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Extending the detectable window of dark matter direct detection experiments through boosted and Migdal effects

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The exploration of the nature of dark matter (DM) keeps attracting worldwide attention. Nevertheless, after several decades of efforts in detecting weakly interacting massive particles (WIMPs), one of the leading DM particle candidates, in underground laboratories, no signal has been revealed yet and stringent limits on the interaction strength between DM particles and standard model particles have been set [1]. Due to the (relatively high) energy thresholds of the direct detection experiments, the detectable DM masses are usually required to be large enough (e.g., $\gtrsim$ GeV/c^2 for nuclear recoils) to produce detectable recoil energies exceeding the thresholds. It has been noted that, to lower the detector's threshold through new technologies, to boost the Galactic DM particles to higher energies, or to resort to the atomic ionization effect during a DM induced nuclear scattering (the Migdal effect), the detectable masses of DM can be effectively extended to sub-GeV ranges, enlarging the probability of capturing DM particles (e.g., refs. [2-4]).

In a paper recently published in *Science China-Physics, Mechanics & Astronomy*, Flambaum et al. [5] put forward the campaign to survey the DM parameter space in the sub-GeV window utilizing the boosted and Migdal effects in a detector material. The momentum transfer effects in the DM-nucleus scattering are scrutinized in this work. An important point highlighted in the study is the suppression of the Earth-stopping effect of DM by the nuclear form factor in the high momentum transfer regime. Consequently, DM particles with enhanced momenta via e.g., the decay of mesons produced by air showers induced by high-energy cosmic rays, experience less absorption by the Earth and would have a higher chance to be detected than previously thought. This effect has significant impacts on the experimental searches of sub-GeV DM, indicating that a much larger parameter space of DM can be probed by current experiments.

When the momentum transfer of the DM-nucleus scattering is small, the Migdal effect offers a way to detect DM via electron ionization. The other interesting finding in Flambaum et al. [5] is that the widely used Hartree-Fock approach to calculate the ionization factor of electrons violates the orthogonality of wave-functions in the low momentum transfer regime, leading to incorrect predictions for the expected signal in a detector. The authors propose a new method that accounts for the orthogonality of wave-functions to overcome this issue. The results demonstrate that this approach leads to a considerable difference in the expected signal. It illustrates that precise modeling of the theoretical prediction of the DM interaction in ordinary materials is crucial to interpreting the experimental data.

With the improvements of the above two points, the authors re-interpret the direct detection experimental data

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and derive the constraints on the parameter space of DM in the sub-GeV mass window. It turns out that existing bounds on the DM-nucleon scattering can be improved significantly, showing the great potential of searching for low-mass DM with the current experiments and the minimum assumptions of interactions between DM and the nucleus.

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