New approaches to the electroweak hierarchy problem

PhD project proposal

The Standard Model of Elementary Particle Physics contains a single dimensionful parameter, the mass parameter of the Higgs field, which sets the scale of electroweak symmetry breaking. Regarding the Standard Model as a low-energy effective field theory with an ultraviolet embedding in some unknown more complete theory, this parameter is expected to be sensitive to large quantum corrections from new physics effects at short distances. This so-called electroweak hierarchy problem was long expected to be solved by new dynamics in the experimental reach of the Large Hadron Collider, associated with new symmetries. Extensions of the Standard Model space-time symmetries (as in supersymmetric models) or its internal global and gauge symmetries (as in composite Higgs models) were postulated to manifest themselves at energies not far from the electroweak scale, protecting it from quantum corrections at higher scales due to, for example, grand unification or quantum gravity. Models with new TeV-scale symmetries generically predict new particles beyond the Standard Model with TeV-scale masses. During the first decade of LHC operations, however, no indications for the existence of such new particles were found. TeV-scale solutions to the hierarchy problem are now severely constrained and thus seem less and less likely to be realized in nature.

In recent years, several scenarios have been proposed to solve the hierarchy problem in a different manner, by coupling the Higgs field to light additional degrees of freedom. Notably, light scalar fields coupling to the Higgs bilinear could take expectation values such as to give an effective Higgs mass much smaller than the ultraviolet completion scale. The potential for these scalars may contain several local minima. The cosmological evolution of a scalar field may lead it to relax towards a local minimum where the electroweak symmetry is only marginally broken, thus solving the hierarchy problem [1]. It can also be envisaged to connect the hierarchy problem to an athropic solution to the cosmological constant problem, if the only minima with small vacuum energies are those with a small effective Higgs mass [2]. Alternatively, an additional scalar field might not be at the minimum of its potential but rather constitute a form of dynamical dark energy, in which case it has been argued to be able screen the effective Higgs mass from leading-order quantum corrections [3].

The first part of the proposed PhD thesis project will consist in studying this class of models, with the aim of extending and improving existing examples and constructing new ones. Some of the models in the literature require extreme parameter choices which, while technically natural, are unsatisfactory from the model-building point of view and tend to make it difficult to realize concrete UV embeddings. One of the project's goals will be to find new models with more clearly-defined UV origins and to investigate their properties and phenomenology. It should be particularly interesting to study possible signatures, either in cosmology or in terrestial experiments, which allow to differentiate between the various models.

A second, complementary approach to the hierarchy problem will form the second part of the thesis project. Given that the unnaturalness of a large hierarchy between the electroweak scale and a fundamental UV scale is a notion whose origins are in effective field theory, the aim will be to investigate what can be said about the problem beyond effective field theory. More specifically, it is generally expected that quantum gravity will not allow to cleanly separate ultraviolet from infrared effects as required in the EFT paradigm. It should be instructive to study a priori unrelated physical systems where IR and UV modes are connected by symmetries which are invisible from the low-energy point of view, with the long-term goal to learn something about the renormalization of the Higgs sector in quantum gravity. For example, a naturalness problem in the the effective field theory of black hole binary mergers has very recently been argued to be resolved by a symmetry of this kind [4]. To cite another example which is closer to actual particle physics, non-commutative fied theory has been proposed as a framework mimicking similar UV-IR mixing effects as could arise from quantum gravity, and has been studied as a toy model for addressing the electroweak hierarchy in [5]. This part of the thesis project has a less clearly defined roadmap and is conceptually more ambitious, but potentially more fruitful since new insights about the nature of the problem itself could be gained. The initial focus will certainly be on model-building and phenomenology, however the project may take a more theoretical turn depending on the evolution of the field and the student's preferences.

Candidates should have excellent analytical skills, a deep and earnest interest in fundamental problems, and a strong background in mathematics and theoretical physics. In particular, during their master's studies they should have taken courses in quantum field theory, theoretical elementary particle physics and general relativity, and by preference worked on a master's project in high-energy theory.

Practical information:

Funding will be provided for three years, subject to approval by the I2S graduate school of Montpellier University. The envisaged starting date is in October 2021.

The members of the Montpellier high-energy theory and cosmology group are affiliated either the Laboratoire Univers et Particules de Montpellier (LUPM), which will be student's host institution, or the Laboratoire Charles Coulomb (L2C). The group consists of nine permanent academic staff members (F. Brümmer, S. Davidson, M. Frigerio, C. Hugonie, K. Jedamzik, J.-L. Kneur, J. Lavalle, G. Moultaka and V. Poulin), three post-docs and four PhD students as well as a number of emeritus researchers. Research interests include dark matter, early-universe cosmology, new physics at colliders, flavour physics and neutrinos, finite-temperature QCD, composite Higgs models and supersymmetry. There are also thematic intersections with some of the members of the L2C's field theory and mathematical physics group (S. Alexandrov and D. Polarski).

For any questions about the scientific or organizational details, please contact Felix Brümmer (`felix.bruemmer@umontpellier.fr`).

References:

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