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Editorial

Origins and Natures of Inflation, Dark Matter and Dark Energy

Kazuharu Bamba

Faculty of Symbiotic Systems Science, Fukushima University, Fukushima 960-1296, Japan; bamba@sss.fukushima-u.ac.jp

Various precise cosmological observations, e.g., Supernovae Ia (SNe Ia) [1,2], the cosmic microwave background (CMB) radiation [3–8], the large-scale structure (LSS) of the universe [9,10], the baryon acoustic oscillations (BAO) [11,12], and the effect of weak lensing [13–15], have strongly suggested that the accelerated expansion of the present universe is realized in addition to inflation in the early universe [16–19]. In particular, according to the recent Planck results [7,8], for the spatially flat universe, the energy of the current universe is composed of the following three components: (i) Dark energy (around 70%), an unknown type of energy with negative pressure; (ii) Dark matter (around 25%), which does not shine and has only its gravitational interaction; (iii) Baryon (around 5%), i.e., basically protons and nucleons.

It is expected that more detailed and precise observational data in terms of modern cosmology will be obtained by the Euclid satellite [20] of the European Space Agency (ESA) [21–27]. Moreover, the events of gravitational waves have been detected [28,29], along with cosmology, through further future observations of the gravitational waves not only from astrophysical compact objects, but also the origins in the early universe, including inflation and cosmological phase Electro-Weak (EW) and QCD transitions [30–33].

Two representative approaches have been explored so that the mechanism of the accelerated expansion of the late-time universe can be understood. The first approach is to assume the existence of dark energy such as the cosmological constant within general relativity. The second is to extend a gravity theory from general relativity at large scale. The latter is interpreted as a kind of geometrical dark energy. Various extended theories of gravity have been studied (for detailed reviews of the physics of the cosmic acceleration, dark energy, alternative theories of gravity, and their cosmological and astrophysical applications and investigations, see, e.g., Refs. [34–63] and references therein). This Special Issue of *Universe*,"Origins and Natures of Inflation, Dark Matter and Dark Energy", collects eleven original research manuscripts on the topics of inflation, dark matter, and dark energy. The Special Issue is organized as follows. Firstly, the topic of inflation [64] related to the origin of dark matter is discussed. Secondly, both theoretical and experimental studies of dark matter are described. In particular, quark-nugget dark matter [65–67] and axion-like particles [68–70] are investigated. After that, the subjects of dark energy [71,72] and modified gravity theories [73] are explored. In the end, acting as a summary of sorts, a recent review on modern cosmology in terms of dark energy, dark matter, as well as inflation [74] is included in this Special Issue. See below for a brief overview of the ten research articles and one review included in this Special Issue.

In Ref. [64], as a candidate of small primordial black holes, the discretely charged dark matter is studied in inflationary cosmology with the holographic spacetime. A new model of black holes created by inflation is proposed. The Big Bang universe is realized by the decay of the black holes, and the charge of a discrete symmetry has the smallest value. The fraction of the inflationary black holes carrying this charge is determined for the case in which the universe enters the matter-dominated stage from the radiation-dominated stage at a cosmic temperature of approximately 1 eV.

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In Ref. [65], as a candidate of dark matter, the limits on magnetized quark nugget constructed by up, down, and strange quarks, whose numbers are approximately equal, are analyzed based on episodic natural events. This is an application of the implication that the center part of magnetar is composed of quark nuggets, which are a liquid state with a ferromagnetic nature. Magnetized quark nuggets are known to form and aggregate before decaying, and their mass distribution is broad and stabilized by magnetic fields. Through the magnetopause, magnetized quark nuggets can interact with ordinary matter. During this process, their translational velocity decreases and their rotational velocity increases, and the energy of electromagnetic fields radiates. In this work, rare events compatible with the property of magnetized quark nuggets are explored. The strength of magnetic fields covering quark nuggets is constrained and a proposal to test whether magnetized quark nuggets can be a candidate of dark matter is supported.

In Ref. [66], for a possible candidate of dark matter, magnetized quark nuggets are evaluated based on their radial impacts on the earth. At the early stage of the universe, magnetized quark nuggets formed and aggregated before decaying through the weak force with a wide distribution of mass. An event has been reported which may support the presence of magnetized quark nuggets. The parameter of magnetic fields on the surface determines the distribution of the mass of magnetized quark nuggets and the cross section of the interaction. Sufficient energy may be transferred to create craters that do not originate from meteorites. In the present work, the computer simulations for the energy deposition of magnetized quark nuggets are performed for an environment containing peat saturated by water, soft sediments, and granite. Moreover, the report of the excavation of the crater is shown. Five agreement points of the observations with the computer simulations support the second event, which suggests magnetized quark nuggets. Furthermore, the potential qualification of more events for magnetized quark nuggets is discussed.

In Ref. [67], the possibility that the multi-modal events of the Horizon-10T are related to quark nuggets of axion fields is discussed. Multi-modal events with several peaks, implying they originated from clustering, were reported by the Horizon-10T collaboration. It is proposed that the events of the annihilation of dark matter would lead to these multi-modal events in a dark matter model of quark nuggets of axion fields. This is because it is too difficult to understand these events based on an ordinary interpretation with cosmic rays. It is demonstrated that various observational results such as the frequency of their appearance, the intensity, the distribution of space, the duration of time, and the property of the clustering may be compatible with the nature of the emission from the events of the atmosphere for the annihilation of quark nuggets of axion fields. In addition, in light of the ordinary air showers of the cosmic rays, many properties relating to the events of quark nuggets of axion fields are discussed.

In Ref. [68], a photon collider of the resonance of the stimulation with the fields of the focused lasers is investigated. The present collider with three beams is used for the direct production of particles like axions. Two beams are used to create axion-like particles and the other beam is used to simulate the decay of such particles. This research explores how suitable the photon collider is for examining particles like axions whose mass range is about eV. It is shown that the particles like axions with a mass around the eV range may be probed. In addition, the sensitivity of the coupling between particles like axions and photons is analyzed.

In Ref. [69], a pilot survey of particles like axions is performed using a photon collider. The photon collider is used for the resonance of the stimulation, and it has three beams with the lasers emitting short pulses. In the case of the present photon collider of the resonance of the stimulation, three laser beams with short pulses are focused into a vacuum so that the particles like axions, with a mass range around eV, can be detected systematically. In order to realize such a collider, a proof-of-principle experiment is described. The incident angles of these three beams are made large to solve the problem in that the overlap of the spacetime of the lasers with short pulses must be maintained. Moreover, a way of evaluating the bias of the states of the polarization is investigated. This method is important in a system for a collision with variable incident angles in the future. This paper describes the consequences of this pilot survey, as well as this method by using the exploited system. The result of this survey is compatible with the null state. The largest possible value for the minimum of the coupling between particles like axions and photons is also derived.

In Ref. [70], the plan and composition of a photon collider are presented. The photon collider that provides the resonance for the stimulation has three very strong laser beams with variable angles. The purpose of this collider is to survey particles like axion whose mass scale is around eV. The angle of the emission of these three laser beams can be changed, and therefore the energy of the collision for the system of the center of mass may vary. As a result, the mass range around eV can be surveyed continuously. Furthermore, through the calibration of laser beams, the mechanism of the variation of the angle is verified. The realistic value of the sensitivity of the photon collider is also projected for a future survey.

In Ref. [71], a scenario in which dark energy is unified with dark matter is proposed as a novel version of a dark energy model of generalized Chaplygin gas. The evolutions of the Hubble parameter and distance modulus for the present scenario under considerations and the ΛCDM model are explored. The theoretical consequences are verified using cosmological observations. In addition, two geometric diagnostics are analyzed to distinguish the new model from ΛCDM. Furthermore, with different observational data points, the trajectories of the evolution for the planes of the diagnostic are explicitly depicted to investigate the geometric property of the proposed new model.

In Ref. [72], the solutions of the homogeneous and anisotropic spacetime of the Bianchi type I are derived for a quintom theory with multifield chirality. In such an extended chiral model, the energy density of one or two scalar fields is negative. When a degree of freedom of this theory is removed, the original quintom theory appears. The Kasner type analytic solutions and an exponential form with anisotropy are found in terms of the potential of the scalar field with its specialized functional expression. Moreover, based on the Noether symmetry, the theories are classified by their symmetries and the laws of conservation are also demonstrated.

In Ref. [73], a solution of charged, nonlinear black holes with is explored as part of the Rastall gravity theory. The model parameter in the theory does not influence the solution of the linear gravitational field equation for a charged black hole with spherical symmetry. On the other hand, if a nonlinear electrodynamic source exists, a new spherically symmetric black hole solution involved with the Rastall parameter, mainly originated from the non-vanishing trace part of the nonlinear electrodynamic source, is derived. In addition, it is demonstrated that the new black hole solution is regarded as the Reissner–Nordström one for the anti-de Sitter spacetime, where the cosmological constant includes the model parameter of the Rastall gravity. When the case is limited to general relativity, in which the Rastall parameter vanishes, the new solution corresponds to the solution of Reissner–Nordström spacetime. Furthermore, by analyzing the geodesic deviation of gravitational field equations and thermodynamic properties, including the first law of thermodynamics, it is shown that this black hole solution is stable, differing from the charged case with the linearity, in which the second-order phase transition occurs.

In Ref. [74], with recent various cosmological observational data, the constrains on dark energy models in which a dynamical scalar field plays the role of dark energy are overviewed in detail. Such scalar fields are classified into two types: a canonical scalar field called quintessence, whose value of the equation of state is larger than -1 and less than $-1/3$; and a kind of non-canonical scalar field called the phantom field, whose value of the equation of state can be less than -1. The value of the equation of state of the cosmological constant is -1. The energy density of such a scalar field can lead to the late-time accelerated expansion of the universe. The background and theoretical motivations of these models are presented. A scenario in which dark energy interacts with dark matter is also described. The recent observational constraints on the theoretical model parameters are explained. It is demonstrated that the ΛCDM model with spatial flatness is favored by the observations, and that the dark energy models consisting of such a scalar field may still be compatible with the cosmological observations.

It is considered that the eleven papers that comprise this Special Issue will provide useful references for future works investigating the origins and natures of the mechanism of inflation, dark matter and dark energy in modern physics and cosmology.

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