論文内容の要旨

論文題目

Small-scale density perturbations as a probe of the nature of dark matter

(小スケール密度揺らぎで探る暗黒物質の性質)

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The existence of dark matter in the Universe has been established by numerous cosmological and astrophysical observations on a wide range of scales. Its nature, however, has remained unknown for almost eighty years since its first postulation, and hence, the identification of dark matter is arguably the most important challenge in cosmology, astrophysics, and particle physics.

We investigate imprints of dark matter properties on small-scale density perturbations. Although cold dark matter (CDM) model is currently popular, particle physics candidates of dark matter are not completely cold and dark. In the structure formation with realistic candidates, the large-scale density perturbations are almost the same with CDM, but small-scale ones are not. Therefore, the deviation in the matter power spectra from CDM contains information of properties of dark matter.

Not only does the imprint on the matter power spectrum give us valuable information about the nature of dark matter, but also it may resolve the problems in the formation of small-scale structure in ΛCDM model ("small scale crisis"). The hierarchical structure formation in ΛCDM model predicts an order of hundred gravitationally-bounded objects in Milky Way-sized halos, while only a few tens of satellite galaxies are observed in Milky Way. This mismatch is called "missing satellite problem" and is an example of "small scale crisis". One possible solution to "small scale crisis" is warm dark matter (WDM). The thermal velocity of WDM behaves like effective "pressure" of dark matter fluid and suppresses the gravitational growth of small-scale matter density fluctuations. Several WDM candidates are suggested in the well-motivated particle physics models (e.g. light gravitino, sterile neutrino). In these models, the WDM particles are produced in different ways. On the other hand, the astrophysical and cosmological constraints (e.g. by the Lyα absorption lines in emission spectra from high-redshift quasars) on WDM is usually reported in terms of the light gravitino mass. It should be clarified how the WDM matter power spectra in different WDM models can be related. To this end, we introduced two quantities, the fraction of warm dark matter $r_{\rm warm}$ and the Jeans scale at the matter-radiation equality $k_{\rm J}$. We follow the time evolution of density perturbations in WDM models. From the simulation results, we confirm that the halo and the subhalo abundances and the radial distributions of subhalos are indeed similar between the different WDM models. The radial distribution of subhalos in Milky Way-size halos is consistent with the observed distribution for $k_{\rm J} \sim 20 - 260\,h\,{\rm Mpc}^{-1}$; such models resolve the so-called "missing satellite problem".

We also study how "warm" the wino dark matter is when it is non-thermally produced by the decays of the gravitino in the early Universe. The wino, which is the supersymmetric (SUSY) partner of the weak boson, is well-motivated candidate of dark matter after the discovery of the Higgs boson with a mass around 126 GeV. The "warmness" of the wino dark matter leaves imprints on the matter power spectra and may provide further insights on the origin of dark matter via the future 21 cm line survey. In addition, we perform similar analysis to the bino-wino co-annihilation scenario in high-scale supersymmetry breaking models. Although the collider experiment can not search the bino dark matter directly, the imprints on the matter power spectra can be a direct probe.

Finally, we explore the discovery potential of light gravitino mass $m_{3/2}$ by combining future cosmology surveys and collider experiments. The gravitino mass is one of the fundamental parameters in SUSY theory that is directly related to the SUSY breaking energy scale. We focus on the gauge-mediated supersymmetry breaking (GMSB) model that generically predicts the existence of light gravitinos with $m_{3/2} \sim$eV-keV. We show that the light gravitino mass can be determined with an accuracy of $m_{3/2} = 4 \pm 1\,{\rm eV}$ by a combination of the Hyper Suprime Cam survey and cosmic microwave background anisotropy data obtained by Planck satellite. Data from experiments at Large Hadron Collider at 14 TeV will provide constraint at $m_{3/2} \simeq 5\,{\rm eV}$ in the minimal framework of gauge-mediated supersymmetry breaking model. We conclude that a large class of the GMSB model can be tested by combining the cosmological observations and the collider experiments.