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Correlation Analysis between Spin, Velocity Shear, and Vorticity of Baryonic and Dark Matter Halos† ⋆

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Abstract Based on the cosmological hydrodynamic simulations, we investigate the correlations between the spin, velocity shear and vorticity in dark matter halos, as well as the relationship between the baryonic matter and the dark matter. We find that (1) the difference between the vorticity of baryonic matter and that of dark matter is evident on the scales of $< 0.2\ \mathrm{h}^{-1}$ Mpc; (2) the vorticity of baryonic matter exhibits a stronger correlation with the tensor of velocity shear than the vorticity of dark matter does; and (3) the spinning direction of small-mass dark matter halos tends to be parallel to the direction of their host filaments, while the spinning direction of massive dark matter halos tends to be perpendicular to the direction of their host filaments, and the intensity of this kind correlation depends on the size of simulation box, and the simulation accuracy. These factors may cause the relationship between the the spins of dark matter halos and those of galaxies to be complicated, and affect the correlation between the galaxy spins and the nearby large-scale structures.

Key words Cosmology: dark matter, large-scale structure of Universe—Methods: numerical, statistical

1. INTRODUCTION

Both the cosmological simulation and galactic redshift survey show a net-like structure of the large-scale mass distribution in the universe, which is composed of 4 geometric configurations of cluster, filament, sheet, and void[1]. The large-scale environment plays an important role

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in the evolutions of dark matter halos and galaxies[2,3]. In the past 20 years, the relation between galaxy properties and surrounding environments has been extensively studied, in which the correlation between the galactic spin direction and the filament/sheet structure is an important content to be studied.

In the study on the origin of galactic angular momentum, the tidal torque theory (TTT) is widely accepted, which has an important deduction that there is a correlation existed between the galactic spin direction and the tidal tensor[4,5]. And now there has been a lot of observational evidence to conform the existence of such a correlation[6,7].

There are some cosmological N-body simulation results to show that the spinning direction of dark matter halos is perpendicular to the direction of host filaments[8,9]; some other numerical simulations show that the spinning direction of small-mass dark matter halos is parallel to the direction of host filaments, while the spinning direction of massive dark matter halos is perpendicular to the direction of host filaments[10,11], and they suggested that the evolution of the spinning direction of dark matter halos in the nonlinear period is divided into two stages: (1) the small-mass dark matter halos are mainly formed by the accretion of surrounding matter, thus the spinning direction is parallel to the direction of host filaments; and (2) the massive dark matter halos are mainly formed by merging the small-mass halos along the direction of host filaments, thus the spinning direction of massive dark matter halos is perpendicular to the direction of host filaments. By the study of cosmological N-body simulations, Libeskind et al.[12] found that the turn-off mass M_{tr} of the parallel/perperdicular relations depends on the resident environment of the dark matter halos, the studied results of Aragon-Calvo et al.[10] showed that in the major filaments $M_{tr} \sim 1.5\times10^{12}\, M_{\odot}$, while in the secondary filaments, $M_{tr} \sim 4\times10^{11}\, M_{\odot}$. In addition, Zhang et al.[9] found that the spinning direction of dark matter halos is perpendicular to the normal vector of sheet structures. After studying the correlation between the spinning direction of dark matter halos and the vorticity, Libeskind et al.[12] found that there is a strong parallel relationship between the spinning direction of dark matter halos and the direction of vorticity.

In recent years, the correlation between galaxy properties and surrounding environments was analyzed by using the cosmological hydrodynamic simulations in some studies[13−15]. In the study of Dubois et al.[15], it was found that the spinning direction of small-mass galaxies tends to be parallel to the direction of filaments, while the spinning direction of massive galaxies tends to be perpendicular to the direction of filaments, and their results are consistent with the results of dark matter halos obtained by the N-body simulations, both of them are consistent with the assumption that the evolution of spinning direction is divided into two stages. The simulation results of Laigle et al.[14] also showed that in a scale larger than $0.39h^{-1}$ Mpc, the direction of vorticity tends to be parallel to the direction of filaments, while the spinning direction of dark matter halos also tends to be parallel to the direction of vorticity.