Snowmass2021 Letter of Interest:
Theory developments for low-threshold dark matter direct detection

Thematic Areas:

■ (TF9) Theory Frontier: Astroparticle
■ (CF1) Cosmic Frontier: Dark Matter: Particle Like

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In recent years, there have been major developments in the direct detection of sub-GeV dark matter (DM), also known as light dark matter (see *e.g.* [1]). These developments include new theoretical studies of the interactions of light dark matter in a wide variety of detector materials as well as significant experimental progress, which together have resulted in novel experimental proposals. In a number of cases, ideas originating from the theory community have led directly to novel experimental directions, some of which have received significant private and public funding.

As a result, the direct detection of dark matter has grown beyond searching for nuclear recoils, which are primarily sensitive to WIMP DM with masses of GeV and above; currently, dedicated electron recoil experiments are sensitive to eV-scale energy depositions, which correspond to DM masses down to ~ 500 keV, while future detectors may have sensitivity to meV energy depositions, corresponding to DM masses down to 1 keV or below. The theoretical studies of sub-GeV DM direct detection live on the boundary between particle theory and condensed matter/materials science theory and require new understanding and dedicated calculations in the energy ranges relevant for sub-GeV DM searches. In contrast to WIMP DM scattering, the momentum and energy transfers for these sub-GeV DM scattering processes are sufficiently low that the free-particle approximation is no longer adequate, and the detailed material properties must be accounted for when calculating both signal and background rates. These calculations are being accomplished with a variety of theoretical tools, including analytic methods, numerical computations using density functional theory (DFT), and rate extractions from experimental data. Close collaboration with condensed matter and material science experts has not only been essential to accomplish some of the technical aspects of this program, but has also led to qualitatively new experimental directions.

With this letter of interest (LoI), we propose a Snowmass white paper to review the progress made over recent years. Proposed topics include, but are not limited to

- Dark matter-electron scattering in noble liquids, solid state materials such as semiconductors and superconductors, and organic molecules [2–13];
- Dark matter-nuclear scattering which produces above-threshold secondary signals, including the Migdal effect, bremsstrahlung, plasmon emission and de-excitation of metastable nuclear isomeres [14–23];
- Excitation of collective modes induced by dark matter scattering in molecules and crystals (including

phonons, plasmons and magnons) [24–36];

- Absorption of light dark matter, including axion-like particles and dark photons [37–43].
- Viable DM models and operators which give rise to experimental signatures in different materials [44]
- Studies and identification of novel materials with properties well-suited for light dark matter detection, such as Dirac materials, molecular magnets, spin-orbit semiconductors and compounds with multiple polymorphs like SiC and graphene/carbon nanotubes [45–52].
- and more

We invite all members of the community to join in our effort to draft the white paper, irregardless of whether or not they have signed on to this LoI.

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