Designing an X-ray Transmission Window for DarkNESS

Samriddhi Bhatia[1], Nate Saffold[2], Juan Estrada[2]
University of Illinois Urbana Champaign[1], Fermilab[2]

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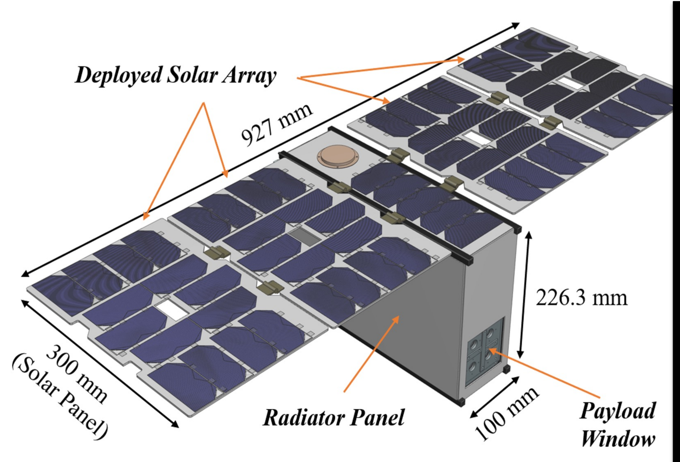
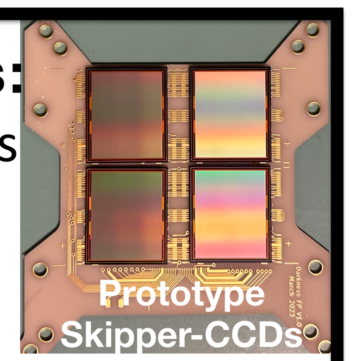
DarkNESS Mission



Dark matter Nanosatellite Equipped with Skipper Sensors

Skipper CCDs: Imaging sensors that perform repetitive non-destructive measurement of the charge in each pixel, reducing the readout noise to sub-electron (3.6 eV) levels.

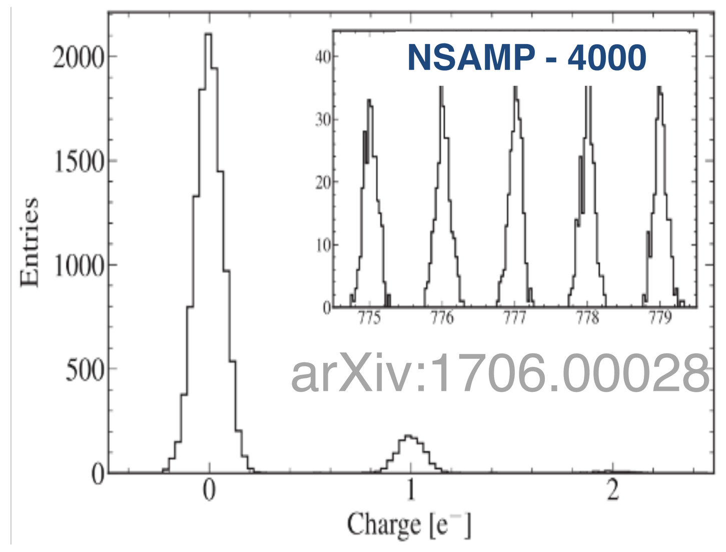


DarkNESS is a 6U CubeSat housing four 1.3 Mpix skipper-CCDs.

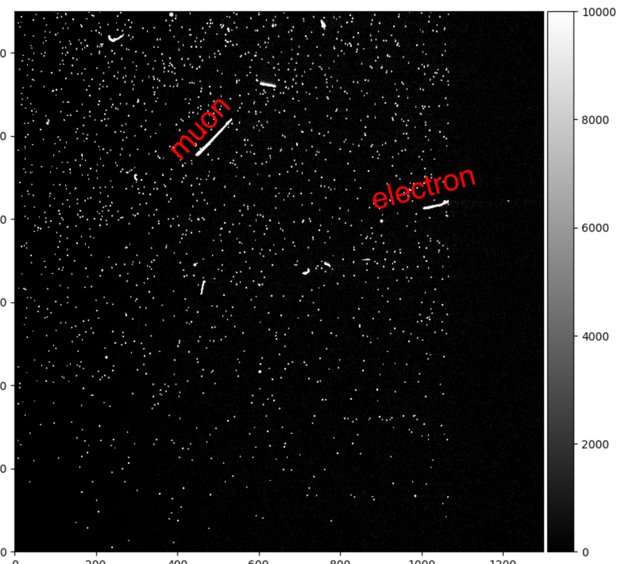
Objectives

- **Search for Dark Matter (DM).**
  - Sub-GeV DM
  - Sterile neutrino DM
- **Demonstrate skipper-CCD technology in space.**
  - Sub-electron noise
  - Single-photon counting

Key parameters of the **sensor performance** include noise and gain. **Noise is** measured in **analog-to-digital units (ADU)**, **energy,** or **electrons**, and improves with the number of samples measured (NSAMP). **Gain** is the **number of ADU per electron**, is essential for **calibrating the detector**.



Spectrum demonstrating sub-electron noise with a Skipper-CCD, providing single-electron charge resolution.



X-ray image from a DarkNESS Skipper CCD.

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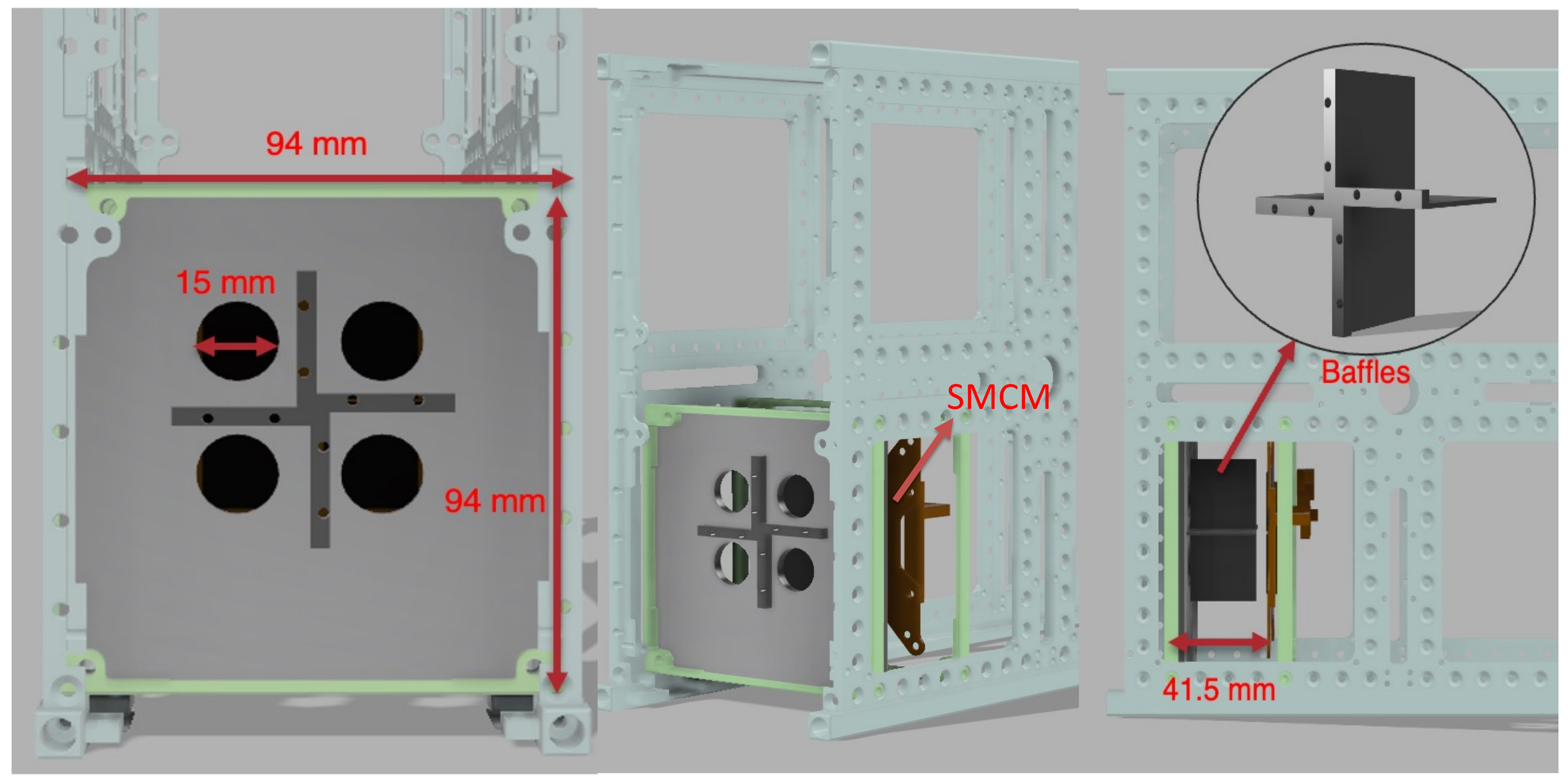
Payload Window Design

Purpose of the Payload Window: To define the detector's **20-degree field of view** and ensure that the window and baffles **block photons** in the **1-20 keV** energy range.



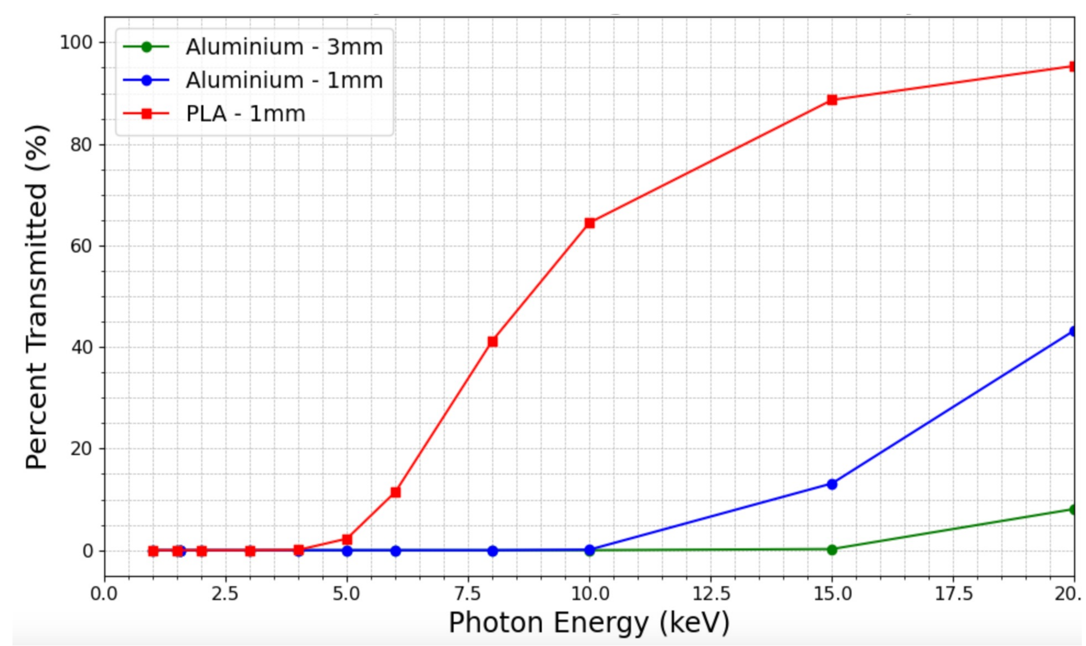
This CAD image illustrates the payload window and baffle design for the DarkNESS CubeSat

Design Considerations: The payload window design must accommodate the CubeSat's **size, weight,** and **thermal constraints** and be **robust** to mechanical stresses during **launch** and **deployment.**

Importance of Baffles: To **shield** each CCD and **prevent interference** from photons entering through other apertures. We are limited to **1 mm thick** baffles due to the size of the CCDs and their **Multi-Chip Module (MCM)** packaging.

X-ray Attenuation Calculations

We compared the **X-ray transmission properties** of **Aluminum** and **PLA** to select the optimal window thickness and baffle material.



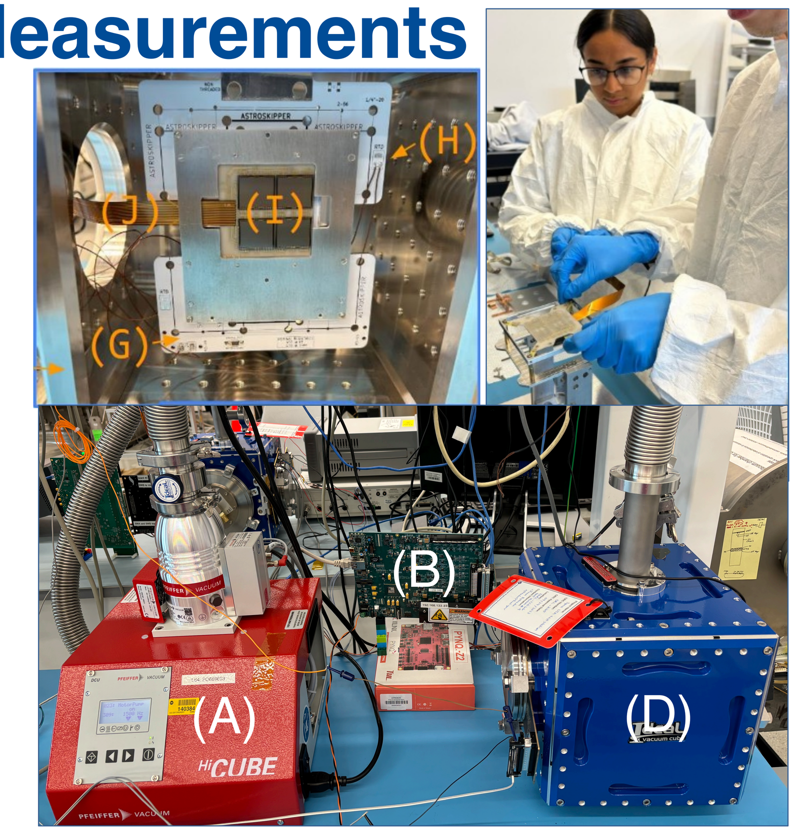
Photon transmission percentage as a function of photon energy for Aluminum and PLA.

Baffles (PLA:1 mm): Transmits 60% of the 10 keV photons and up to 90% of the 20 keV photons.

Window (Al: 3 mm): Blocks nearly all photons in the 1-20 keV range.

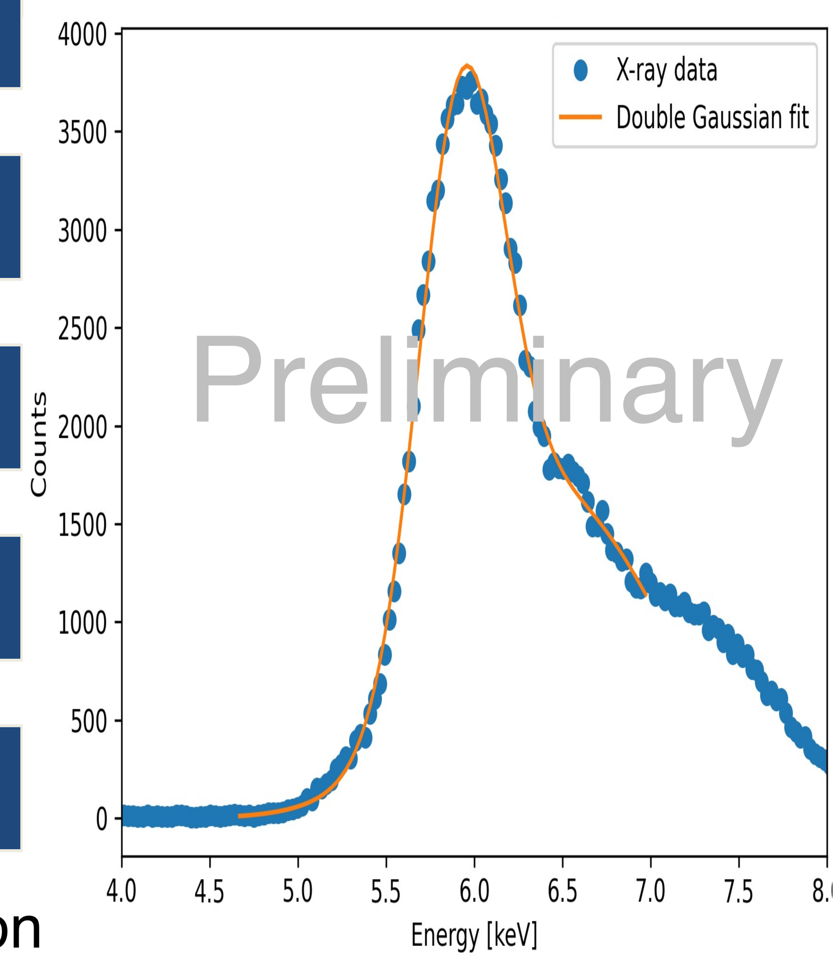
Detector Calibration Measurements

Testing Setup:
Vacuum Chamber (D)
Vacuum Pump: 10^{-5} Torr (A)
Cryo-Cooler: 150 Kelvin
Space MCM: 4 CCD Array (I)
Readout Board: LTA (B)
X-ray Source: Iron-55
RTD: Temperature sensor (H)
Thermal Interface Board (G)



DarkNESS test stand in IERC CCD lab

Collect data using a known X-ray source → Data Processing → X-ray Spectrum → Fit X-ray peaks to Gaussian → Determine gain and energy resolution



Fe-55 X-ray spectrum showing peaks at 5.89 keV and 6.49 keV

Gain: 140 ADU per electron
Energy resolution: 242 eV

Conclusion

In summary, the work focused on **finalizing the window design** for the DarkNESS **Critical Design Review** (CDR) and **analyzing X-ray data** to determine **detector noise and gain.** The **next steps** include **fabricating the window**, **testing it with X-rays**, and observing the spatial distribution of X-rays hitting the CCD to **confirm window's effectiveness**.

Potential Improvements: The detector's preliminary energy resolution was initially hampered by charge transfer inefficiencies but will improve in the future with optimized parameters. The current window design uses 1 mm PLA baffles for ease of fabrication. In the future, switching to **1 mm aluminum** baffles would be more effective for our purpose.