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Editorial

What Lies Beyond the Standard Models of Particle Physics and Cosmology?

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What are the fundamental blocks of Nature, and how do they interact? This is the question since ancient times that modern theoretical physics tries to answer. In addition to that, despite the fact that our observable Universe is clearly four-dimensional, with the advent of Kaluza-Klein theories and Superstring Theory and the Lovelock theorem, one also may ask the questions: “How many spatial dimensions are there?” and “Is Einstein’s General Relativity the correct theory of gravity?” Although as of today all Einstein’s predictions have been confirmed, the current cosmic acceleration may be due to a modified theory of gravity. Besides, quantum effects are expected to generate higher curvature terms of the Gauss-Bonnet type.

On the one hand the Standard Model of Particle Physics and on the other hand the concordance cosmological model, based on cold dark matter and a positive cosmological constant, have been extremely successful explaining a wealth of experimental and observational data. Despite their success, however, it is nowadays widely accepted in the community that one must go beyond the Standard Models for several different reasons, such as the g-2 muon anomalous magnetic moment, tiny neutrino masses, dark matter and baryon asymmetry, the Hubble parameter H0 and the σ8 tensions etc, to mention just a few.

After the historical first direct detection of gravitational waves from binary black hole mergers, and the first image of a supermassive black hole shadow a few years back, we are now convinced that both black holes and gravitational waves exist in Nature. Radial and non-radial oscillation modes of pulsating stars, quasi-normal modes and tidal Love numbers of black holes, compact objects and ultra-compact stars/black hole mimickers depend on both the inner structure of the object and the underlying theory of gravity and/or the number of extra spatial dimensions. On the one hand, the frequencies of pulsating stars are extremely sensitive to their inner structure and composition. On the other hand, the inspiral and relativistic collision of two compact objects in a binary system, and the gravitational wave signal emitted during the process, contain a wealth of information on the nature of the colliding bodies.

Future gravitational wave observatories, such as LISA and the Einstein Telescope, combined with the PLATO mission on the Asteroseismology side and the Euclid mission, designed to investigate the mysteries of the “dark sector”, hopefully will help us understand in more detail “What comes beyond the Standard Models?” of Particle Physics and Cosmology.