universe

MDPI

Editorial

Shedding Light to the Dark Sides of the Universe: Cosmology from Strong Interactions

Roman Pasechnik [1,*] and Michal Šumbera [2]

[1] Department of Astronomy and Theoretical Physics, Lund University, SE-223 62 Lund, Sweden
[2] Nuclear Physics Institute CAS, 25068 Řež, Czech Republic
* Correspondence: roman.pasechnik@thep.lu.se

The basic aim of this Special Issue was to reflect upon the modern status of research on strong interactions and their implications in Cosmology. In addtion to a few important original research articles, our Special Issue comprises a collection of reviews on existing implications of the physics of strongly coupled and non-perturbative phenomena such as those in Quantum Chromodynamics (QCD) to the universe evolution in different epochs. Such implications concern, in particular, cosmological aspects of quark–gluon plasma and phase transition dynamics, the physics of neutron stars, QCD equations of state (EoS), as well as the origins of Dark Matter (DM) and Dark Energy (DE) from both dark sectors and QCD, inflationary cosmology, etc.

A broad review [1] by the Guest Editors and their collaborators provides a comprehensive outlook of the key research results in the field of confined and de-confined QCD dynamics and their implications in physics of the early Universe. In addition, it briefly covers the basic methodology for studies of quantum field theories in the strongly coupled regime on the non-stationary background of the expanding Universe. A few rather important connections between currently pursued research in particle physics and possible dynamics of the early Universe have been identified and elaborated upon, potentially addressing such fundamental questions as particle production mechanisms in the early Universe, the origins of cosmic acceleration, and the non-perturbative real-time dynamics of the QCD ground state, among others. Given the broadly inter-disciplinary coverage of a variety of different and challenging topics, this review represents an important, but not exhaustive, reference for frontier research at an intersection of particle physics and cosmology.

The review [2] by Vitaly Beylin, Maxim Khlopov, Vladimir Kuksa, and Nikolay Volchanskiy discusses some of the basic cosmological effects of strongly coupled New Physics focusing on the possible nontrivial role of strong interactions. One particular example is the presence of new stable colored particles, such as exotic quarks, which could give rise to a composite DM candidate. In addition, an overview of new stable DM composite candidates was given in the context of QCD-like interactions in various scenarios of New Physics, broadly referred to as Techni (or Hyper)-Color. A particular emphasis was given on possible interactions of new stable particles with those in the Standard Model, with interesting implications for cosmic-ray and high-energy neutrino astrophysics and for the phenomenology of stable fractionally charged particles.

Another review [3] by Ralf Hofmann overviews possible cosmological consequences of a scenario when the SU(2) gauge principle governs the Cosmic Microwave Background (CMB) instead of U(1) one attempting to address the existing tensions between local and global cosmological measurements in the framework of ΛCDM. These consequences concern possible changes in the radiation and dark sector components of the Universe, as well as in the structure formation assisted by the de-percolation of condensed ultralight axion configurations with the Peccei–Quinn scale close to the Planck mass. It has been demonstrated that a compatibility of the axionic field profiles with typical DM galactic

check for updates

Citation: Pasechnik, R.; Šumbera, M. Shedding Light to the Dark Sides of the Universe: Cosmology from Strong Interactions. *Universe* **2022**, *8*, 545. https://doi.org/10.3390/universe8100545

Received: 9 October 2022
Accepted: 14 October 2022
Published: 19 October 2022

halos emerges if cosmological Yang–Mills fields confining at much higher energy scales than that of $SU(2)_{CMB}$ are responsible for the generation of the axion mass.

An extensive review [4] by G. Fiorella Burgio and Isaac Vidaña considers possible correlations between astrophysical observables of neutron stars (NS) and the properties of atomic nuclei. This review focuses in particular on the major role of the EoS of nuclear matter in defining the main characteristics of NS, including the existing experimental constraints. Such aspects of the NS phenomenology as the NS tidal deformability and its correlations with the stellar radius, the stiffness of the symmetry energy, and the neutron-skin thickness have been discussed.

The article [5] by Petr Jizba, Lesław Rachwał, Stefano G. Giaccari, and Jaroslav Kňap addresses the issue of a dynamical breakdown of scale invariance in quantum Weyl gravity (QWG), together with the related cosmological implications. In their study, which is based on the approach of functional renormalization group, the authors investigate the infrared (IR) physics of the quantum Weyl gravity and find it to be surprisingly rich and interesting, in particular in connection with the structure of its IR fixed point and the corresponding cosmological consequences. In a cosmology that is implied by the broken phase of QWG, they are able to map the broken-phase's effective action on a two-field hybrid inflationary model that, in its low-energy phase, approaches the Starobinsky $f(R)$ model with a gravi-cosmological constant that has a negative sign in comparison to the usual matter-induced cosmological constant. The implications of this finding for cosmic inflation are also discussed.

In the article [6] by Roland Kirschner and George Savvidy, it has been considered a new possibility that inside hadrons inhabitated by standard $SU(3)_c$ partons—quarks and gluons—there are additional partons–tensorgluons, which can carry a part of the proton momentum. Since the gluons do not couple directly to the photon in deep-inelastic scattering measurements, their density inside the hadrons is one of the least constrained functions. Here comes the opportunity for the tensorgluons: although their existence does not predict a new hadronic state, it leads to a modification of the parton distribution functions of a proton. Moreover, because tensorgluons have a larger spin than ordinary gluons, they can influence the spin structure of the nucleon.

The study [7] by Andrea Addazi, Stephon Alexander and Antonino Marcianò addresses an important fundamental issue of origin of the late-time cosmological acceleration due to the possible existence of an addition dark QCD-like matter sector. Using the arguments of strong dynamics, such as the formation of dark gluon and dark quark condensates breaking the chiral symmetry in the dark sector, the authors draw a conclusion that the interaction energy between the dark condensates may cause late-time cosmic acceleration, reproducing the observable effect of the cosmological constant.

Last but not least, the article [8] by Dmitri N. Voskresensky is devoted to evolution of quasiperiodic structures in a non-ideal hydrodynamic description of phase transitions. It starts with a general introduction to first- and second-order phase transitions. The latter could have taken place either in the early universe, in the course of heavy-ion collisions and supernova explosions, and also in proto-neutron stars, in cold compact stars, and in the condensed matter at terrestrial conditions. The author presents some novel solutions of non-ideal hydrodynamics describing the evolution of quasiperiodic structures that are formed in the course of the phase transitions. The most important result of this work concerns the finding that viscosity and thermal conductivity are the driving forces of the first-order liquid–gas and quark–hadron phase transitions to the state characterized by the zeroth wave number and by the instability occurring for temperatures below the isothermal spinodal region.

Funding: This Guest Editors' activity received no external funding.

Data Availability Statement: Not applicable.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Addazi, A.; Lundberg, T.; Marcianò, A.; Pasechnik, R.; Šumbera, M. Cosmology from Strong Interactions. *Universe* **2022**, *8*, 451. [CrossRef]
2. Beylin, V.; Khlopov, M.; Kuksa, V.; Volchanskiy, N. New physics of strong interaction and Dark Universe. *Universe* **2020**, *6*, 196. [CrossRef]
3. Hofmann, R. An SU(2) Gauge Principle for the Cosmic Microwave Background: Perspectives on the Dark Sector of the Cosmological Model. *Universe* **2020**, *24*, 135. [CrossRef]
4. Burgio, G.F.; Vidana, I. The Equation of State of Nuclear Matter: from Finite Nuclei to Neutron Stars. *Universe* **2020**, *6*, 119. [CrossRef]
5. Jizba, P.; Rachwał, L.; Giaccari, S.G.; Kňap, J. Dark side of Weyl gravity. *Universe* **2020**, *6*, 123. [CrossRef]
6. Kirschner, R.; Savvidy, G. Parton Distribution Functions and Tensorgluons. *Universe* **2020**, *6*, 88. [CrossRef]
7. Addazi, A.; Alexander, S.; Marcianò, A. Invisible QCD as Dark Energy. *Universe* **2020**, *6*, 75. [CrossRef]
8. Voskresensky, D.N. Evolution of Quasiperiodic Structures in a Non-Ideal Hydrodynamic Description of Phase Transitions. *arXiv* **2020**, arXiv:2001.10841.