Setting Stronger Dark Sector Limits on Monopole-Monopole and Monopole-Dipole Interactions Using Cylinders

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Some extensions to the standard model predict a new interaction mediated by an as of yet undiscovered boson [1–3], while others predict compact extra dimensions [4]. Both approaches result in a monopole-monople Yukawa-like interaction, $V(r) = -G\frac{m_1 m_2}{r}\alpha e^{-r/\lambda}$, where α is the relative strength of the interaction when compared to gravity, λ is the interaction's characteristic length and r is the separation between test and source point masses. The monopole-monopole interaction has been studied by many groups and α is tightly constrained for $\lambda > 10^{-4}$m [5]. For short ranges, however, the best constraints on α are on the order of 10^{11} to 10^{7} for $\lambda = 10^{-7}$m to 10^{-6}m [6]. While this interaction is spin-independent, it is possible for the interaction to have a spin dependence [1]. Spin-dependent forces are fermion dependent and can be mass-spin (monopole-dipole) coupled or spin-spin (dipole-dipole) coupled. These could be second order perturbations of monopole-monopole interactions [3, 7] or due to single exchange of fields [1].

At Indiana University Purdue University Indianapolis (IUPUI) we are developing a system to probe monopole-monopole interaction and monopole-dipole interaction by improving on a previous apparatus. A previous study used a spherical test mass attached to a micromechanical oscillator which could be brought down to 200 nm above a source mass [6]. The old system was able to achieve a sensitivity of 1 fN/$\sqrt{\text{Hz}}$ [6]. In the new system the spherical test mass will be replaced with a cylindrical test mass increasing the effective volume of interaction by $\sim$ 100-fold, yielding a $\sim$ 100-fold improvement on the monopole-monopole limits. When the source mass is a material engineered to have a zero net magnetization but a remnant spin, the new system will probe the monopole-dipole interaction. The cylindrical test mass will be 500 µm long with a radius of 150 µm and a sagitta of 20 µm. It will be manufactured using maskless grayscale photolithography. This lithographic technique allows for the test mass to be deposited directly onto a micromechanical oscillator, with a deviation of less than 80 nm over the distance between alignment marks. This means that the misalignment between the oscillators axis of rotation and the axis of the cylinder will be better than 24×10^{-6} radians. The orientation of the cylinder with respect to the source mass, however, poses more of a technical challenge. To determine the cylinder's positioning, a scheme is being developed which uses capacitance as an alignment indicator. A detailed explanation of the capacitance approach, as well as the zero magnetization ferromagnetic samples, will be presented during the talk.

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