Chapter 1

Introductory Chapter: The Physics of Dark Sector

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1. On the physics of dark sector

In the last two decades, researches in cosmology and astrophysics provided an important source of data about the gravitational and evolutionary structure of the universe, which stimulates a demand for gravitational theories beyond general relativity in the face of the new conjuncture of the problems of contemporary physics. The physics of dark sector has been one of the most intriguing problems of physics. Since the rise of dark matter problem in the very beginning of the twentieth century and the appearance of the dark energy in the end of 1990s, they launched a new scenario for contemporary physics and some examples of questions can be made such as: Have those problems a true substance of reality? Is there an underlying new physics that describes such issues? Is it possible to explain those problems without changing the ordinary physical theories? Do we need another particle theory? And the central point, what is gravity?

Since the works of Einstein, our sense of gravity had been radically changed since it can be interpreted as a geometrical effect. Einstein's new approach indicated that geometry plays a fundamental role in a physical process. More interestingly, one can state a more profound meaning on gravity as: gravity does not need matter to exist. In Einstein's sense, gravity is also self-interactive, that is, Einstein's field equations exist on vacuum that evinces the grandeur of a geometric approach on a physical theory. In other words, general relativity is the only physical theory that allows a nontrivial vacuum solution. It must be said that it is rather different from Newton's theory of gravitation that a vectoral field of force does exist to provide interaction between two separated masses. Nonetheless, the problem of searching physics for dark sector essentially involves finding eventually new prospects on the meaning of gravity, once dark matter problem and the dark energy are at the first instance effects of gravity.

This book is devoted to discussing fundamental aspects of the dark matter problem. The modern roots on the dark matter problem were basically launched in the 1930s, with Zwicky's observations [1] on a notorious discrepancy of mass in coma cluster that presented 500 times of mass than expected using Newtonian theory (virial theorem). Curiously, this fact passed practically unnoticed in scientific community and it was taken seriously decades later with the observations of galaxies. Only in 1970s, Zwicky's *missing mass problem* was reinforced by Vera Rubin [2] with observations in spiral galaxies showing a huge discrepancy of Newton's law on that scale. Until now, the so-called dark matter problem is still one of the greatest challenges of both observational and theoretical physics.

According to recent observations on Planck collaboration [3], roughly 5% of the universe is known and the rest of it is made of dark components. The dark matter accounts for 26.8% and the dark energy, a sort of energy that may drive the universe to speed up with negative pressure, responds to 68.3% of the universe composition. Moreover, the gravitational field of dark matter cannot be produced by baryons-only by the analysis of the first peak in the power spectrum of the cosmic microwave background radiation. The observations on optical X-ray and gravitational lensing [4] also suggest that the bullet cluster cannot be explained without dark matter.

Since the mid-1980s, astrophysicists have been compiling evidence—such as cosmic microwave background observations, the supernova type Ia data and large-scale structure—that the late-time universe is accelerating. The simplest candidate to explain this acceleration, within the framework of general relativity (GR), is a positive cosmological constant (CC). Many theoretical physicists were reluctant to consider CC as an explanation for acceleration of the universe, since the natural predicted value for CC from particle physics is $\rho_\Lambda \sim 10^{18}\mathrm{GeV}^4$, which has an enormous discrepancy with the astronomical bound for CC, $\rho_\Lambda \sim 10^{-3}\ \mathrm{eV}^4$, about 10^{122} times smaller.

The first evidence of a possible accelerated expansion of the universe was obtained through the Hubble Space Telescope of type Ia (SN Ia) supernova in 1998 [5, 6]. The data suggested the existence of some form of energy, or nonagglomerated matter, that should permeate most of the whole universe with negative pressure generating an accelerated expansion of the universe, that is, roughly speaking, providing a repulsive gravitational effect within the scope of general relativity, known as dark energy, and this finding is further reinforced with the agreement of 250 other events in supernova [5, 6] in independent astronomical observations.

One successful theoretical model for explanation of the accelerated expansion is to attribute the dark matter a role in the acceleration problem. The cosmological constant (Λ) plus cold dark matter (CDM) parametrization [7, 8], for short ΛCDM, aims at explaining both formation and growth of large structures in the universe as well as the accelerated expansion problem [9, 10]. One fundamental characteristic that favors the ΛCDM model concerns its applications to cosmological scale and provides a simulation of the growth of the larger structures of the universe consistent with the observations on large scale structure (LSS) surveys [11]. On the other hand, it lacks a more underlying explanation on the nature of the CC itself and dark matter, which leaves unsolved the question from the first principles.

This book is divided into two sections. The chapters aim at discussing different aspects on the dark matter problem by some experts in the field. The first section is devoted to historical aspects of dark matter phenomenology. The author presents a critical review of the dark matter problem. The subsequent chapters discuss technical scientific advances in the field with a study on a mechanism of couplings of dark matter and dark energy. Moreover, a study of black hole physics is present with the research of interior solutions of Schwarzschild black hole, a discussion on black hole thermodynamics and its role in the dark sector. It has been a great opportunity to work again with InTech's editorial team and such an honor to read all the proposed chapters.

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