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Discriminating Dark Energy Models by Statistics of the Peak Count and Scale-scale Correlation of Weak Gravitational Lensing[⋆]

LI Ming[△]

Department of Astronomy, Nanjing University, Nanjing 210093

Abstract In order to study the weak gravitational lensing effect under different cosmological models, the 2-dimensional κ-field samples are generated by using the ray-tracing method with high-resolution N-body simulation data. These samples correspond to three models with different parameters of dark-energy equation of state, i.e., ω =-0.8, ω =-1.0 and ω =-1.2, and have the same field of view of $3^{\circ}\times3^{\circ}$. It is assumed that all galaxies, as background sources, are distributed on the plane of z =1. The statistics of peak count and scale-scale correlation are performed on these samples. The statistical result of peak counts indicates that in the noisy κ field, some differences of peak distributions exist among various models. The noise has changed the distributions of the peaks with medium and low amplitudes, but has nearly no effect on high-amplitude peaks. However, after denoising the differences of high-amplitude peak distributions among various models become very clear. For the statistics of scale-scale correlation, the cumulative probability distribution functions of scale-scale correlation coefficients of different models are analyzed. It is found that the differences between the model of ω =-1.2 and the models of ω =-1.0 and ω =-0.8 can reach 20% and 30%, respectively. Hence the statistics of scale-scale correlation combining with the statistics of peak count can be taken as a new method to determine the dark energy equation-of-state parameter.

Key words: cosmology: large-scale structure of universe—gravitational lensing: weak —methods: numerical

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[△] disiheng@gmail.com

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1. INTRODUCTION

In the past ten and more years, the phenomenon of gravitational lensing has become a powerful measure for understanding the mass distribution in the universe. The action range of gravitational lensing may have the scales from a single galaxy or galaxy cluster to the cosmic large-scale structure. As the galaxy cluster is the maximum virial celestial body in the universe, the spatial distribution of galaxy clusters as well as their formation and evolution depend on the cosmological parameters[1−2].

As the weak gravitational lensing is insensitive to the specific states of matter, in the past it was believed that the samples of clusters can be precisely reconstructed by using the high-SNR peaks in the shearing field or κ field of weak gravitational lensing. But the observed effect of gravitational lensing has undergone a projection along the line of sight, hence the signal of weak gravitational lensing represents in fact the intensity of the mass density projected along the line of sight, or in other words, it is determined by the strength of the shearing field produced by the mass density projected along the line of sight. Therefore, the sample of clusters selected from the weak gravitational lensing signals has certain difference from the real sample. Besides, as a kind of noise, the intrinsic ellipticity of background sources affects also the efficiency to select the cluster sample by using the weak gravitational lensing signals[3−4]. The background noise can be described with a smoothed 2-dimensional Gaussian random field[5]. The introduction of noises makes the number of peaks in the κ field increase, and makes the form of their distribution change[4,6], but it has not changed the differences among various models[2]. For the noisy shearing field, the cluster sample can be reconstructed through an analysis of aperture mass with corresponding filter windows[7−9]. Reference [10] compares the effects of 3 kinds of filter windows, and indicates that the optimized filter window proposed by Maturi et al.[9] can suppress very well the spurious peaks caused by the projection effects of large-scale structures. But the background noise is still the major factor affecting the reconstruction of the cluster sample.

In order to study the properties of the peaks in the κ field under the different ω-parameters of dark energy equation of state and by using N-body simulations, the dark matter distributions in different models are obtained at first, then with the ray-tracing method[6,11−13], the sample of κ fields is simulated. As the κ field is pixelized, we define the local maxima as the peaks, including the positive and negative ones. Because in the simulations with different models, the identical initial power spectrum is used, so at the time of z =0, the normalization parameter σ_8 is model-dependent. Hence the peak statistics in this paper embodies the dependence on both parameters ω and σ_8.

Besides, in the wavelet space, the correlations at different scales are studied for the κ field. In the 3-dimensional matter distribution, the nonlinear evolution of matter makes the matter structures on different scales strongly correlated, reflecting the effect of the graded clustering process. Under various models, the evolution of matter structures will affect the correlations on the scales in a small range, therefore it causes a difference between the shearing field and the κ field. By using the scale-scale correlation statistics[14], we have tested the difference and similarity among the κ fields under different models.

The remaining part of this paper is organized as follows: Sec.2 introduces briefly the ray-tracing method that is used for simulating the weak gravitational lensing effect of a large-scale structure; Sec.3 describes the methods of the peak statistics and scale-scale correlation

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