Dynamical vacuum selection in extensions of the Standard Model - cosmological consequences in the context of experimental results

Description for the general public

The great triumph of the physics of elementary particles and fundamental interactions is the successful construction of the Standard Model which satisfactorily describes results of experiments performed at energies lower than the Fermi scale, i.e. the characteristic scale of the electroweak symmetry breakdown. At energies higher than the Fermi scale the electroweak symmetry becomes restored, and electromagnetism and weak interactions look to a good approximation as the same force. However, this model has a number of parameters and suffers from theoretical problems. As of today, we do not understand neither relations between these parameters nor their absolute values, which happen to be very different from each other. In addition, the Standard Model has problems in describing such important cosmological phenomena as bariogenesis and inflation, not to mention the mystery of the selection of the proper vacuum (which is a version of the famous big hierarchy problem). One of the reasons for the trouble is the necessity to embed the Standard Model into a theory fully operational at very high energies, perhaps dramatically higher than the Fermi scale. High energy physicists are convinced, that the Large Hadron Collider (LHC) will make it possible to learn about the detailed structure of the mechanism of the electroweak breaking and will pave the way towards the truly fundamental theory of elementary interactions. Nevertheless, it is the Early Universe which is the natural arena where the very high energy physics was fully operative. One recent important experimental result is the discovery of the gravitational waves from a binary black hole merger reported by VIRGO/LIGO collaboration, which opens the way towards gravitational wave spectroscopy as a tool of probing the phenomena occurring during the evolution of the Universe, as most of the cosmological events generate a specific signal via gravitational radiation. In this project we want to use to combine cosmological and astrophysical data with the precise measurements performed at the LHC to limit the freedom in the construction new of theories of elementary interactions (BSM - New Physics). In particular we shall concentrate on the issues of bariogenesis and of vacuum (meta)stability and on the considerations of dynamical vacuum selection in the early universe. Particular attention shall be given to natural and simple extensions of the Higgs sector of the Standard Model, including new light scalar and pseudo-scalar fields. The analysis of UV extensions of the Standard Model in the context of the LHC data and complementary cosmological tests, proposed in this project, offers an unique opportunity of addressing two fundamental questions. How does Nature select among multiple possibilities the low energy vacuum which corresponds to observed hierarchy of mass scales? And how is the stability of the electroweak vacuum achieved and cosmological catastrophes avoided, while a sufficiently large baryon asymmetry becomes generated? We also expect to extend the general knowledge about cosmological history history of our Universe. As a result, we should be able to learn about the mathematical structure of the extension of the Standard Model that is realized in Nature.