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Research Progress on Dark Matter Model Based on Weakly Interacting Massive Particles† ⋆

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Abstract The cosmological model of cold dark matter (CDM) with the dark energy and a scale-invariant adiabatic primordial power spectrum has been considered as the standard cosmological model, i.e. the ΛCDM model. Weakly interacting massive particles (WIMPs) become a prominent candidate for the CDM. Many models extended from the standard model can provide the WIMPs naturally. The standard calculations of relic abundance of dark matter show that the WIMPs are well in agreement with the astronomical observation of $\Omega_{DM}h^2 \approx$0.11. The WIMPs have a relatively large mass, and a relatively slow velocity, so they are easy to aggregate into clusters, and the results of numerical simulations based on the WIMPs agree well with the observational results of cosmic large-scale structures. In the aspect of experiments, the present accelerator or non-accelerator direct/indirect detections are mostly designed for the WIMPs. Thus, a wide attention has been paid to the CDM model based on the WIMPs. However, the ΛCDM model has a serious problem for explaining the small-scale structures under one Mpc. Different dark matter models have been proposed to alleviate the small-scale problem. However, so far there is no strong evidence enough to exclude the CDM model. We plan to introduce the research progress of the dark matter model based on the WIMPs, such as the WIMPs miracle, numerical simulation, small-scale problem, and the direct/indirect detection, to analyze the criterion for discriminating the "cold", "hot", and "warm" dark matter, and present the future prospects for the study in this field.

Key words dark matter—weakly interacting massive particles—relic abundance—free-streaming scale

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1. INTRODUCTION

The cosmological study has entered the era of precise cosmology in the past ten and several years because of the accurate measurement of cosmic microwave background (CMB) radiation by the WMAP satellite[1], the observations of Sloan Digital Sky Survey (SDSS)[2] on the large-scale structures, and the observation on a larger sample of supernovae[3], etc. The cold dark matter (CDM) model with the dark energy and a scale-invariant primordial power spectrum has successfully explained the observed cosmic large-scale structures, and the predicted clustering scenario of cosmic structures is also in agreement with the observations to a certain degree, hence, this model is considered as a standard CDM cosmological model (ΛCDM model).

What kind of particles correspond to the dominant dark matter in the ΛCDM cosmological model? It is widely accepted that they are the weakly interacting massive particles (WIMPs). We plan to introduce the research progress of the WIMP dark matter model, thus to understand the reason why the WIMPs become a prominent candidate for the CDM.

Different dark matter models can produce different microwave background fluctuations, to affect the formation and evolution of cosmic structures. Though the ΛCDM cosmological model has successfully explained the formation and evolution of large-scale structures, it is not consistent with the astronomical/cosmological observations in the aspect of small-scale structures. To establish a cosmological model self-consistent with the observation based on the dark matter is always an attractive research field of cosmology. Herein, the dark matter becomes a hot point in the research of contemporary cosmology, which is of important significance for understanding the matter distribution and evolution in the universe and the nature of dark matter, as well as for the direct/indirect detection of dark matter.

2. WIMPS

Because that the standard model of particle physics cannot provide a kind of elementary particles to construct the main part of dark matter, and that the interaction between the dark matter particle and the standard model particle is very weak, which makes the direct detection become difficult, so that we almost know nothing about the nature of dark matter, even for the knowledge of its mass, there is an uncertainty of several ten orders of magnitude existed.

It is interesting that for solving the problems of gauge hierarchy, strong CP (charge parity), parity violation, etc., the physicists have constructed many so-called new physical models beyond the standard model[4−7], such as the super-symmetry model, extra-dimension model, axion model etc. Something like "buy one and get one free", these models often contain a new kind of stable and neutral particles, which may be a candidate of the dark matter particles. In general, if there is an independent symmetry in the physical models, then the lightest particle with an odd charge under this symmetry should be the most stable