Snowmass2021 - Letter of Interest

Status and plans for Oscura: A Multi-kilogram Skipper-CCD Array for Direct-Detection of Dark Matter.

Thematic Areas:

■ (CF1) Cosmic Frontier: Dark Matter: Particle Like
■ (IF2) Instrumentation Frontier: Photon Detectors

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Abstract: Recent advances in silicon skipper-CCDs have demonstrated this technology as a powerful probe for sub-GeV dark matter by enabling ultra-sensitive searches for electron recoils from dark matter-electron interactions. World-leading results have already been produced by the SENSEI collaboration using a single skipper-CCD with an active mass of $\sim$2 gram. Pathfinder experiments using skipper-CCDs are planned for the coming years, with SENSEI-100 ($\sim$100 g detector) and DAMIC-M ($\sim$1 kg detector) expected to start operations during 2020 and 2023, respectively. We are preparing a white paper describing the status and plans of the Oscura R&D effort to develop a $\sim$10-kg skipper-CCD experiment for dark matter.

1 Physics Goals

Identifying the nature of dark matter (DM) is one of the most important tasks of particle physics today, and direct-detection experiments play an essential role in this endeavor. The search for DM particles with masses a few orders of magnitude below the proton mass ("sub-GeV DM") represents an important new experimental frontier that has been receiving increased attention, e.g.[1–4]. Among the most promising detector technologies for the construction of a large multi-kg experiment for probing electron recoils from sub-GeV DM[5–8] are a new generation of silicon Charged Coupled Devices with an ultralow readout noise, so-called "skipper-CCDs"[9;10]. The Oscura project has the goal of taking the skipper-CCD sensor technology to its full potential, and enable the development of a skipper-CCD experiment with an active mass of 10 kg.

The scientific potential of a search for dark matter scattering off electrons, with a 30 kg-year exposure of skipper-CCDs, is summarized in Fig. 1. There is also substantial physics reach (not shown) for dark matter with masses $\gtrsim$1 eV being absorbed by electrons[11–13], from dark matter with masses $\gtrsim$100's MeV scattering elastically off nuclei, and from dark matter with masses $\gtrsim$ 1 MeV scattering off nuclei using the Migdal effect[14;15].

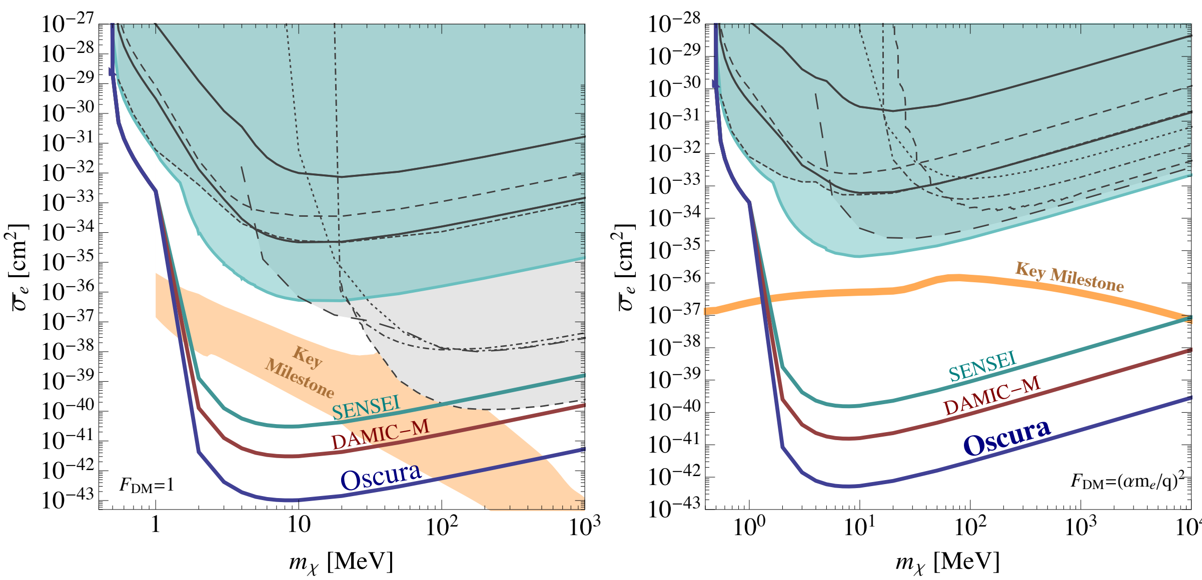

Figure 1: Projected sensitivity to dark-matter-electron scattering of a low-background silicon skipper-CCD array, assuming a 30 kg-year exposure ("Oscura", blue line). We assume zero background events for events with two or more electrons, and a fixed single-electron dark-count event rate. Projected sensitivities for SENSEI and DAMIC-M[16] are shown with cyan and red solid lines, respectively. Existing constraints from a single skipper-CCD from SENSEI are shaded in cyan[17–19], while gray regions show constraints from DAMIC at SNOLAB, XENON10, XENON100, XENON1T, DarkSide-50, EDELWEISS, and CDMS-HVeV[20–28]. Orange regions labelled "Key Milestone" are from[4]. The left (right) plot assumes the dark-matter-electron interaction is mediated by a heavy (light) mediator.

2 Status

The Department of Energy has approved the Oscura R&D effort to develop a 10 kg skipper-CCD detector for dark matter[29;30]. This effort is now completing its first year addressing the three major challenges for the experiment:

1. A new method needs to be developed for the fabrication of the large number of skipper-CCDs needed for Oscura. The foundry currently used for the skipper-CCD fabrication will discontinue the production line for these sensors. This challenge also represents a new opportunity for migrating the fabrication of skipper-CCDs into the more modern CMOS technology. R&D activities on skipper-CCD fabrication and CCD-in-CMOS development are part of this proposal.
2. The second technical challenge is related to the low noise readout needed for Oscura with 10 kg of active mass. This readout system requires several thousand channels, comparable in size with that of the largest cameras ever built for astronomy, but with more stringent noise requirements. An R&D effort to develop low-noise, cost-effective, and scalable readout systems is part of this proposal.
3. Finally, Oscura requires a background more than an order of magnitude lower than planned for SuperCDMS at SNOLAB[31]. This requirements comes from a goal of zero ionization events in the 2-10 e- signal range. This challenge will be addressed from the early stages of our project, by focusing on controlling fabrication procedures and mitigating cosmogenic backgrounds.

3 Plans

The plan for this R&D project is to complete the preliminary design for the experiment in September 2022. This will include a decision on the sensor fabrication technology, readout electronics, and the underground site of the the experiment. The goal is to present a full project execution plan to the Department of Energy in September 2023, for the construction and operation of the experiment.

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