Snowmass2021 - Letter of Interest

A Strategy for Low-Mass Dark Matter Searches with Cryogenic Detectors in the SuperCDMS SNOLAB Facility

Topical Group(s): (check all that apply by copying/pasting ☐/☑)

☑ (CF1) Dark Matter: Particle Like
☑ (CF2) Dark Matter: Wavelike
☐ (CF3) Dark Matter: Cosmic Probes
☐ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
☐ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
☐ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
☐ (CF7) Cosmic Probes of Fundamental Physics
☑ (Other) *[Please specify frontier/topical group]*

IF01: Quantum Sensors

NF3: BSM

NF10: Neutrino Detectors

UF3: Underground Detectors

UF2: Underground Facilities for Cosmic Frontier

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Abstract:
The SuperCDMS Collaboration seeks to build on the foundation laid by the SuperCDMS SNOLAB Experiment to undertake searches for potential dark matter (DM) candidates in the < 5 GeV mass range as well as to conduct other searches for new physics. A coherent technical R&D plan will enable the improvements in backgrounds and detector performance required to achieve these compelling science goals. There are many opportunities for collaboration with US and international groups. This program promises rich science from the SuperCDMS SNOLAB facility for many years after the completion of the in-construction SuperCDMS SNOLAB experiment.

SuperCDMS SNOLAB Experiment and Facility Status (science runs 2023-2025)

- 24 detectors of four types (iZIP[1] and HV[2], Ge (1.4 kg) and Si (0.6 kg)) to search for
    - nuclear recoils (NRs) from 0.5-5 GeV DM to within a decade of the neutrino floor[3]
    - electron recoils (ERs) from electron scattering of MeV-scale DM and/or absorption of eV-scale dark photons and/or axion-like particles (ALPs)
- Detector operating temperature of 15 mK
- Detectors installed in cryostat cans inside a class 100, low-radon cleanroom; cans installed in cryostat in class 2000 SNOLAB environment
- *Expected* facility-limited background levels for *current experiment*[3]:
    - ER single-scatter:
        - 0.003-2 keV (HV): Ge 25/kg/keV/yr, Si 80/kg/keV/yr
        - 1-50 keV (iZIP): Ge 45/kg/keV/yr, Si 150/kg/keV/yr
    - NR single-scatter (1-50 keV, iZIP): Ge 3.2×10^{-3}/kg/keV/yr, Si 2.3×10^{-3}/kg/keV/yr 2/3 of this is coherent elastic nuclear scattering of solar neutrinos, 2.5-4% is cosmogenic, and 8-10% is from the cavern environment
- *Current experiment*[3] expects to be limited by higher backgrounds from cosmogenic activation (^{3}H, ^{32}Si); ^{210}Pb and dark counts potentially dominant near threshold
- Ancillary science: non-standard interactions in coherent elastic solar neutrino-nucleus scattering, Bragg scattering of solar axions, millicharged lightly ionizing particles (LIPs)
- The facility is amenable to a range of potential upgrades:
    - *Detector count:* more readout channels in same cryostat (currently 288 phonon, 48 ionization); larger cryostat in existing, oversized shield (42 → 186 same size detectors)
    - *Detector temperature:* modify cryostat (6 mK@source), new dilution refrigerator;
    - *Backgrounds:* reduced apparatus backgrounds; class 100, low-radon cleanroom for cryostat; enhanced shield; active external neutron veto

Dark Matter Science Goals of Upgrade Program

In the absence of a signal in the G2 experiments, upgrades on roughly 5, 10, and 15-year timescales would expand the *nuclear-scattering DM* parameter space explored:

- Near-term: Mass reach down to ~0.05 GeV
- Mid-term: Cross section reach to neutrino floor for masses 0.5-5 GeV
- Long-term: Cross section and mass reach to neutrino floor for masses 0.05-1 GeV

For *electron-scattering DM*, the program would yield staged progress toward ultimate goals of:

- Enhanced mass reach for electron-scattering DM, potentially probing freeze-in and freeze-out models for masses $\gtrsim$ 0.1 MeV
- Enhanced mass reach for absorption of dark photons $\gtrsim$ 0.1 eV and ALPs $\gtrsim$ 0.5 eV.

Detector technologies that do not rely on electronic excitations have unique long-term mass reach for all but ALPs. Direct phonon production[2] *provides this reach for SuperCDMS.*

Discovery Scenarios: Should indications of DM emerge from G2 experiments, a number of exciting scenarios are possible. Two examples:

- A result in SuperCDMS SNOLAB, CRESST, DAMIC, or SENSEI implying NRs for $M_{DM} \lesssim$ 5 GeV, ERs for $M_{DM} \lesssim$ 5 MeV, or dark photons or ALPs $\lesssim$ 10-15 eV
  Response: Test by increasing target mass and/or re-optimizing detector type distribution. Install modified detector designs with enhanced background rejection, better match to signal characteristics (e.g., lower threshold, targets with enhanced coupling).
- A discovery in liquid noble experiments of nuclear recoils suggesting $\sigma_{SI} \approx 10^{-46}$ cm^2 at M_{DM} ~ 10 GeV, midway between current and G2 LXe sensitivity

Response: A larger cryostat with Ge iZIPs (x10 mass) could test the SI hypothesis. A Ge signal would narrow the range of allowed effective field theory operators while a Ge null result would disfavor operators to which it is particularly sensitive (e.g., neutron $\vec{L}$, $|\Delta_n|$).

Technical R&D to Enable the Science Goals

To enable these science goals, the SuperCDMS Collaboration envisions a multi-staged, multi-pronged R&D plan. Varying levels of technical maturity and cost provide near-term, mid-term, and long-term options. Multiple lines of attack makes the program robust.

- Detector Performance R&D
  - *Reduce recoil energy threshold, including for direct phonon production unmediated by ejection of a nucleus or electron from its site[4]:* improved phonon energy resolution
  - *Extend NR discrimination to lower recoil energy:*
    - Improve ionization resolution for ionization-yield-based discrimination
    - Improve phonon energy resolution to measure position distribution of Neganov-Trofimov-Luke[5,6] (NTL) phonons at few-V (low) bias voltages
    - Improved understanding and reduction of impurity trapping and impact ionization[7,8] in ~100 V (high) bias voltage (HV, NTL-dominated) mode to reduce non-quantized event fraction[9], enabling spectral NR discrimination and ER background reduction[10]
  - *Reduce dark counts:* Reduction of ionization leakage at high bias (HV mode)
- Detector Configuration R&D:
  - *Reduce surface and/or Compton backgrounds:* active veto cryogenic detectors
  - New insulating or semiconducting target materials to
    - *enhance sensitivity to sub-GeV nuclear-scattering DM and/or to ALP or dark photon absorption or dark-photon-mediated electron scattering*;
    - *reduce susceptibility to cosmogenic activation and/or HV dark counts*
  - *Reduce recoil energy threshold and/or improve ionization resolution:* smaller detectors
- Backgrounds R&D:
  - *Reduce ^{210}Pb surface backgrounds on detectors:* sidewall etching, reduced exposure during fabrication, and eventually fabrication in a low-radon cleanroom
  - *Reduce apparatus background:* improved materials sourcing (e.g., for cabling)
  - *Reduce ^{32}Si backgrounds:* isotopic enrichment
  - *Reduce ^{3}H backgrounds:* crystal growth, crystal preparation, detector fabrication, and detector testing all underground

Collaborative Opportunities

Cooperation on parallel developments pursued by other groups will speed progress:

- Ricochet/EDELWEISS: ionization resolution, underground crystal growth
- MINER: phonon resolution, ionization leakage, phonon-based position information
- SPICE/HERALD: phonon resolution, detection of cryogenic scintillation
- DAMIC/SENSEI: ^{32}Si reduction
- GEMADARC: underground crystal growth, detector fabrication, and testing
- ADMX, HAYSTAC: readout noise reaching/beyond standard quantum limit

New opportunities for sharing the current or an expanded cryostat may materialize.

White Paper: March/April 2021

A white paper with detailed science projections and a reduced, optimized R&D plan to enable near-term (~2026), mid-term (~2030), and long-term (~2035) upgrades will be submitted.

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