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Final Report for DOE Theory Graduate Student Fellowship: Gustavo Marques Tavares:

Marques Tavares was awarded a fellowship for his proposal "The ttbar asymmetry and beyond" to starting in September 2012. This is the final report summarizing the research activities and accomplishments achieved with this grant support.

With support from the DOE graduate fellowship Marques Tavares, Katz and Xu at BU have investigated a new technique for obtaining quantitative results in strongly coupled field theories with broken conformal invariance. Such theories are especially interesting as they may be candidates for physics beyond the standard model with possible applications to strongly coupled electroweak symmetry breaking. However, because of the strong coupling even qualitative results about the spectrum of such theories are not rigorously understood.

In prior work (arXiv:1304.3458) it had been argued that in theories where conformal invariance is broken by a single scale, operators with high scaling dimensions decouple exponentially fast (in their dimension) from the low dimensional operators. If true, this would allow one to focus on a small set of operators to study the low energy states of the theory that would be the most relevant to LHC physics. This would be a very interesting result, potentially opening a new approach to the phenomenology of such theories. To better understand the exponential decoupling, Marques Tavares (with Katz and Xu) studied a generalization of the t' Hooft model to fermions in the adjoint representation of color in the large N limit. The model is sufficiently simple that it is amenable to explicit computation, yet contains most of the important physics that one is interested in. The goal was to compute the bound state spectrum of the theory by restricting to a sector with a limited number of low dimensional operators and confirm in a concrete example the exponential decoupling of the higher dimensional operators. Marques-Tavares and collaborators found that indeed the spectrum of low-lying states is reproduced correctly with exponentially small corrections from operators of high scaling dimensions (arXiv:1308.4980). Since this method only requires diagonalizing the Hamiltonian on a small set of low-dimensional operators the computational effort required is orders of magnitude less than in the conventional DLCQ approach.

Subsequently, Xu, Marques-Tavares and Katz tested the above conformal basis approach at small N. They found that for a 2D version of QCD with three colors and one quark flavor, the convergence of the basis is just as efficient (arXiv:1405.6727). Thus 2D QCD can be solved numerically, with the spectrum and wave functions of the lowest lying states well approximated analytically due to the rapid convergence.

In a separate line of investigation Marques-Tavares with collaborators Schmaltz and Skiba (Yale) examined a recent suggestion that electroweak symmetry breaking may be natural (i.e. the Hierarchy problem solved) if the Standard Model merges into a conformal field theory (CFT) at short distances. I was argued that in such a scenario the Higgs mass would be protected from quantum corrections by the scale invariance of the CFT. In order for the standard model to merge into a CFT at least one new ultraviolet (UV) scale is required at which the couplings turn over from their usual standard model running to the fixed point behavior (in the standard model the hypercharge gauge coupling does not approach a fixed point in the UV). Schmaltz and collaborators Skiba and Marques-Tavares showed (arXiv:1308.0025) that relevant operators like the Higgs mass are sensitive to such a turnover scale even if there are no associated massive particles and the scale arises purely from dimensional transmutation. They demonstrated this sensitivity to the turnover scale explicitly in toy models. Therefore, if scale invariance is responsible for Higgs mass naturalness, then the transition to CFT dynamics must occur near the TeV scale with observable consequences at colliders.

In the area of Astro-particle physics, Marques-Tavares, Schmaltz and Buen-Abad (graduate student at BU) constructed a model of dark matter in which the dark matter is charged under a dark non-Abelian gauge group with weakly coupled dark gluons (arXiv:1505.03542). They showed the dark gluons contribute to the radiation background of the universe and that dark matter can scatter off this dark radiation background. The most important effect of this scattering is to suppress the power spectrum of density perturbations in the dark matter fluid. This is interesting because current measurements of density perturbations at large scales are in disagreement with predictions in the standard ΛCDM model.

Marques-Tavares, Schmaltz, and Lesgourgues (Aachen) then further explored the predictions of this model for precision cosmology (arXiv: 1507.04351). In particular they performed a global fit of the non-Abelian dark matter and dark radiation model to the Planck 2015 CMB temperature correlation spectrum, measurements of the baryon acoustic oscillation scale, supernova measurements of the current Hubble expansion rate, and measurements of large scale structure from galaxy surveys. The precision fit confirmed that the non-Abelian dark matter model can provide a significantly better fit than the standard ΛCDM model. The best fit was found for a dark radiation component that has an overall energy density of a fraction of a neutrino, $N_{eff} \sim 0.4$, and a non-vanishing scattering rate between dark matter and dark radiation. The improvement in the fit is significant with the new minimum preferred by about 3 σ over ΛCDM (i.e. zero dark radiation and zero scattering rate).

In performing the fit Marques-Tavares and collaborators discovered that there is a second region in parameter space that also significantly - and unexpectedly - reduces the χ^2 of the fit. This second region corresponds to very small values of $N_{eff} < 0.2$ with somewhat larger dark matter - dark radiation scattering rates. This scattering is sufficiently strong to make the two fluids tightly coupled, effectively giving rise to a small pressure for the dark matter fluid. A manuscript reporting on these results and the precision fit to cosmological data is in preparation and will appear in early 2016.

Marques Tavares graduated in the summer of 2015, and is now a postdoc at Stanford University.

Yours Sincerely,

Martin Schmaltz
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