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Editorial

Editorial for the Special Issue "The Modern Physics of Compact Stars and Relativistic Gravity 2017"

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This Special Issue arose from the presentations of the authors at the international conference "The Modern Physics of Compact Stars and Relativistic Gravity 2017" https://indico.cern.ch/event/597202/. It covers several modern topics from the fields of dense matter, compact stars, cosmology, and relativistic gravity.

The first conference of the seires "The Modern Physics of Compact Stars and Relativistic Gravity" was held in 2008, which was dedicated to the 100th anniversary of the prominent Soviet-Armenian astrophysicist Viktor A. Ambartsumyan (1908-1996). The 2017 edition, from which the articles collected in this issue originate, was the fifth in this series. It was held at Yerevan State University, Armenia, in September 2017. Traditionally, the major themes of the conferences are the astrophysics of compact stars, physics of dense matter, gravitation and cosmology, observations of pulsars, and gravitational waves. Interestingly, the conference was held just a month after the first observation of a binary neutron star merger in gravitational and electromagnetic waves. This event (labeled GW170817) heralded the beginning of the multi-messenger astronomy of compact stars. While the physics of neutron star mergers and related topics were, indeed, discussed during the conference, this discovery had not been announced publicly at that time. It is gratifying that the physics of these phenomena went beyond pure theory (as discussed at the conference) and now can be tested against the data.

Compact stars play an important role in fundamental physics, as they provide us with an insight into the state of matter at very high (energy) densities. Comparable energy densities can be reached in terrestrial accelerators; however, the matter created in a laboratory is short-lived and out of equilibrium. Compact stars probe a unique portion of the phase diagram of dense matter, which is characterized by low temperatures, high densities, and large isospin asymmetries (neutron excess). The article by S. Typel [1] describes one of the most successful methods for treating the dense nuclear matter in compact stars. It is based on the relativistic density functional theory of nuclear matter, where the density functional is constructed starting from a certain baryon–meson Lagrangian and application of the mean-field approximation to obtain the thermodynamic characteristics of nuclear matter (typically pressure, energy density, number density, entropy, and so on). The focus of this article is on a sub-class of density functionals, which avoid introducing non-linear meson field terms but allow for density dependence of the meson–nucleon coupling accounting for the modifications of the form-factors due to the dense medium. The inter-relation between the equation of state of matter, as explored in heavy-ion collisions and astrophysics of compact stars, is discussed in the article by M. Hanauske et al. [2]. The article highlights the idea that models of nuclear matter, both phenomenological and microscopic, should successfully describe the observed phenomena in a unified way, thus manifesting the commonality of the underlying strong force that governs the physics at very different scales. The article by Harutyunyan and Sedrakian [3] is devoted to the microphysics of dense matter and focuses on the transport processes in quark–gluon plasma, which is a state of matter of deconfined nucleons that has been created in heavy-ion collisions at RHIC and LHC and has been conjectured to exist in the cores of neutron stars. The authors compute the bulk viscosity of such plasma, which is an important input (along with the shear viscosity) in the dissipative fluid dynamics description of hot and dense quark–gluon plasma. The article uses diagrammatic methods based on the computation of covariant correlation function(s) at non-zero temperature and density. It should be of interest, from the methodological point of view, to workers in the related fields of strongly correlated fermionic matter (e.g., neutron matter or ultra-cold quantum gases).

Turning to the macroscopic properties of compact stars, we start with the work of E. Abdikamalov et al. [4], which studies the supernova explosions in which compact stars are born. The complexity of supernova physics is best illustrated by the fact that, despite a half a century of numerical studies of stellar collapse and explosions, the precise mechanism that underlies the physics of type-II supernova explosions is not known. The neutrino-driven mechanism, due to Bethe and Wilson, is one of the most promising avenues to achieve a successful explosion. It relies on energy deposition by the neutrinos to revive the shock wave propagating through the matter. The article is a detailed numerical study of the interaction of the fluid vorticity and entropy waves with the supernova shock [4]. After their birth in supernova explosions, compact stars cool during the first ten thousand years through neutrino emission from their interiors. Their measured surface X-ray radiation is controlled by the neutrino losses from their interior, their thermal content, their composition, and (of course) their integral parameters, such as mass and radius. D. D. Ofengeim and D. A. Zyuzin perform, in their article, a new analysis of the X-ray emission by the prominent Vela pulsar [5] by considering a wide range of possible masses and radii for this pulsar. They argue that the cooling of the Vela pulsar does not require fast cooling agents, in general, or a direct Urca process, in particular. Compact stars are strongly magnetized objects, as is evidenced by their rotational slow-down by magnetic dipole radiation. In her article, M. Sinha [6] discusses an array of problems related to strongly magnetized compact stars, including the equation of state of magnetized matter, neutrino emission, and the interrelation between superfluidity/superconductivity and strong magnetic fields.

The equilibrium of compact stars arises from the balance of inwards-acting gravitational forces and the degeneracy (quantum) pressure, which resists this force. The most common approach to constructing macroscopic equilibria of compact stars is to assume that the gravity is described by Einstein's general theory of relativity (GR). This theory predicts that there exists a maximum mass, beyond which compact stars are unstable and should collapse. From 2010, a number of pulsars orbiting white dwarfs have been observed, with masses around two solar masses. The inferred values are rather close to the theoretically predicted maximum mass of a neutron star. While the majority of researchers have focused on the features of the equation of state of dense matter to explain these large masses, assuming that GR is the correct theory of gravity, there exists the possibility that GR must be replaced by an alternative theory of gravity. The article by L. Grigorian et al. [7] discusses the masses (and other parameters) of compact stars in such an alternative theory of gravity, known as the bi-metric scalar-tensor theory of gravity. The authors show that in this theory, the masses of compact stars can, indeed, be significantly larger than in GR.

The formation of strings as a result of symmetry breaking in the early Universe and the consequences in modern cosmology and astrophysics is of great interest, both theoretically and observationally. The two articles by M. de Sousa et al. [8] and A. Saharian et al. [9] deal with cosmic string physics. Both calculate the vacuum expectation values (VEV) in the presence of a single straight cosmic string: The first paper deals with the VEV of the azimuthal current, while the second papers considers the electromagnetic field in various backgrounds. These articles provide new insights into some of the most fundamental properties of cosmic strings.

The review by K. A. Bronnikov [10] exposes the research developments on the spherically symmetric solutions of Einstein's equations which describe gravity coupled to a scalar field, where the author uses wormholes and black holes as examples. The article exposes some general results (theorems), before going on to discuss the stability of such objects against spherical perturbations.

The review by S. Pavluchenko [11] is devoted to the theories with extra dimensions, a topic that has been actively pursued within the past 20 years. The author concentrates on cosmological models with Einstein–Gauss–Bonnet gravity and discusses recent developments, focusing on the implications of various parametrizations of the scale factor.

The discovery of the accelerated expansion of the Universe has spurred immense activity in modeling the cosmological evolution of the Universe consistent with this observation. A line of approach is the reconstruction of the scalar field potential in a manner consistent with the SNe Ia data. The article by A. Piloyan et al. [12] suggests a method of reconstruction of this potential and concludes that the accuracy of the current data is insufficient for such a reconstruction.

The only experimental work in our collection is the report by R. Ajvazyan et al. [13] on the current state of the development of a specific target for low-energy nuclear astrophysics experiments. As such, it provides an update of a specific task in a large-scale experimental effort to measure astrophysics-relevant processes in the laboratory.

To conclude this brief editorial, it is hoped that the cross-disciplinary nature of this special issue, as well as the focus on frontier results, will make it a helpful resource, equally useful for students, early career researchers, and experienced practitioners.

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

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