Composite dark matter and lattice simulations†

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The existence of a dark matter sector, which interacts gravitationally with ordinary, baryonic matter, solves several known observational puzzles in astrophysics and cosmology. However, the observed relic abundance of dark matter (DM) in the Universe today differs from the abundance of baryonic matter by a relatively small factor, $\rho_{DM}/\rho_b \approx 5$. This apparent coincidence motivates the existence of some sort of coupling of the dark sector to the Standard Model (SM), to give rise to the DM relic density by way of a primordial asymmetry or by coupling to the early-universe thermal bath of SM particles. Such interactions between DM and SM are strongly constrained by present-day experiments which seek to directly detection the impact of galactic dark matter particles with SM targets.

If the dark sector contains a new, strongly-coupled gauge force, then it may give rise to a composite dark matter candidate as an electroweak-neutral bound state of charged, fundamental constituent particles. This structure generically leads to very strong momentum dependence in interactions of the bound state with the SM, which can resolve the tension since the momentum scales probed in modern direct-detection experiments are much lower than those relevant for early-universe cosmology.

As part of the LSD collaboration, my research focuses on the use of lattice simulation as a tool to study the physics of strongly-coupled gauge theories, of which QCD is only a single example in a broad class. Gauge theories with different choices of the number of colors N_c, number of light fermions N_f, or fermion gauge representation R can exhibit strikingly different properties[1)].

In connection with the study of composite dark matter, we have undertaken a calculation from first principles of electromagnetic "nucleon" form factors in SU(3) gauge theories with $N_f = 2$ and $N_f = 6$, in particular the magnetic moment κ and electromagnetic charge radius r_E^2[2)]. In a candidate composite dark matter theory, these form factors would govern the interaction of the baryon-like dark matter with ordinary nuclei through single photon exchange. Our calculation results for the magnetic moment (shown in Fig. 1 below) and charge radius indicate no significant trend as the number of fermions N_f is increased. This suggests that regardless of other dynamical considerations, bounds on composite dark matter states may apply quite generally. As studied in the reference[2)], these bounds can be quite wrong, with the magnetic moment interaction excluding composite dark matter states in this model below 10 TeV.

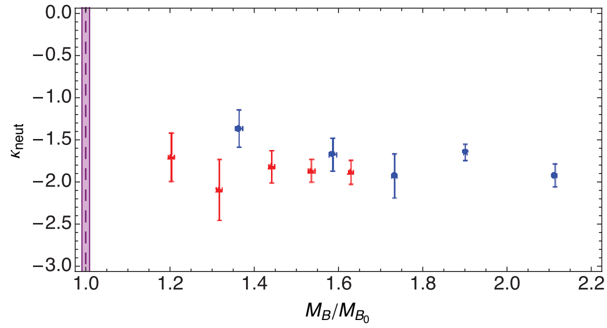

Fig. 1. From[2)], magnetic moment κ_{neut} of a neutral baryonic bound state in SU(3) gauge theory with $N_f = 2$ (red) and $N_f = 6$ (blue) light fermions, vs. ratio of simulated "baryon" mass M_B to extrapolated chiral limit mass M_{B_0}.

Additional studies have focused on the properties of SU(2) gauge theories. The fundamental representation of SU(2) is real, leading to an enhancement of the chiral symmetry group. For a gauge sector in which this chiral symmetry spontaneously breaks, this can lead to the existence of "baryonic" pseudo-Goldstone modes, which can play the role of a dark matter candidate with interesting and unique properties[3)]. Recent LSD collaboration results on SU(2)[4)] have clarified the range of N_f values for which the spontaneous breaking of chiral symmetry will take place, paving the way for future dynamical studies relevant to SU(2) composite dark matter models.

Finally, extension of our results for composite dark matter form factors to SU(4) gauge theory is planned, with a model construction and a detailed lattice study to be published soon. With an even choice of N_c, the "baryon" states will be bosonic, and can exhibit internal symmetries which cause the leading electromagnetic form factors (magnetic moment and charge radius) to vanish. Our initial studies will therefore focus on the next leading operator, the electromagnetic polarizability, as well as on scalar form factors for Higgs boson exchange.

References
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