Capstone Evaluation: "Dark Photons from the Center of the Earth"

ArXiV: 1509.07525v3

Adam Green

agree019@ucr.edu

Department of Physics & Astronomy, University of California, Riverside, CA 92521

This paper presents a phenomenological study of a dark sector with a massive spin-1 gauge boson. The authors present the background information on the theory and then present a novel way to test it.

What the scientific community has been calling "dark matter" may actually be a dark sector, dark gauge bosons in addition to dark matter particles. This paper considers a dark sector mediated by a massive spin-1 dark gauge boson, the "dark photon," which kinetically mixes with the Standard Model photon. The dark photon and standard model photon mix according to the mixing parameter ϵ which is constrained to be on the order of $\mathcal{O}(10^{-5} - 10^{-10})$. When the mass of the dark photon is much less than the mass of dark matter, some interesting effects arise which give rise to new ways to search for dark sectors. In this framework, dark matter will collect at the center of the Earth, annihilate into dark photons which may decay near the surface into detectable leptons.

As the Earth traverses the Milky way, it is constantly intercepting dark matter along its journey. Occasionally, a dark matter particle will collide with a nucleus within the Earth. If the dark matter particle imparts enough energy into the Earth, it becomes gravitationally captured and falls to the center of the Earth. The capture rate depends on the density of Earth, the relative speed between the earth and dark matter, and the amount of energy imparted into the Earth, called recoil energy. To calculate the capture rate, we integrate these quantities over the volume of earth, all allowed incident velocities, and all allowed recoil energies. This particular capture scenario is interesting because the Feynman diagram describing it is the exact same for direct detection. In this case however, the "detector" is the entire Earth.

At the center of the Earth, captured dark matter will annihilate with itself into dark photons. The rate of annihilation depends on the amount of dark matter that has been captured and the thermally-averaged annihilation cross section. For the special case when the dark photon mass is much lighter than the mass of dark matter, the annihilation rate experiences a *Sommerfeld enhancement*. This enhancement arises when the dark photon mass is light compared to dark matter. Due to dark matter self-interactions, these interactions are now allowed to take place over longer ranges. Now, instead of dark matter annihilations occurring purely due to statistics, dark matter now "feels" a slight attraction to itself. These are seen as resonance peaks in the kinetic mixing parameter. The result from these dark matter annihilations are dark photons. This is a classic beam dump experiment, except on a planetary scale.

These dark photons propagate from the center of the Earth where, with some probability, they may interact with detectable charged leptons near the surface. Upon their creation, these dark photons are relativistic because their mass is so small compared to dark matter. They propagate through the Earth with essentially no interactions. We can calculate their decay length from their Lorentz boost and their branching ration into Standard Model particles. This decay length is inversely proportional to the square of the kinetic mixing parameter, and the mass of the dark photons. If the mixing paramter is high, the dark photons are more likely to decay into standard model particles. Similarly, if the mass of the dark photons is high, it costs more energy to move them and they do not travel as far before they decay. To obtain decays near the surface of Earth, the authors determine that the mixing parameter must lie between $10^{-10} - 10^{-5}$ and the dark photon must have a mass between 10 MeV $-$ 100 GeV.

At the surface of Earth, the dark photon may decay into detectable standard model leptons. To make predictions about their detection signature, the authors characterize the typical size of the accumulated dark matter at the center of Earth. Given that the dark photons are relativistic, when they decay, their daughter particles will have an angular dispersion of 1.3 deg from straight down. The trademark detection signature for this process are highly collimated jets of leptons which point back to the center of the earth to within a few degrees, the so-called “smoking gun” signal. This signal is particularly useful because there are no other known processes with this signal. Perhaps high energy gamma rays could reproduce this kind of signal, but the chances of that are so low they are negligible.