DRF: Thesis SL-DRF-20-0660

RESEARCH FIELD

Theoretical Physics / Theoretical physics

TITLE

The Higgs Boson Mass and Cosmology

ABSTRACT

Context: In our current description of Nature there are two parameters that have the strongest impact on the phenomenology of the Universe. At the same time they are the most sensitive to the details of the underlying theory at high energies. These parameters are the cosmological constant and the Higgs boson mass. The cosmological constant ultimately determines the size of the observable Universe. It was measured about two decades ago by studying the luminosity of high-redshift supernovae [1, 2]. The Higgs boson mass determines the vacuum expectation value of the Higgs field which enters the mass of most known particles and determines the scale of weak interactions. The stability of nuclei, and thus complex chemistry and ultimately life as we know it, are strongly tied to this parameter. The Higgs boson was discovered, and its mass measured, by the ATLAS and CMS experiments at the Large Hadron Collider (LHC) [3,4]. Theoretically it is hard to understand the measured values of the Higgs mass and of the cosmological constant. The difficulty has the same origin for both parameters and can be traced to quantum corrections and the symmetries of fundamental interactions. As a consequence the values of these parameters are still unexplained. In this proposal we study a class of ideas that tie the Higgs boson mass to the evolution of the Universe. This makes the values of the cosmological constant and of the Higgs mass deeply interconnected and points to the sky as the ultimate laboratory to understand their origin.

Thesis Project: We develop a class of ideas that ties the origin of the weak scale to the evolution of the Universe at early times and explore their connections to the cosmological constant. This has experimental

consequences for CMB-Stage4 experiments [5, 6], fifth-force searches [7–14], equivalence principle violation tests [15–17] and high-luminosity lepton colliders [18, 19]. I will consider models where the Higgs mass changes via a scalar field that is slowly rolling during inflation and stops at the observed value [20, 21] (Higgs mass “relaxation”) and models where the Higgs mass is dynamically selected at reheating [22].

Project (1a): Experimental Impact of the Cosmological Origin of the Higgs Mass. The first step of the project is to work out in detail the experimental implications of existing cosmological explanations of the Higgs mass. In the case of the reheating solution in [22], explaining the Higgs mass requires introducing dark sectors with the same particle content as the SM and a new particle that reheats them. We will consider the implications of fixing neutrinos, electrons or protons in the new sectors to be dark matter and work out the signatures in the CMB and in small scale structure [23]. We will also study the induced exotic Higgs and Z decays at lepton colliders and new particles at high-intensity beam-dump experiments. In the case of dynamical effects during inflation (including the class of ideas in [20, 21, 24]), the most interesting research direction is the study of the imprint on the CMB of the very unique models of inflation needed to make the mechanisms work.

Project (1b): Model Building Challenges in Cosmological Explanations. The first half of this project can be enough for a PhD thesis. If the student completes the work ahead of time, there is a second direction of investigation worth pursuing.

In this second part of the project we try to turn the proof-of-concept ideas in the first papers into more appealing, complete theoretical models. In the case of [22] one objective is to find dynamical constructions that require fewer copies of the SM for a fixed fundamental scale in the theory. A second objective is to improve the reheating mechanism, decoupling the mass of the particle responsible for reheating the Universe from the weak scale. This requires employing pre-heating and parametric resonance. In the case of [20, 21] and related ideas, the key open question is what is the model building price to pay to write a complete model that includes an explanation for their tiny dimensionful couplings and at the same time an inflationary sector that successfully reheats the SM. In some sense one can reformulate the question by saying that while these models make the weak scale technically natural they still do not explain its origin. At the end of this effort we will have more solid models or have conclusively disfavored this class of theories.

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