The DarkNESS CubeSat: demonstrating space-based imaging with skipper-CCDs

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Introduction

- Since demonstrating sub-electron noise in 2017, skipper-CCDs have been applied to rare-event searches and ground-based astronomy.
- The DarkNESS mission will deploy a 6U CubeSat to perform a search for dark matter (DM) and demonstrate the single-photon counting capabilities of skipper-CCDs for space-based imaging.

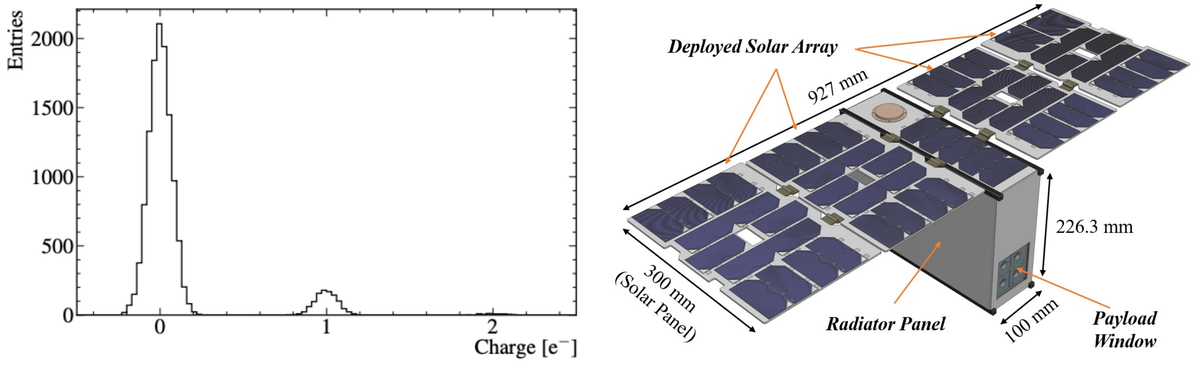


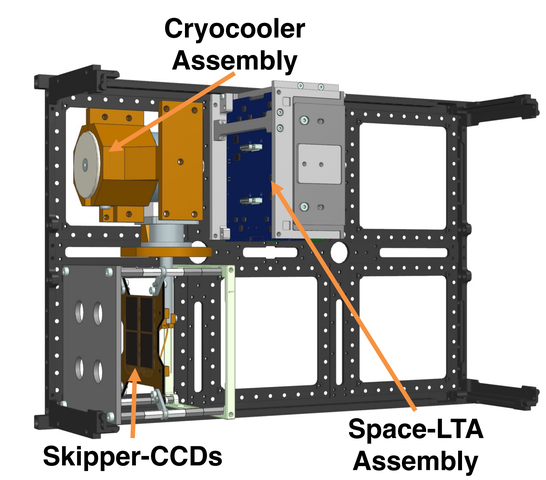
Figure 1: Skipper-CCDs provide repetitive non-destructive readout of the pixel charge, providing deep sub-electron noise. In skipper-CCDs, the readout noise scales with the square root of the number of samples per pixel. The left panel shows the single-electron charge resolution demonstrated with 4000 samples per pixel [1], and the right panel shows the preliminary design of the DarkNESS CubeSat.

The DarkNESS Instrument

- The detector module will consist of four 1.3 Mpix skipper-CCDs and an entrance window.
- The CCDs and a flex cable are epoxied and wirebonded onto an AlN ceramic substrate.
- Each CCD is biased and read out using a small-format Low Threshold Acquisition (LTA) readout electronics board.
- The detectors are cooled to 170 K with a compact cryocooler.
- Fermilab is developing the detector module, readout electronics, and software analysis tools.

DarkNESS Instrument Specifications	
Detector Area	1.6 x 1.9 cm^2
Thickness	250 um
Bias Voltage	80 V
Operating Temperature	170 K
Readout Speed	250 kpix/s

Table 1: Instrument specifications for the DarkNESS detector, thermal, and electronics subsystems.



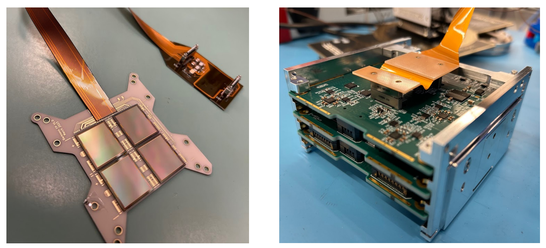


Figure 2: Top panel is a schematic of the DarkNESS CubeSat and its key components. Bottom panel shows prototypes of the DarkNESS detector module and readout electronics.

Operating Skipper-CCDs in Low Earth Orbit (LEO)

- Thermal Management:
  - Thermal Vacuum (TVAC) testing is ongoing at UIUC to optimize the thermal design.
- Radiation Environment:
  - The optimal exposure and readout time will be determined using Geant4 simulations.
  - Irradiation testing is ongoing to assess the radiation hardness of p-channel CCDs.
- Data Management:
  - Data rate limited by radio type and access to ground stations. Plan to downlink histograms regularly, and raw images occasionally for QA.

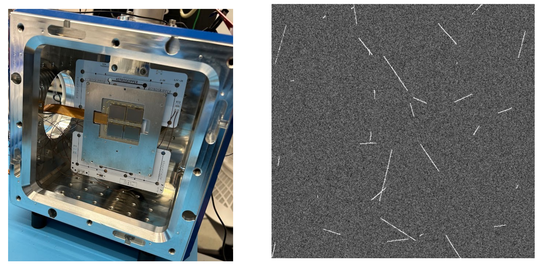


Figure 4: Left panel shows skipper-CCDs mounted in a test chamber at Fermilab for detector characterization studies and development of an in-flight software analysis pipeline. Right panel shows a simulated CCD image of background radiation in LEO produced using Geant4. Simulation framework is used to assess the CCD occupancy as a function of exposure time due to background radiation.

Scientific Objectives

- DarkNESS will search for decaying dark matter by mapping the diffuse X-ray background of the Galactic Center and searching for unidentified X-ray lines.
- DarkNESS will search for electron recoils from strongly-interacting dark matter that would not penetrate the Earth's atmosphere.

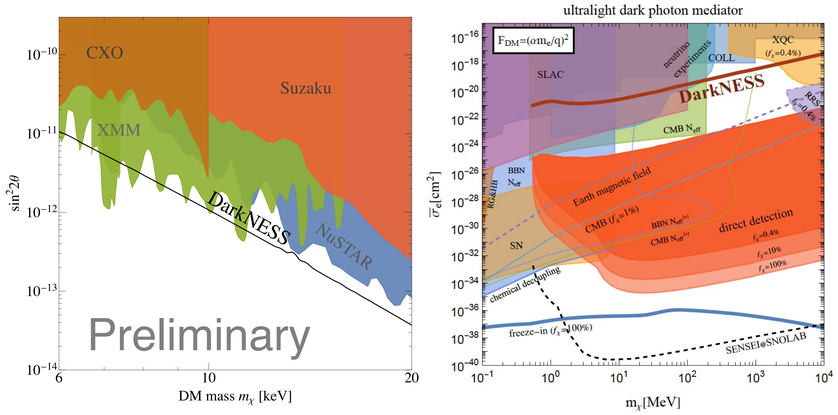
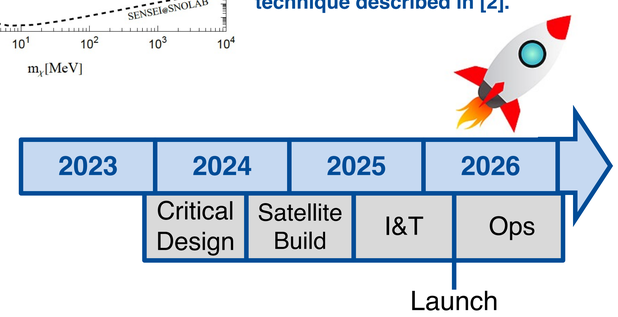


Figure 3: The left panel shows the estimated DarkNESS sensitivity to sterile neutrino decays as a function of dark matter mass using 25 hours of exposure time pointing at the Galactic Center with a 20° FOV. The right panel demonstrates the forecasted DarkNESS upper limit on DM-electron cross section for strongly-interacting sub-GeV DM using the modulation search technique described in [2].

Current Status and Outlook

- DarkNESS is currently in the Critical Design Review (CDR) process to finalize design.
- Preparing for build phase in Fall 2024 to test instrument performance in flight configuration.
- Plan to launch CubeSat in late 2025-2026.



References

[1] Tiffenberg et al, PRL 119 (2017) 131802.
[2] Emken et al, JCAP 09 (2019) 070.