Image Sensors for Precision Astronomy 2024

Fermilab

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A skipper-CCD light shield for X-ray detection in space

We present advancements in the design of Skipper-CCD sensors for X-ray detection in environments with high optical backgrounds, such as those expected in space. These packages incorporate a custom-made aluminum shield on the CCD surface that blocks over 99% of visible light while preserving the efficiency for keV X-rays. These features allow us to perform precise X-ray measurements in environments challenged by visible light interference. Furthermore, we briefly discuss the potential implementation of this design concept in frame-transfer CCDs, opening opportunities for broader applications and advancements in imaging technologies.

1. Why do we need light tight CCDs?

Direct detection in silicon:

- X-ray in Space (i.e. DARKNESS)
- Dark matter detection in cold medium (LN2)
- Frame-transfer CCD

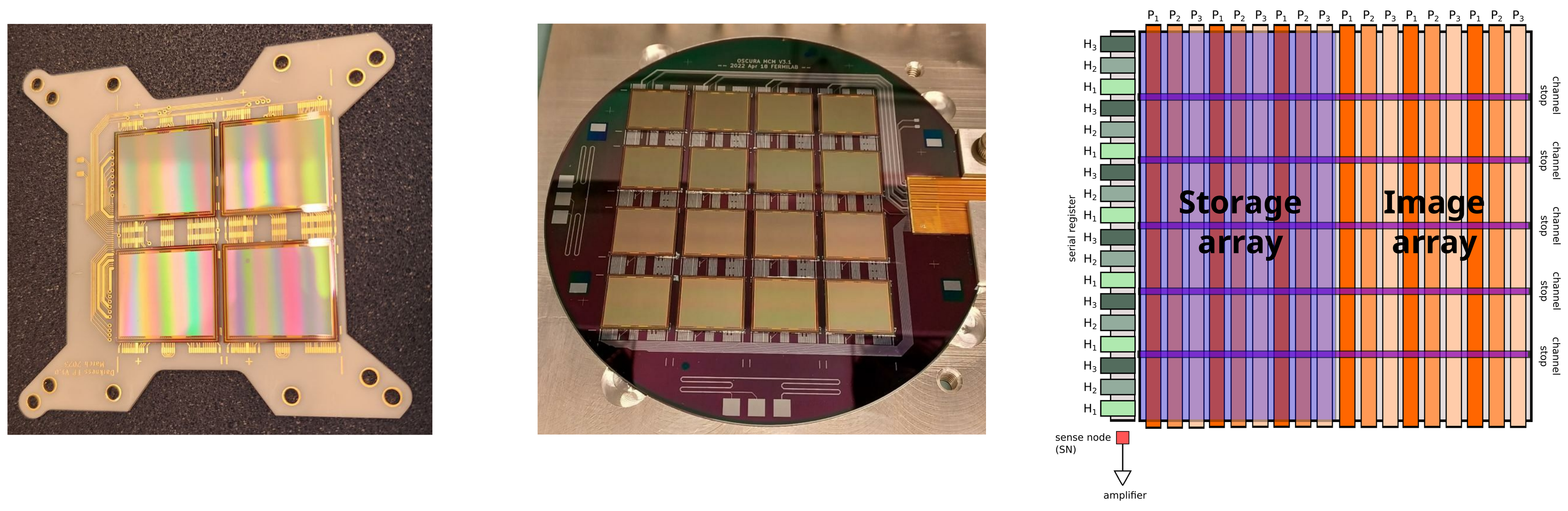


Figure 1: (Left) DARKNESS camera with 4 skipper-CCDs with 1.3 Mpix. (Middle) OSCURA package with 16 skipper-CCDs. (Right) illustration of frame transfer CCD; light is collected in Image array and moved to storage array for read-out.

2. Aluminum shield

Lift-off process at Argonne National Laboratory:

- 1um SPR-955 + Heidelberg MLA 150
- Temescal FC2000 E-Beam Evaporator
- 20 ~ 100 nm aluminum + 1165 remover

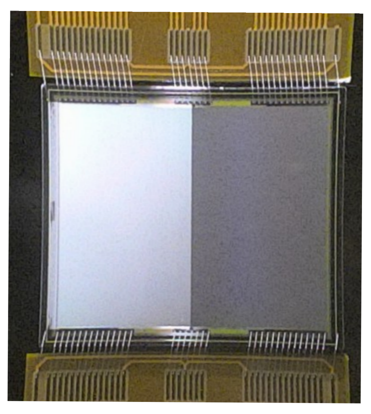


Figure 2: Skipper-CCDs with 50 nm Al shield. (Top) Picture of the sensor with Al layer covering half of the active area. (Left) same with an aluminum plane- and unicorn-shaped Al layers (Right) Image acquired using the CCD upper half after illuminating 30 seconds with and LED.

3. Testing setup

Shield performance when illuminated:

- Front-illuminated package with flex cable
- Monochromator to select wavelength (650 ~ 1000 nm)
- Mechanical shutter to select exposure (0 to 120 s)
- Skipper-CCD with Al shield (0, 20, 50 and 100 nm) with and without GND

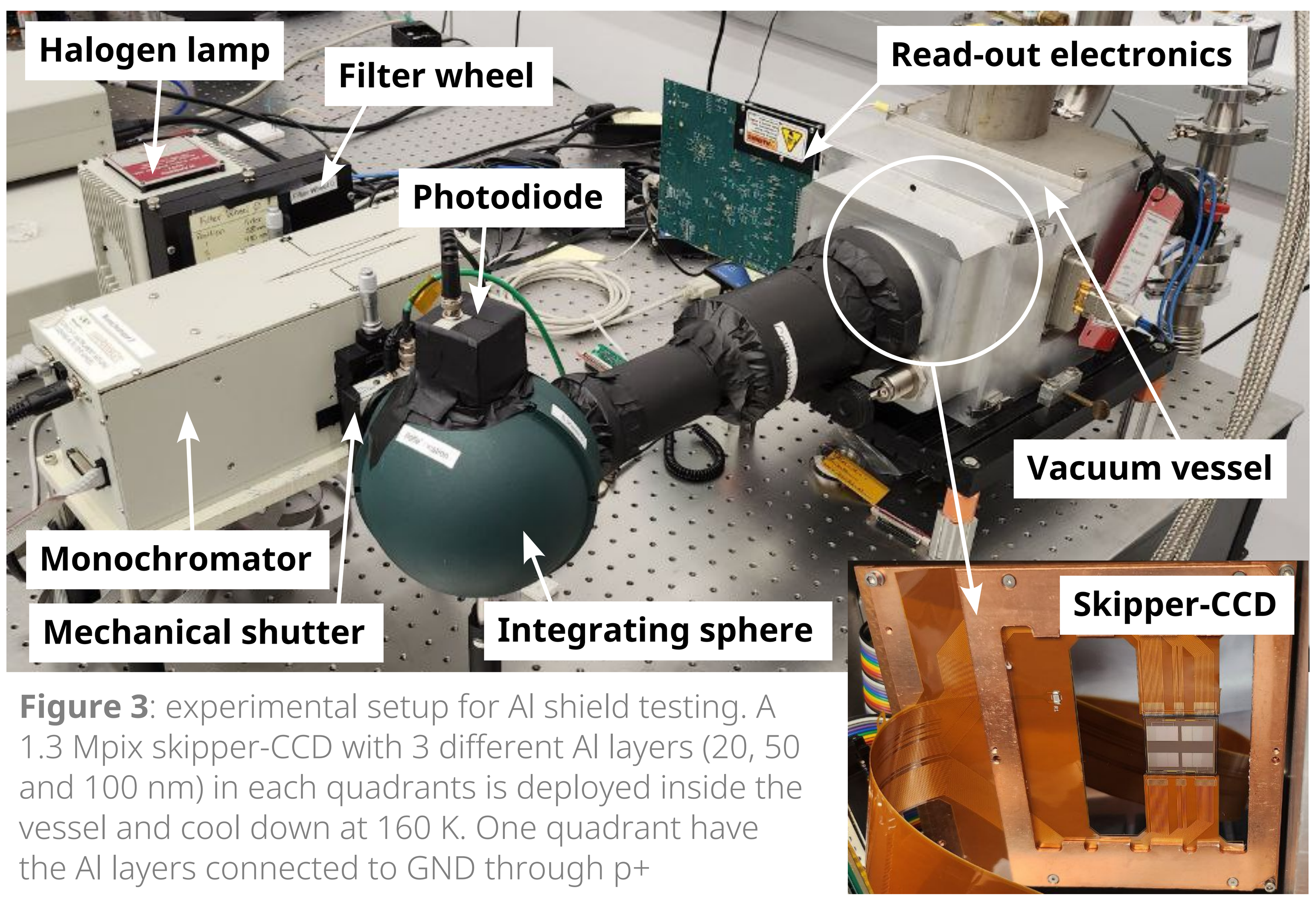
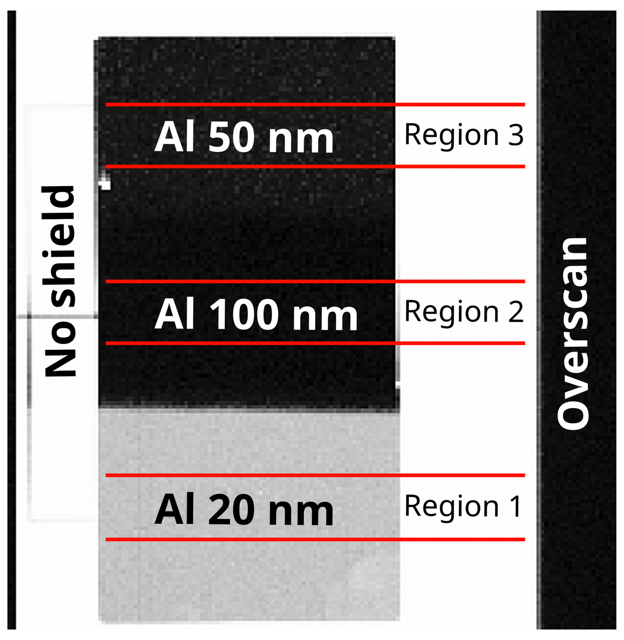


Figure 3: experimental setup for Al shield testing. A 1.3 Mpix skipper-CCD with 3 different Al layers (20, 50 and 100 nm) in each quadrants is deployed inside the vessel and cool down at 160 K. One quadrant have the Al layers connected to GND through p+

4. Monochromator results

- 2 images per wavelength and exposure (one with shutter close for baseline)
- Compute mean charge per second of exposure (Q) on different regions
- Blinding factor: Q in shielded regions / Q in unshielded regions



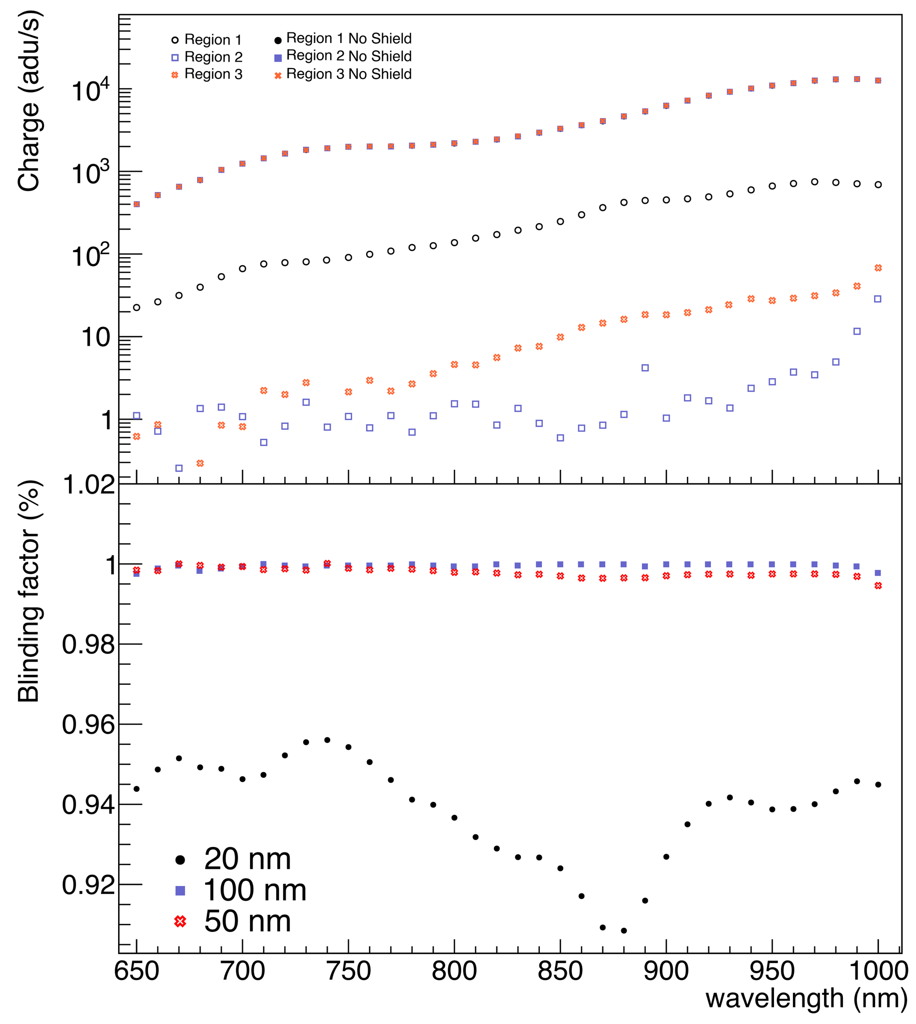
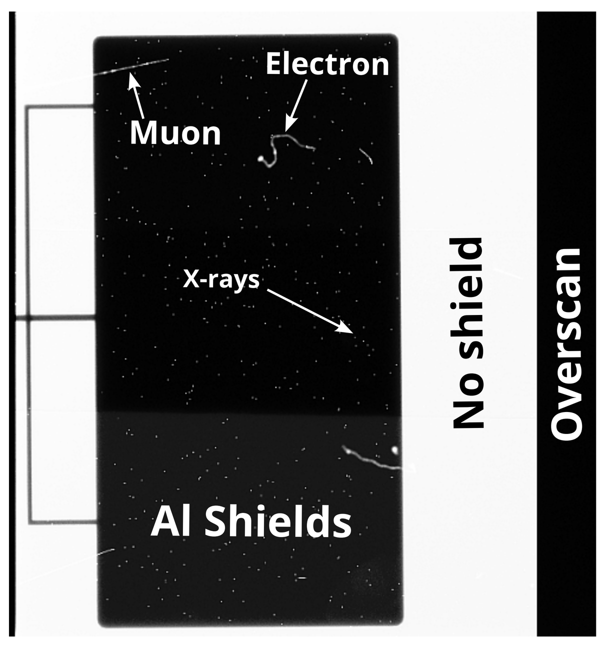
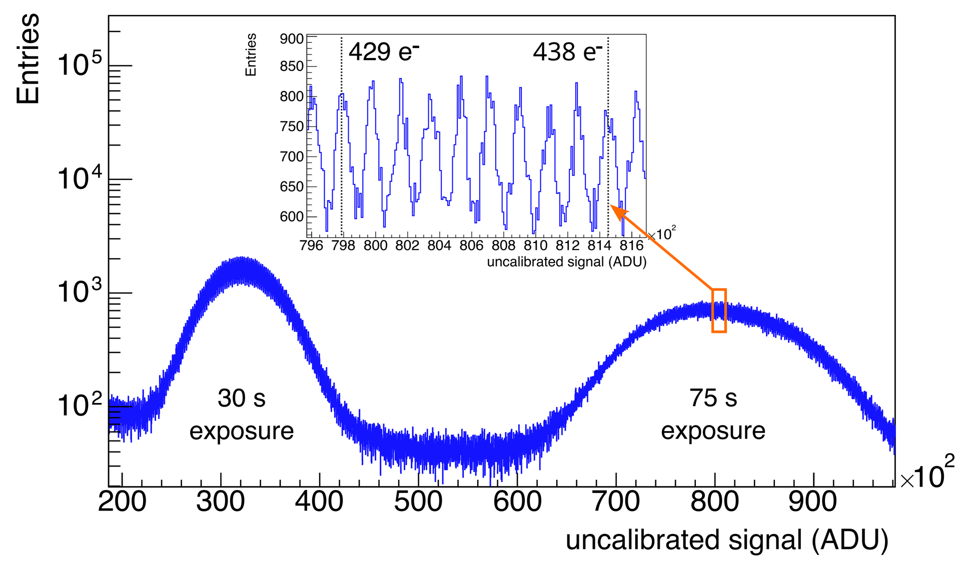


Figure 4: (Left) image with 850 nm and 120 s exposure. (Top-right) Uncalibrated Q as a function of wavelength in different regions of the image. Shape is convolution between monochromator intensity spectrum and quantum efficiency. (Bottom-right) Blinding factor as a function of wavelength for different Al thicknesses

5. ^{55}Fe X-ray results (preliminary)

- ^{55}Fe X-ray source (5.9 and 6.5 KeV) inside vessel between window and CCD
- Measurements with monochromator shutter open and close
- Deep sub-electron resolution (200 samples) for signal calibration
- No apparent X-ray efficiency loss due to shield (work in progress)





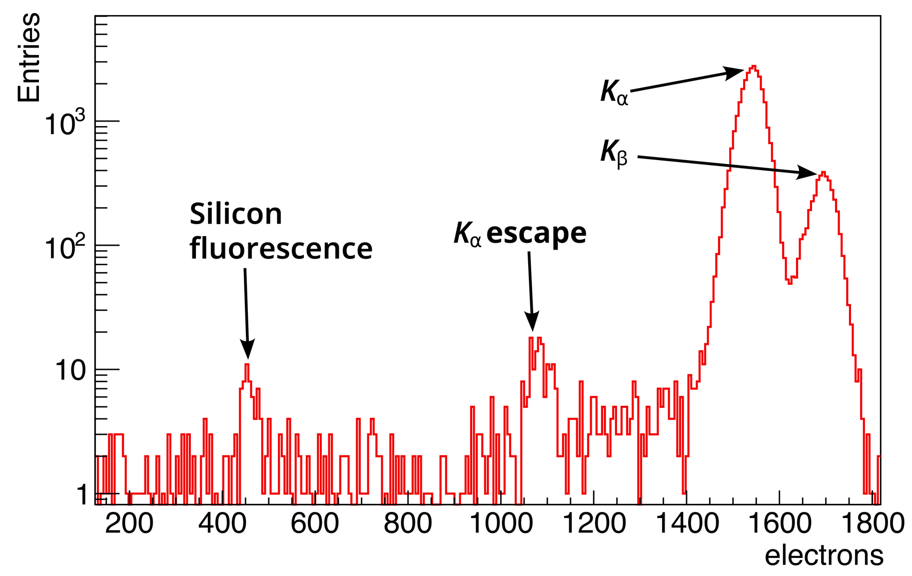


Figure 5: (Left) Illuminated image with 950 nm and 375 s exposure. (Top-right) Histogram of uncalibrated charge per pixel combinning 40 images with 30 s and 75 s exposures with zoom-in inset showing 428 to 439 electron peaks. (Bottom-right) Charge distribution of X-rays bellow Al layer.

Summary

- Many applications for light tight CCDs
- First production of skipper-CCDs with Aluminum shielding at ANL with successful tests
- > 99 % blinding factor for wavelengths bellow 1000 nm demonstrated
- No apparent efficiency loss for ^{55}Fe X-rays (work in progress)

Link to this work and references in QR