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Editorial

Challenges of This Century in High-Density Compact Objects, High-Energy Astrophysics, and Multi-Messenger Observations: Quo Vadis?

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The era of multi-messenger astronomy has recently be inaugurated with pioneering experiments, theoretical interpretation, and models. We have advanced our understanding of many questions regarding gravitational waves, compact objects, and high-energy cosmic-ray physics.

There are reasons to believe that the 21st century will be the best ever for astrophysics: gravitational waves produced by compact objects (such as supermassive black holes (BHs), BH/neutron star (NS) mergers, gamma-ray bursts, and white dwarf inspirals) have unveiled a new area of astronomy. Framed by this background, compact stars represent unique astrophysical laboratories for the development of our theoretical understanding of microphysics (equations of state, particle composition, etc.) and the macrophysical structure of superdense matter in compact objects. In recent years, multi-messenger observations of these compact sources in binaries as well as in isolation, e.g., in X-rays (e.g., NICER, HXMT, XMM-Newton, Chandra, and Swift), gamma-rays (e.g., HESS, Fermi, VERITAS, and MAGIC), radio facilities (e.g., LOFAR, FAST, CHIME, VLA, ALMA, etc.), particles (e.g., Pierre Auger Observatory and Telescope Array), together with synergic analyses of gravitational waves, and neutrinos have given rise to new observational windows and constraints on compact stars' structures, on which this Special Issue welcomes discussions, including perspectives from forthcoming experimental facilities. We stress that several questions in high-energy astrophysics also remain a mystery. In the coming decades, we hope to further our understanding of the nature of ultra-high-energy cosmic rays (UHECRs); their composition; sources of UHECRs and GeV-TeV gamma-rays; the connections between galactic and extragalactic acceleration mechanisms; the generation, interactions, and the propagation of CRs and multi-messengers; and the description of re-acceleration scenarios based on gamma-ray observations. Furthermore, the future of astrophysics with the Cherenkov Telescope Array in operation, along with other high-energy experiments, will be a window of discovery and enhance our understanding of the universe in extreme energy conditions.

The aim of this Special Issue is to review the current state of the art and to explore the potential advancements in high-density compact objects, high-energy astrophysics, and multi-messenger observations.

It is worth mentioning that 2022 marks 55 years since pulsars were discovered. In that time, we have found more than 2000 pulsars, and we have used them to test the general theory of relativity and to hunt for gravitational waves. In fact, pulsars have changed our understanding of the universe, and their true importance is still unfolding. Fifty-five years on, we have a much better (but still incomplete) understanding of these extreme objects. Additionally, in 2022, we celebrated the 110-year anniversary of Victor Hess's discovery of cosmic rays with balloon flights; in these more than 100 years of study, we have advanced several high-energy questions to an unprecedented precision. The aim of this Special Issue is to bring together researchers from the fields of particle physics, nuclear theory and astrophysics who are working on these topics from different but complementary viewpoints. This Special Issue welcomes theoretical, analytical and observational research on these astrophysics topics.

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