power spectrum for a set of input parameters at less than one CPU second. This corresponds to a factor of 10^6 reduction in

computational time compared to brute-force method (run N-body simulations, identify halos, populate galaxies, and then measure the power spectrum from a mock galaxy catalog).

For the assessment of cosmological constraints, we investigate how the nuisance parameters contained in our approach affect the cosmological parameter constraints from the redshift-space galaxy power spectrum which simulates a real galaxy survey. We show that there is the cosmological information content available in the power spectrum on scales smaller than those where the PT is valid, even after the marginalization over various nuisance parameters.

For cosmology inference, we first perform validation tests of the emulator-based method by comparing the emulator-based predictions with the hypothetical power spectrum measured from mock catalogs of SDSS galaxies. We found that our method can recover the underlying cosmological parameters to within the statistical credible intervals. We also confirmed that we can obtain more stringent constraints on cosmological parameters using the power spectrum information beyond $k = 0.1\,h\,\mathrm{Mpc}^{-1}$ up to 0.2 or 0.3 $h\,\mathrm{Mpc}^{-1}$, where the PT-based models tend to break down. We then apply our method to the SDSS-III galaxy power spectrum assuming the flat ΛCDM cosmology. We obtain the constraints on cosmological parameters such as Ω_m, σ_8, and H_0, which are comparable with the recent analysis based on the PT-based method. We succeed to obtain cosmological parameter constraints from the full N-body simulation-based method for the first time, and the method developed here should be useful for upcoming surveys such as Subaru Prime Focus Spectrograph, Dark Energy Survey Instrument, *Euclid* and Roman Space Telescope.