# DarkNESS: Characterization of Space Multi-Chip Module Skipper-CCDs and Readout Electronics

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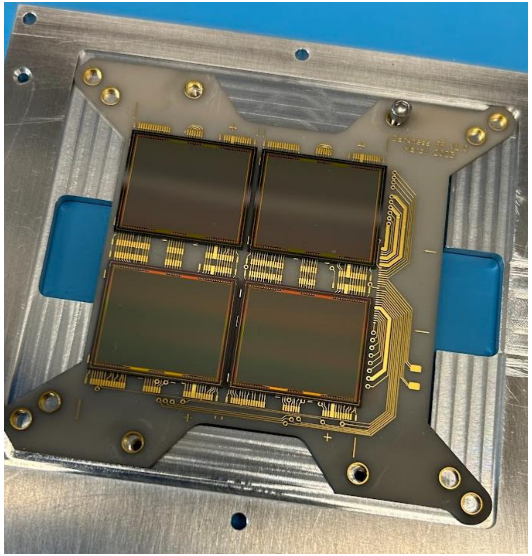
# Introduction

# Dark Matter and Skipper-CCDs

- Dark matter makes up a majority of the universe, yet eludes detection, requiring the need for detection.
- Skipper-Charge-Coupled Devices (CCDs) are photosensitive devices utilizing the photoelectric effect
  - Detect near IR to X-rays
- Cosmic particles can knock out electrons
  - Hypothetical DM as well
- Mainly direct dark matter searches (DAMIC-M. SENSEI, Oscura) and neutrino physics.
- Currently testing the electronics for use in space.

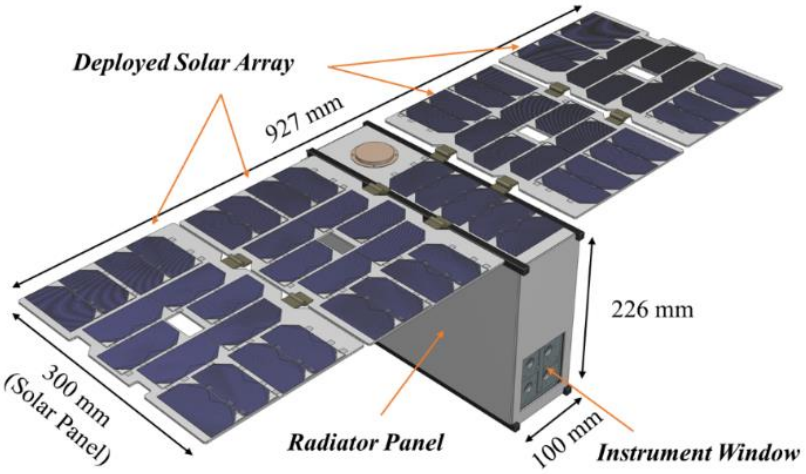


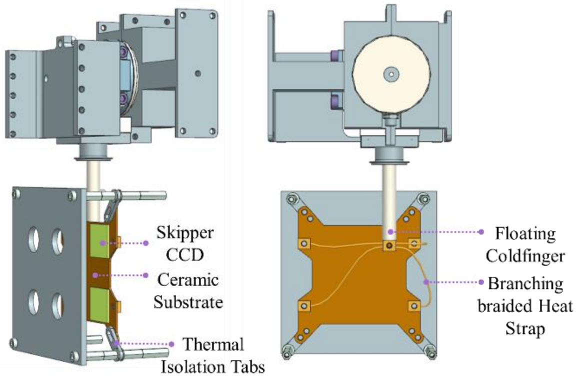
Mechanical sMCM

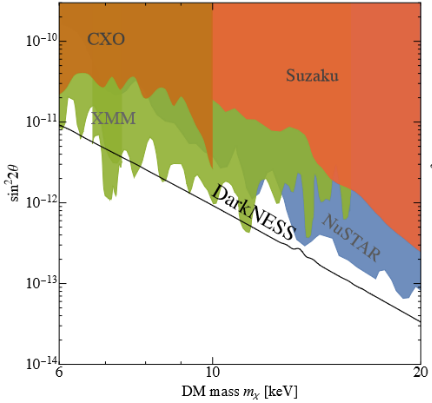
# Motivations

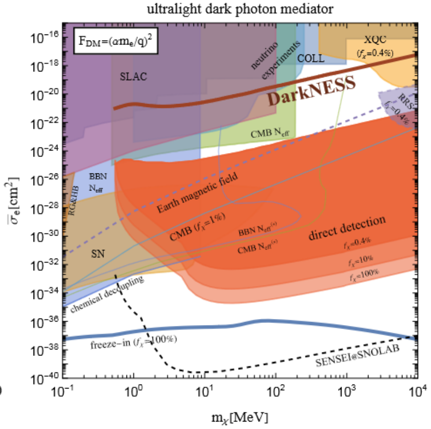
# DarkNESS

- Dark matter Nanosatellite Equipped with Skipper Sensors (DarkNESS) has 3 Goals
  - Test if Skipper-CCDs work in space
  - Search for a ~3.5 keV x-ray from sterile neutrino decay from the galactic center
  - Search for sub-GeV dark matter through electron recoils from Cygnus X-1



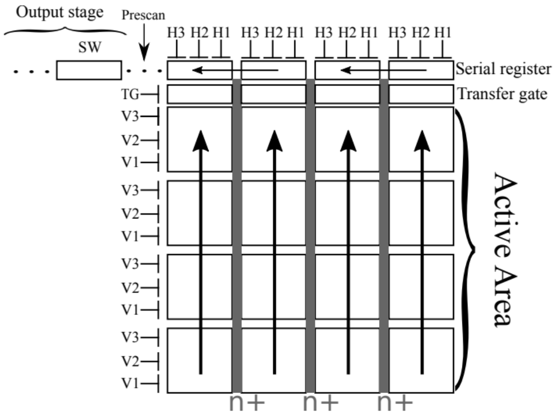



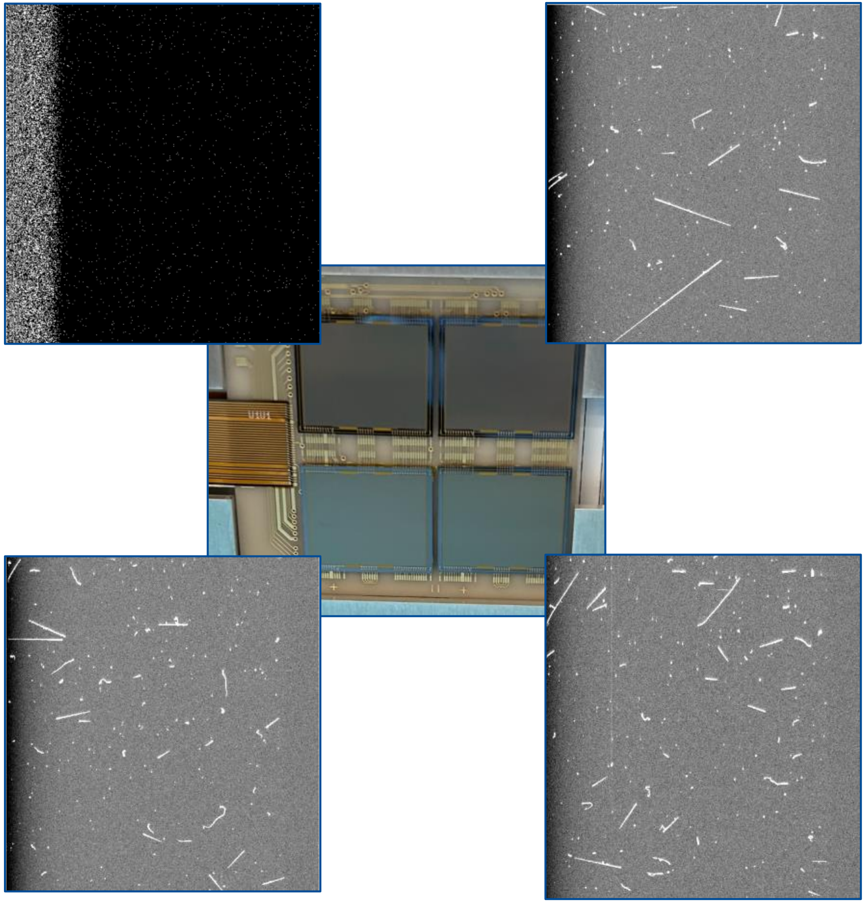



# Experimental Setup

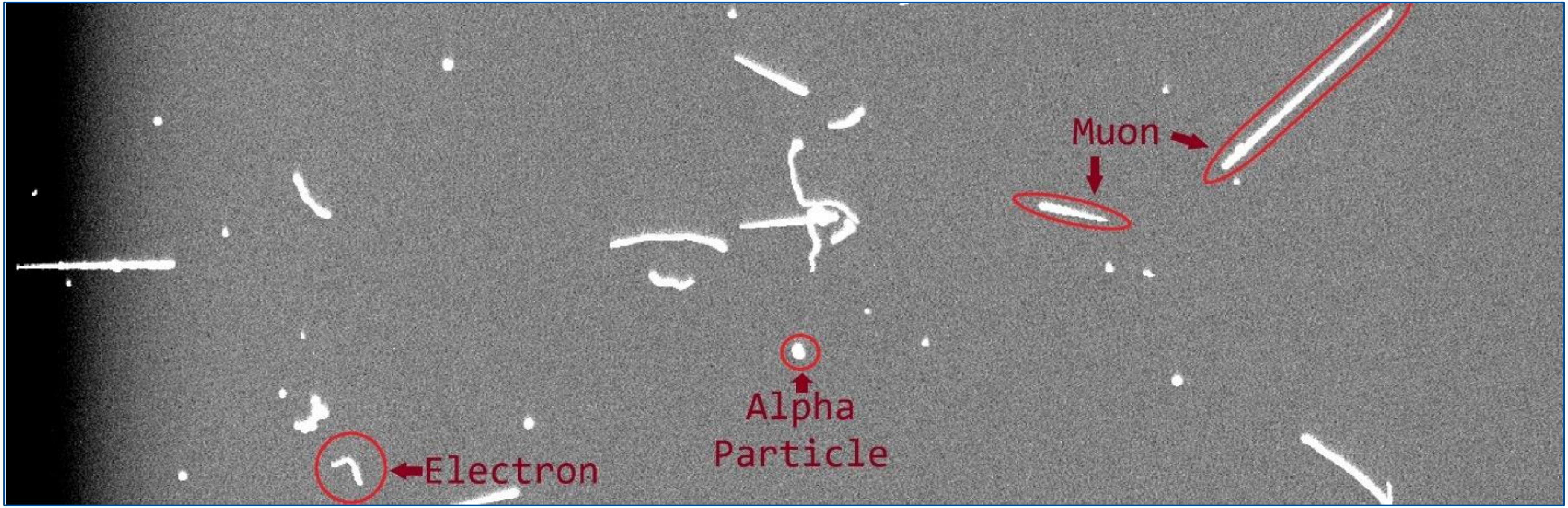
# DarkNESS: Skipper-CCDs and sMCM

- Nondestructive readout
- Sub-Electron noise
- 1278 x 1058 pixels ($15\ \mu m^2$)
- 725 (200) $\mu m$ wafer thickness
- Front (Back) Illuminated



# DS9 Image



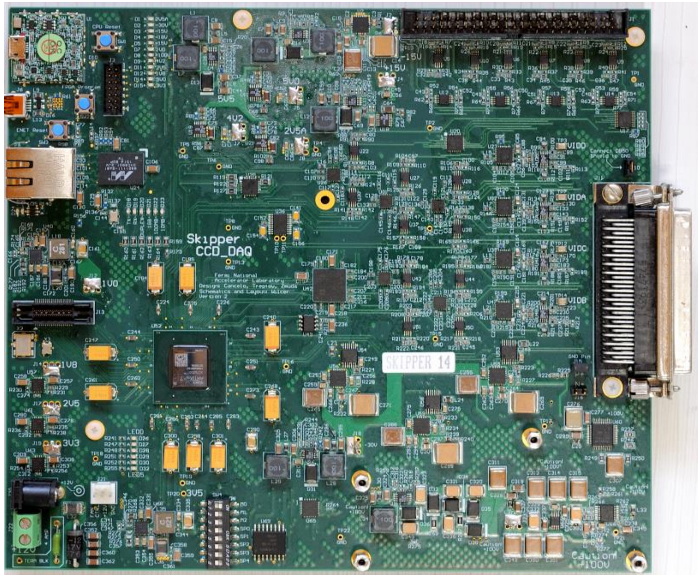

**Slice of Skipper-CCD image**

1st 9 Columns are prescan

The subsequent dark columns are transients

Last couple hundred columns are overscan

# Low Threshold Acquisition Board (LTA)



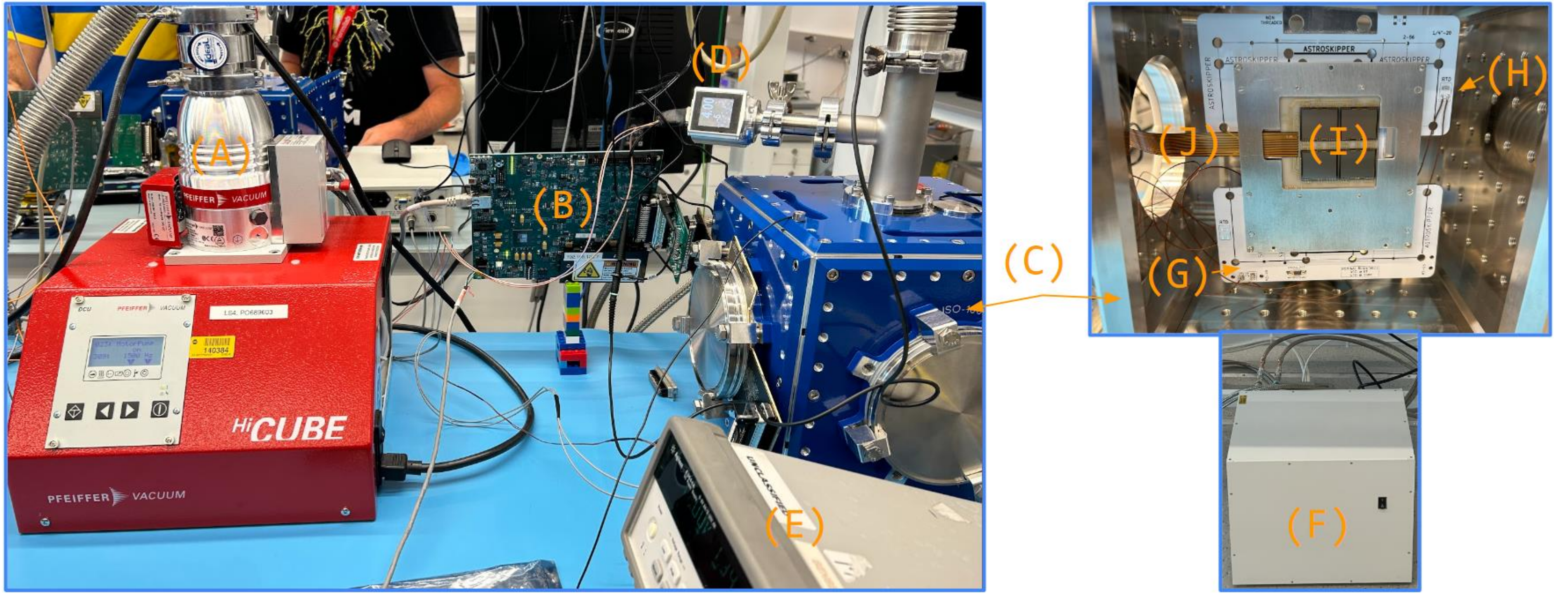

**Standard LTA**

Controls and reads from the sMCM

**Space LTA**

Smaller formfactor of the regular LTA to fit in a 6U CubeSat

# Experimental Setup

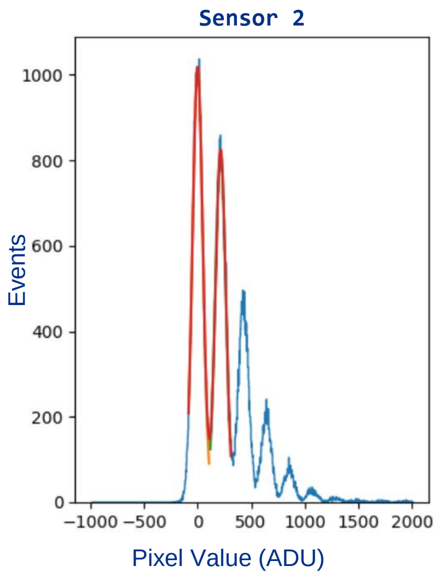



**Test setup for sMCM testing.**

**(A)** Vacuum pump, **(B)** LTA, **(C)** Pressure cube, **(D)** Pressure gauge, **(E)** DC power supply, **(F)** Cryocooler, **(G)** Heater board, **(H)** RTD temperature sensor, **(I)** sMCM, **(J)** Flex cable.

# Characterizers

- **Noise:** ADU or $e^-$
  - Readout noise from measuring charge
  - Correlation between NSAMP (number of samples per pixel) and readout noise
  - Given by the standard deviation of the $0e^-$ peak



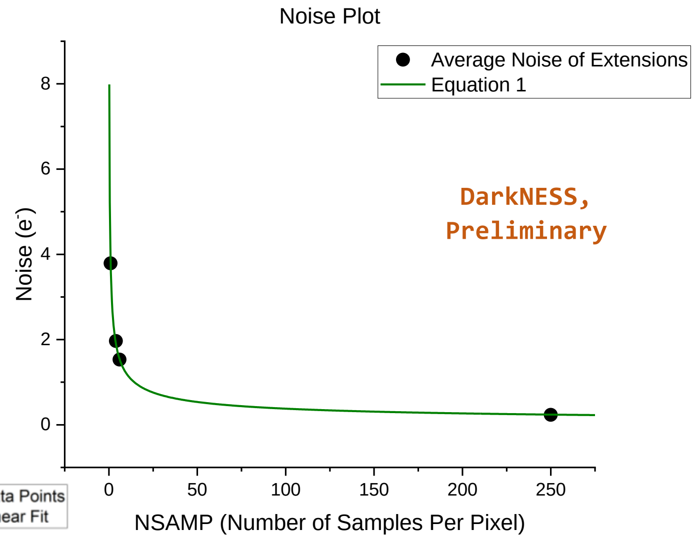

$$\frac{Readout\ Noise\ of\ 1\ NSAMP}{\sqrt{NSAMP}}$$

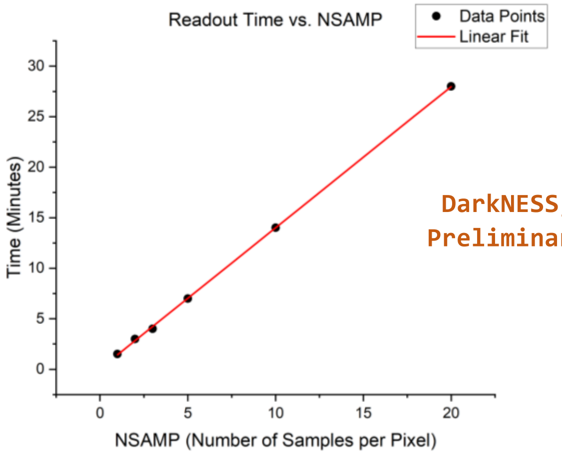
- **Gain:** Number of ADU per electron, characterized by PSAMP and SSAMP (sampling area in the pedestal and signal)
  - Used for calibration when taking data
  - Obtained by subtracting the $0e^-$ and $1e^-$ peaks of a sub-electron readout

# Results

# Noise ($e^-$) and Readout Time

- NSAMPs used: 1, 4, 6, 240
- Converted to $e^-$ by dividing by an expected gain (~200 (ADU/$e^-$))
- Sub-electron readout noise required to resolve electron peaks for gain, and more precise data taking
- Readout time linearly increases with the number of NSAMPs.

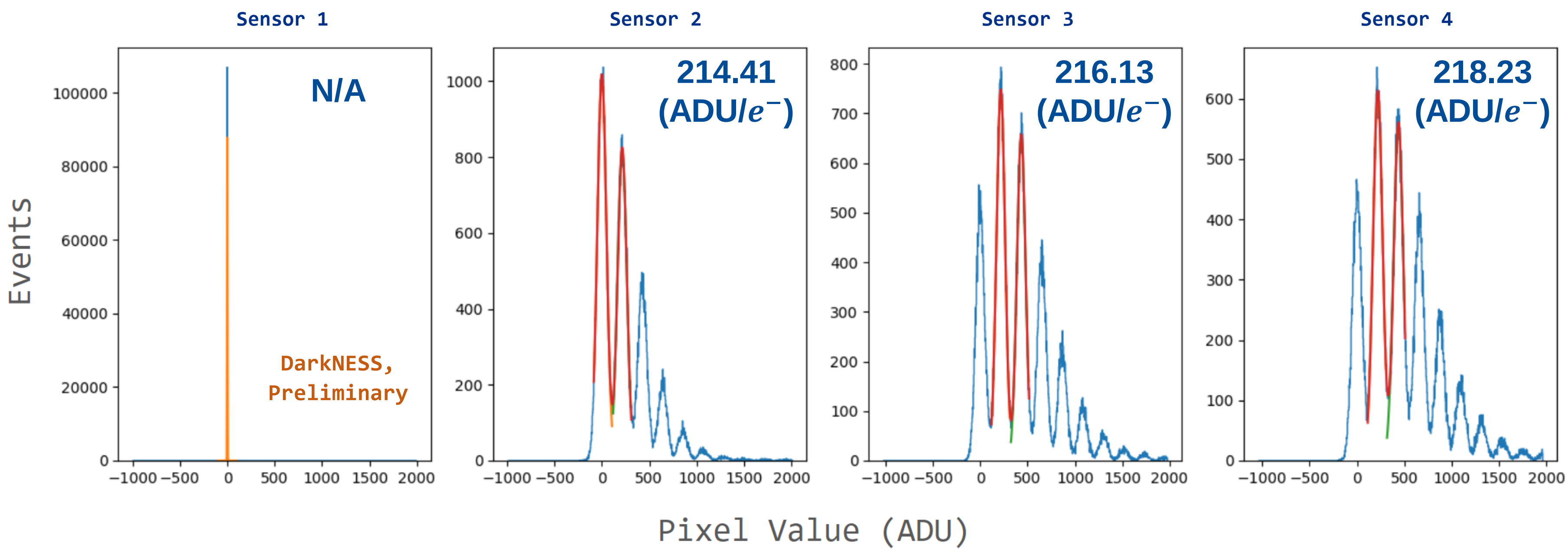




Fermilab

# Gain (ADU/$e^-$)

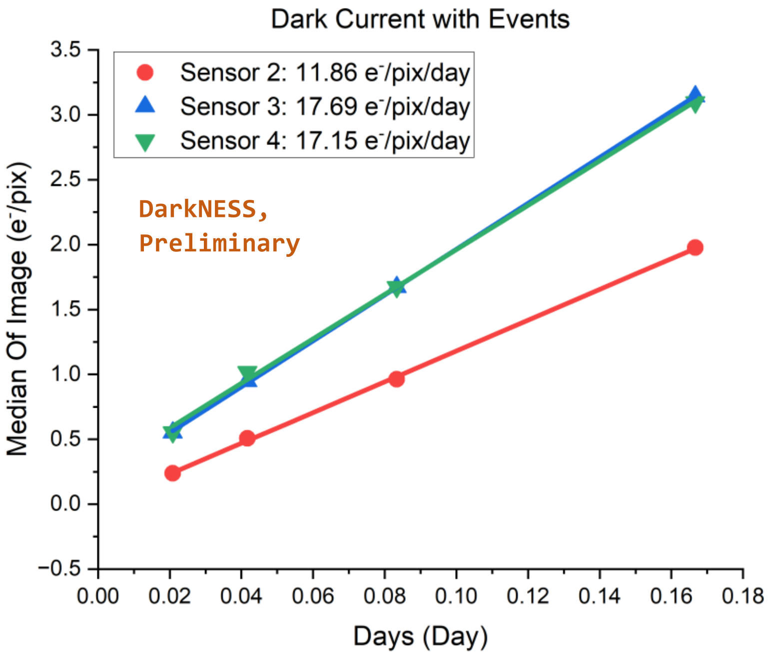



**NSAMP 250, NROW (Number of rows readout) 100, vMCM15 voltage script**
**Calculated with a python script**

Has a slight offset due to imperfect baseline subtraction of the overscan mean.

Not too important for noise and gain but has an impact on actual data analysis if not accounted for.

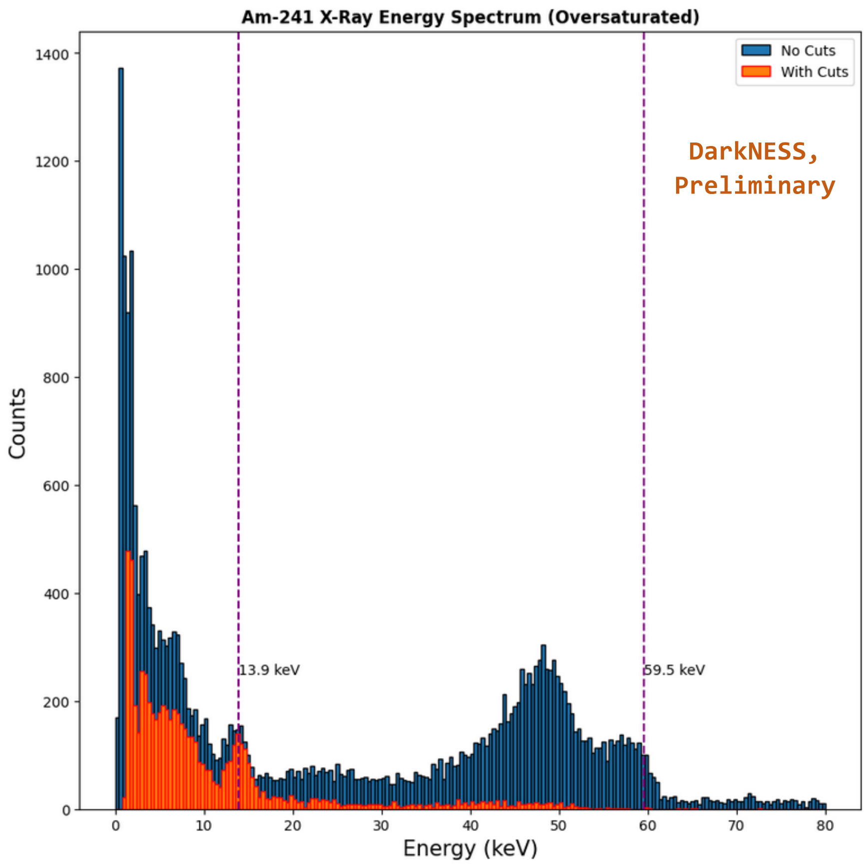
# Dark Current ($e^-$/pix/day)



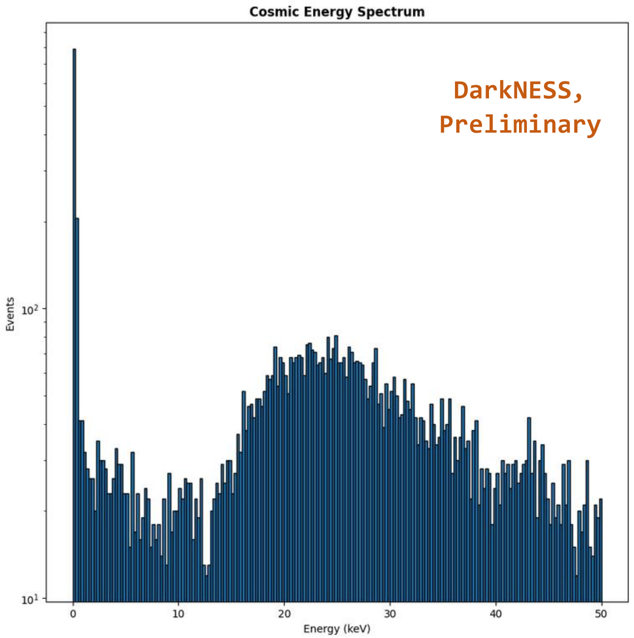

- "Dark current" encompasses a few factors:
  - Thermal excitations in the silicon
  - Amplifier light
  - External radiation
- Can get as low as $10^{-4}$ ($e^-$/pix/day) with sufficient overburden, shielding, and masking
  - We have no shielding
  - No masking of events
- In this case, used to see if there is light bleeding into the chamber, excess voltage, and amplifier light

# Am-241 X-Rays

- Overlay of 104 images, full scan, background subtracted
  - Blue: No cuts
  - Red: Clusters events for a range of pixels in an area and within a certain number of ADU
- Oversaturated by the alpha and gamma rays
  - Can see the 13.9 keV peak
  - Possibly see the 59.5 keV peak, but most likely just oversaturated events, same with the ~49 keV peak.
    - ~49 keV: Once thought to be GaAs, but impossible as we use Silicon



# Cosmic Data




**NSAMP 4 (Ignore 1st Sample – Pure Noise), Full Active Scan, combined EXPO and READ time of 15 minutes.**

**45 Images overlayed, Extension 4**

- Converted to keV by dividing by $1\ e^-$ (3.75 eV) by the gain
- Muon bump lower than expected (reason not fully known)
  - Expect it to be around 250 keV
  - Suggests an issue with the reconstruction at higher energies

# Conclusion

# Conclusion

- As you may have noticed, there is still a lot of work to be done on characterizing the sMCM
- Currently, we do reach the expected sub-electron noise levels
- We are working on dealing with oversaturation from high energy events, as this will inevitably happen in the data taking cycle in space
- Currently trying to use the sLTA with the sMCM together to more closely mimic the real mission
- Plan to thin our skipper-CCDs to 200 μm back-illuminated for better quantum efficiency
  - Very difficult to process

# Acknowledgements

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