Direct detection of composite dark matter via electromagnetic polarizability[†]

E. T. Neil[*1,*2] for the LSD Collaboration

Direct-detection experiments are becoming increasingly sensitive, quickly approaching the expected irreducible background from coherent scattering of cosmic neutrinos[1)]. Most dark matter candidates which couple to the visible sector through Standard Model force carriers have been ruled out by several orders of magnitude. However, models of *composite dark matter* provide an intriguing exception.

A dark sector consisting of electroweak-charged fermions and a new strongly-coupled gauge force can give rise to neutral composite bound states, which will nevertheless interact with the Standard Model through photon and Z-boson exchange. These exchanges are described by momentum-dependent electromagnetic form factors, which are highly suppressed for small momentum transfers (typical in direct-detection experiments.)

Making predictions within composite dark matter models can be challenging, due to the strongly-coupled nature of the underlying interactions. Lattice simulations provide an important tool to give quantitative information about such theories. Here we consider a specific model known as "Stealth Dark Matter"[2)], based on a dark confining SU(4) gauge theory. Due to symmetry considerations, stealth dark matter has the novel feature that its leading interaction with photons is through the dimension-7 electric polarizability operator,

$$\mathcal{O}_F = C_F B^* B\, F^{\mu\alpha} F_\alpha^\nu v_\mu v_\nu \ , \qquad (1)$$

where $F_{\mu\nu}$ is the electromagnetic field-strength tensor, B is the "baryon" composite dark matter field, and v_μ is the four-velocity of B. Because this is a two-photon vertex, scattering of "stealth baryons" off of ordinary nuclei thus involves a virtual photon loop, leading to an order-of-magnitude nuclear uncertainty partly due to the poorly constrained effects of nuclear excited states.

The unknown coefficient C_F must be determined by a non-perturbative lattice calculation. We generate a series of SU(4) gauge configurations with lattice volume $V = 32^3 \times 64$, and apply the standard background field method[3)] to study the polarizability and determine C_F. The "baryon" ground-state energy is determined from a two-point correlation function in the presence of an applied background electric field, $\mathcal{E}$. The polarizability operator induces a quadratic Stark shift in the mass of the "baryon" proportional to C_F,

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*1 RIKEN Nishina Center
*2 Department of Physics, University of Colorado, Boulder

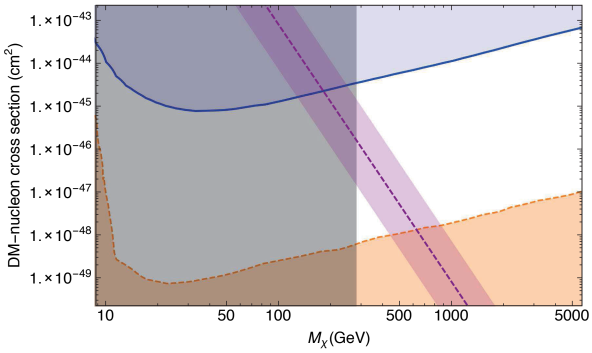

Fig. 1. Predicted spin-independent xenon scattering cross section per nucleon for stealth dark matter due to the electric polarizability (purple band). The width of the purple band indicates the uncertainty in the nuclear two-photon matrix element. The top region (blue) is excluded by the LUX experiment[4)], while the left shaded region (grey) is excluded by the LEP II bound on charged mesons[2)]. The bottom region (orange) shows the expected coherent neutrino background[1)].

$$E_B = m_B + 2C_F|\mathcal{E}|^2 + \mathcal{O}\left(\mathcal{E}^4\right) \ . \qquad (2)$$

Repeating the calculation of E_B for several values of $\mathcal{E}$ and fitting to this formula allows us to determine C_F.

In units of the "baryon" mass M_B, we find that the value of C_F is similar for SU(4) and SU(3) gauge theories, obtaining $C_F M_B^3 \approx 1.3$ at relatively heavy fermion masses. This translates into the direct-detection scattering cross section shown in Fig. 1. Although the signal is strongly suppressed for heavy dark matter, scaling as $1/M_B^6$, there remains an intriguing window up to $M_B \sim 1$ TeV where this candidate may still be detectable above the coherent neutrino background. Because interaction through the polarizability scales as Z^4/A^2, where Z and A are the atomic and mass numbers of the target, stealth dark matter would provide a distinctive signature if a signal were found in experiments using different nuclear targets.

References

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