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There is evidence for dark matter (DM) from the rotation curves of galaxies and the Bullet cluster [1,2]; however, there is no firm evidence from direct detection in terrestrial experiments. These experiments search for nuclear recoil from coherent scattering of 10–100 GeV mass DM particles with heavy nuclei to put constraints on the scattering cross section. In these experiments, the ionization of electrons is assumed to be from the radioactivity in the background, and only nonionizing nuclear scatterings are considered as evidence of a DM signal. Consequently, the bounds on leptophilic DM which scatter with the electrons in the atoms are weak [3]. There are well-motivated models of leptophilic DM with mass in the sub-GeV range [4–8] and it will be of interest to put constraints on the scattering cross section from observations.

Fitting the rotation curve of the Milky Way with the DM profile leads us to believe that DM has a specific (Navarro-Frenk-White, Einasto, isothermal, etc.) profile in position space and a Maxwellian distribution in momentum space. The density of the DM in the Solar neighborhood—which is relevant for determining the scattering rates in terrestrial experiments—is fixed to be 0.4 GeV/cm$^3$ in all the profiles [9].

In this paper we investigate the gravitational capture of leptophilic DM, and its subsequent annihilation/decay in the Earth. DM in Earth-intersecting orbits can scatter off electrons and lose energy, and be gravitationally bound to the Earth. Eventually, they lose enough energy and accumulate at the core. It is assumed that DM annihilates/decays predominantly into Standard Model particles inside the Earth. The heat flux from these processes is compared with the experimentally measured value of the internal heat flux of the Earth, which is 44 TW. Assuming a steady state between capture and annihilation/decay, we put constraints on leptophilic DM.

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Constraints on leptophilic light dark matter from internal heat flux of Earth

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I. INTRODUCTION

There is evidence for dark matter (DM) from the rotation curves of galaxies and the Bullet cluster [1,2]; however, there is no firm evidence from direct detection in terrestrial experiments. These experiments search for nuclear recoil from coherent scattering of 10–100 GeV mass DM particles with heavy nuclei to put constraints on the scattering cross section. In these experiments, the ionization of electrons is assumed to be from the radioactivity in the background, and only nonionizing nuclear scatterings are considered as evidence of a DM signal. Consequently, the bounds on leptophilic DM which scatter with the electrons in the atoms are weak [3]. There are well-motivated models of leptophilic DM with mass in the sub-GeV range [4–8] and it will be of interest to put constraints on the scattering cross section from observations.

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The problem of gravitational capture of dark matter has been extensively studied in the past [12–16] and the internal heat flux of the Earth has previously been used to constrain the weakly interacting massive particle (WIMP) parameter space [16,17]. However, the mass of DM in these studies typically ranges for 1–10$^3$ GeV. When applied to light DM, these techniques do constrain the WIMP-nucleon cross section, but yield uninteresting results. However, interesting parameter space can be probed for light DM if it interacts with the electrons in the atoms rather than the nucleons. In this paper it is shown that novel constraints can be obtained for light leptophilic DM using Earth’s internal heat.

In Sec. II we calculate the capture rate and the total accretion rate of DM by the Earth. In Sec. III we calculate the heat flux by annihilations/decays of DM inside the Earth. In Sec. IV we discuss our results and compare with existing bounds.

II. CAPTURABLE PHASE SPACE

The phase space for gravitational capture of DM was first worked out in Ref. [18]. There are some discrepancies that were pointed out in Ref. [19] regarding a factor of 2, and motion relative to the Galactic halo. We redo the calculation here for completeness and include these factors. It is assumed that the galactic dark matter is thermal and follows a Maxwellian distribution characterized by a rms velocity.