Testing CMOS image sensors for future space telescope missions

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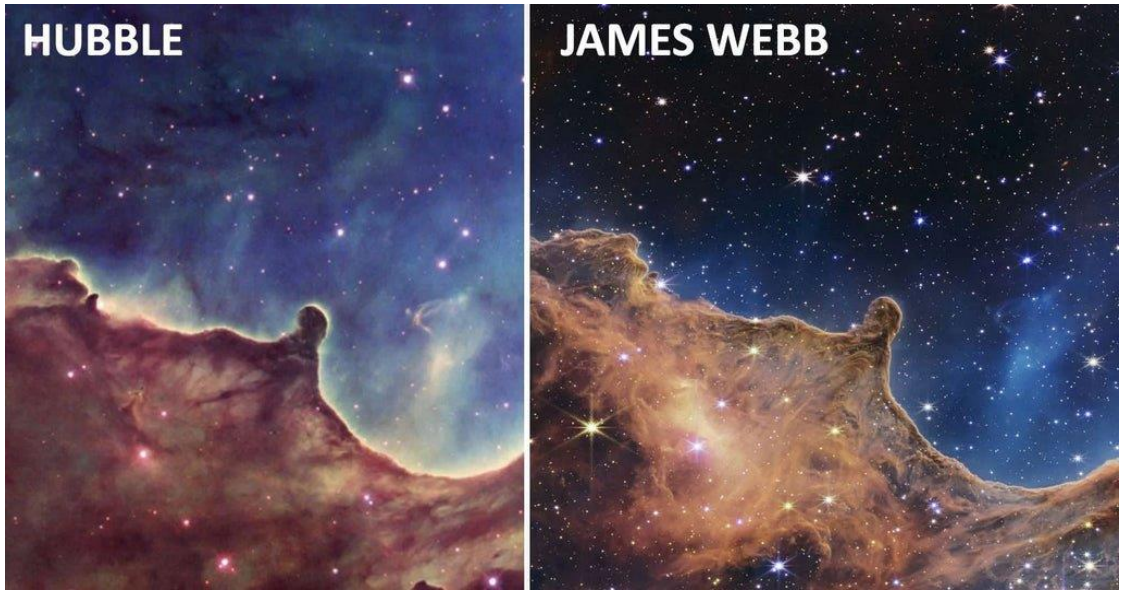
Habitable Worlds Observatory (HWO)

- Future space telescope to look for signs of life in other planets.
- Envisioned to be as versatile as the Hubble Space Telescope (HST) but with an aperture as large as the James Webb Space Telescope.

Possible design for HWO



Carina Nebula as seen by the Hubble and James Webb space telescopes

Hubble Space Telescope

Discoveries by HST:

- Age of the universe.
- Dark energy.
- Black holes at the center of galaxies.

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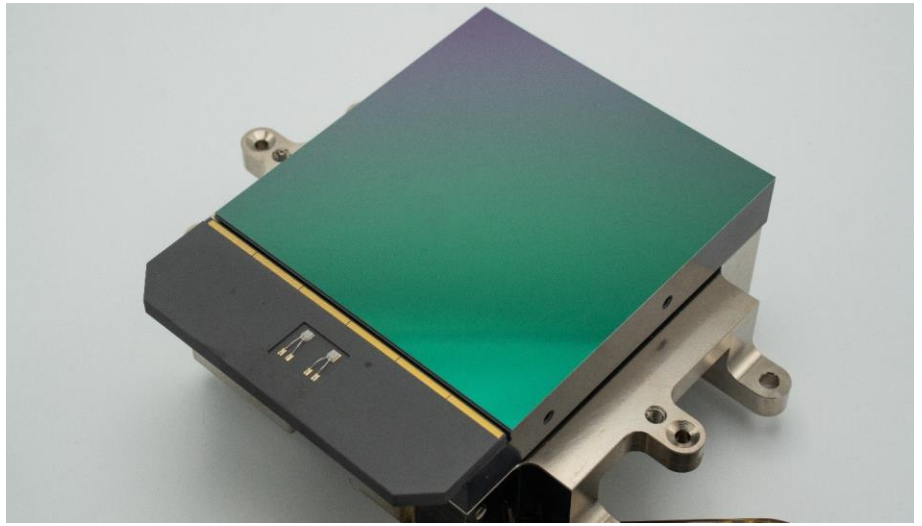
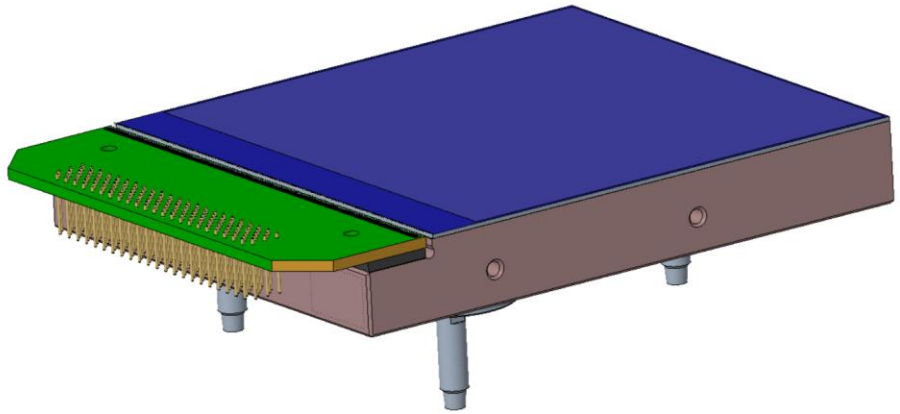
Detectors for HWO: Teledyne e2v's CIS300-series

- Large area CMOS image sensor in a three-side-buttable package.
- The nominal version consists of 9000×8600 pixels with a 10 μm pitch.
- Detects UV to near-IR light.
- Can operate in a wide range of temperatures and has radiation-hard versions.
- Readout noise below 2 e- RMS.
- Modes of operation: rolling shutter, global shutter with optional digital double sampling, staircase, and high dynamic range.
- Multiple independent gains at the pixel and preamplifier level.
- Operation set through Serial Peripheral Interface (SPI).



CIS300 detector



CIS300 model

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Heavy ion test

- HWO detectors will have to withstand the harsh conditions in space, including radiation from cosmic rays.
- To simulate the space radiation, detectors are irradiated with:
  - Protons.
  - Gammas.
  - Heavy ions.
- A heavy ion test was done on a CIS303 detector to quantify:
  - Single Event Effects (SEE): detector states created by the incident ions.
    - Single Event Upsets (SEU): a non-destructive state in which a logic cell changes from one to zero or vice-versa.
    - Single Event Latch-Ups (SEL): a state in which incident ions create parasitic thyristor structures and high current, low impedance paths that can be destructive.
  - SEE cross-section: number of SEE events per unit fluence.
    - Localized cross-section: obtained for a partial area instead of the full device.

Beamline

- Heavy ion beamline at the Radiation Effects Facility (RADEF) at the University of Jyvaskyla in Finland.
- The facility provides ion beams with varying linear energy transfer (LET), and a beam shutter that can be controlled remotely.
- The heavy ion test was done in air and at room temperature.
- Worked mostly with a flux of 10^4 ions/cm^{2}s and took data in runs with a fluence of 10^7 ions/cm^2.

Heavy ion cocktail

Ion	LET at surface (MeV cm^2/mg)	Range (µm)
$^{54}Fe^{15+}$	18.1	102
$^{84}Kr^{23+}$	31.3	104
$^{109}Ag^{30+}$	47.5	95
$^{126}Xe^{35+}$	58.5	93
$^{197}Au^{54+}$	85.6	107

Heavy ion beamline at RADEF

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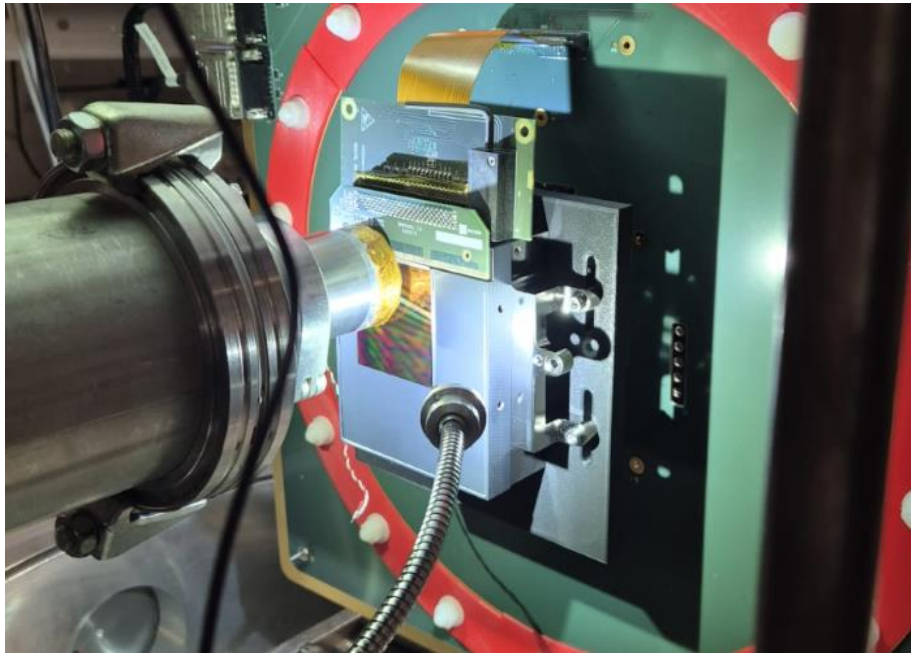
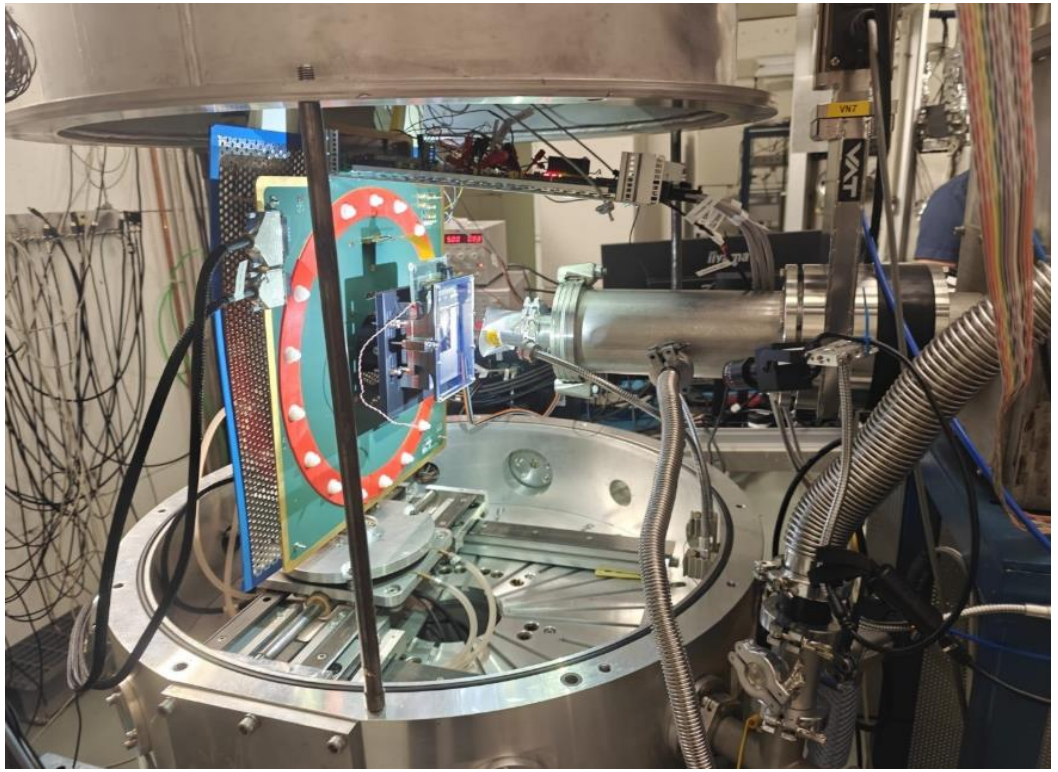
Experimental setup

- The CIS303 detector was placed on a mount designed to integrate the system into the RADEF beamline.
- The detector was connected to an electronics board and frame grabbers that communicate with a computer.



Detector facing the beamline



Detector and camera electronics board on a mount in front of the beamline

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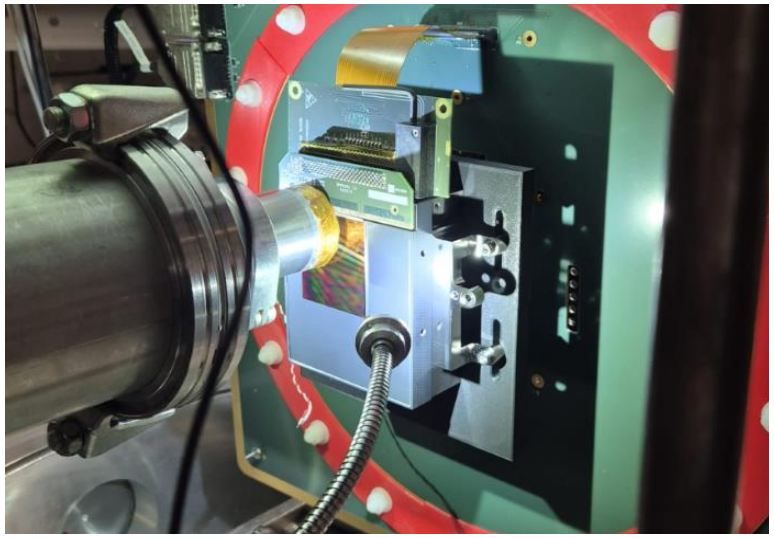
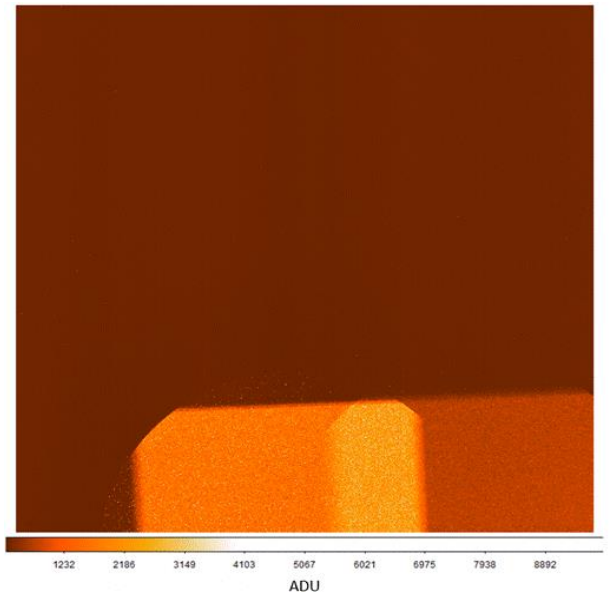
Beam position and device architecture

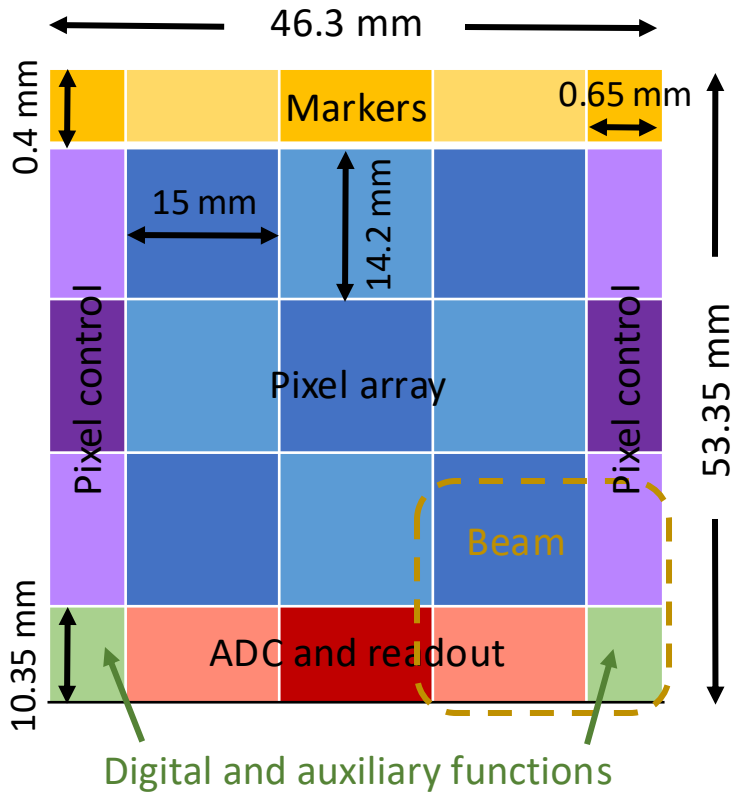
- Approximately square beam area of ~2x2 cm^2 pointed at two positions, bottom right corner and bottom center of the detector.
- The corner targets both the horizontal and vertical circuitry, while the center targets only the horizontal.



Beamline pointed at the bottom right corner of the detector (detector mounted upside down)



Frame taken with the detector after heavy ion irradiation.



Device architecture (not to scale)

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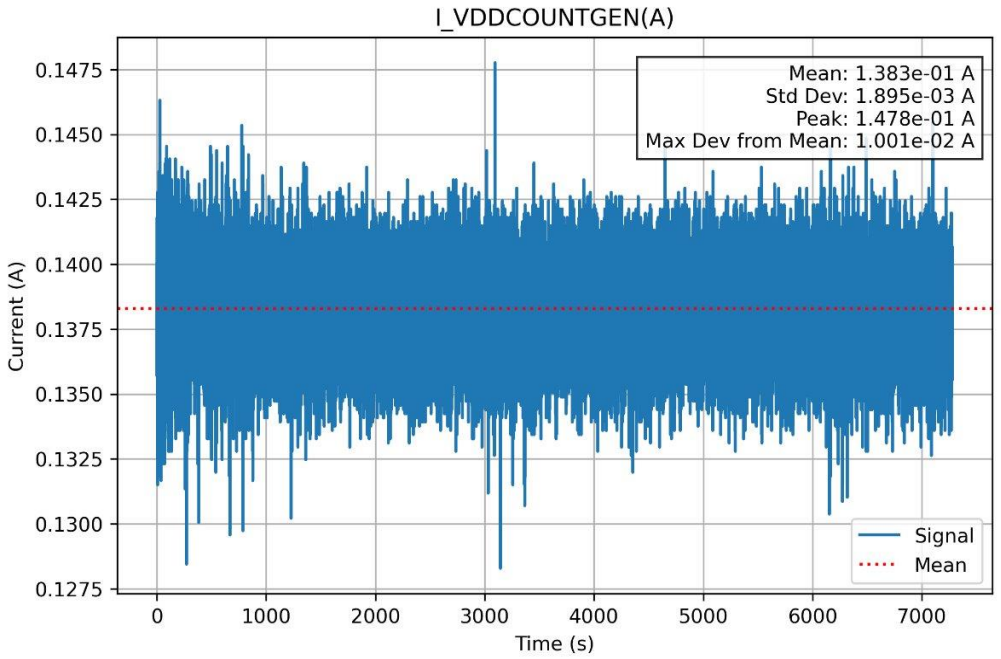
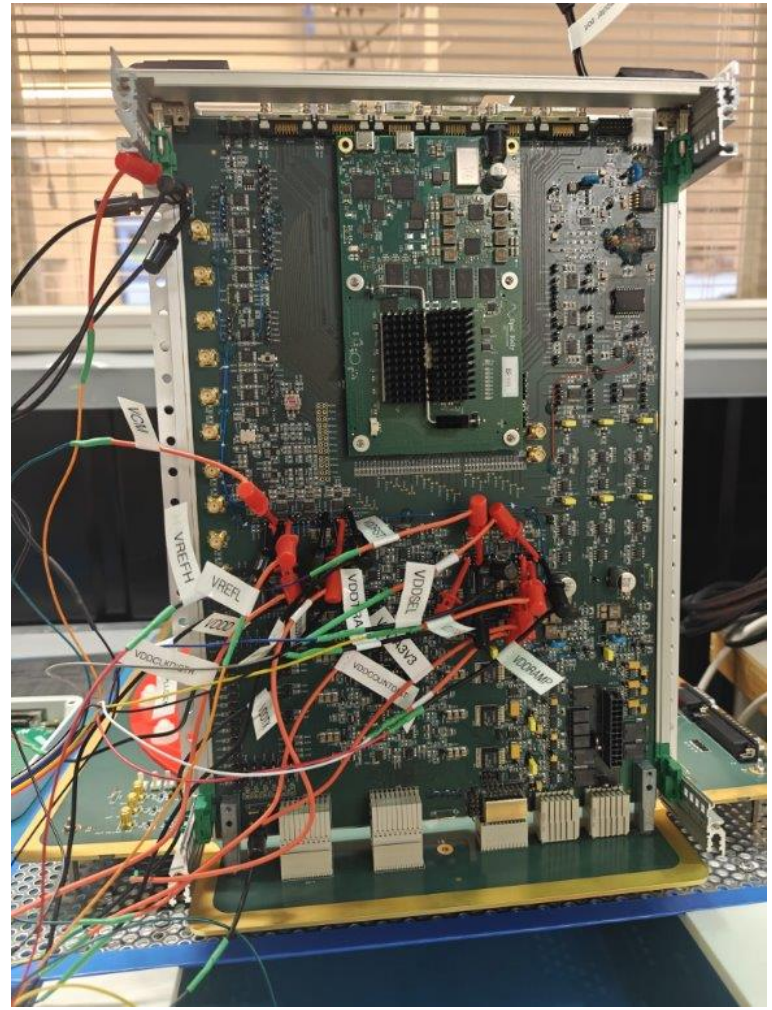
Current monitoring

- Probes were placed on test points on the electronics board to measure the voltage on the detector bias lines.
- The voltages were recorded and converted into a current considering the type of amplifier or regulator the bias line uses.
- Over-currents: ~200 mA above the maximum of the baseline current.

Current vs. Time for one bias line





Camera electronics board with probes for the detector bias lines

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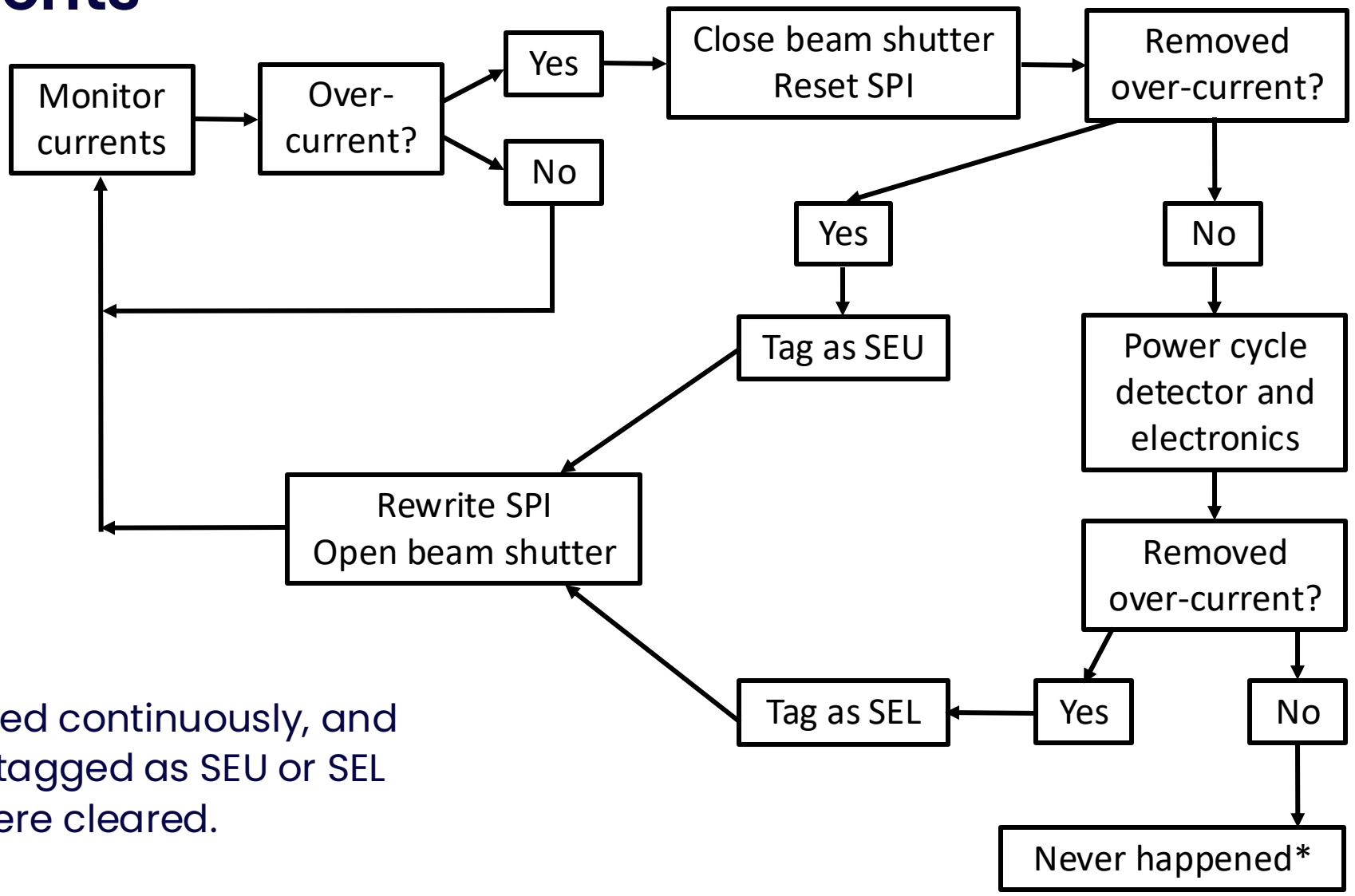
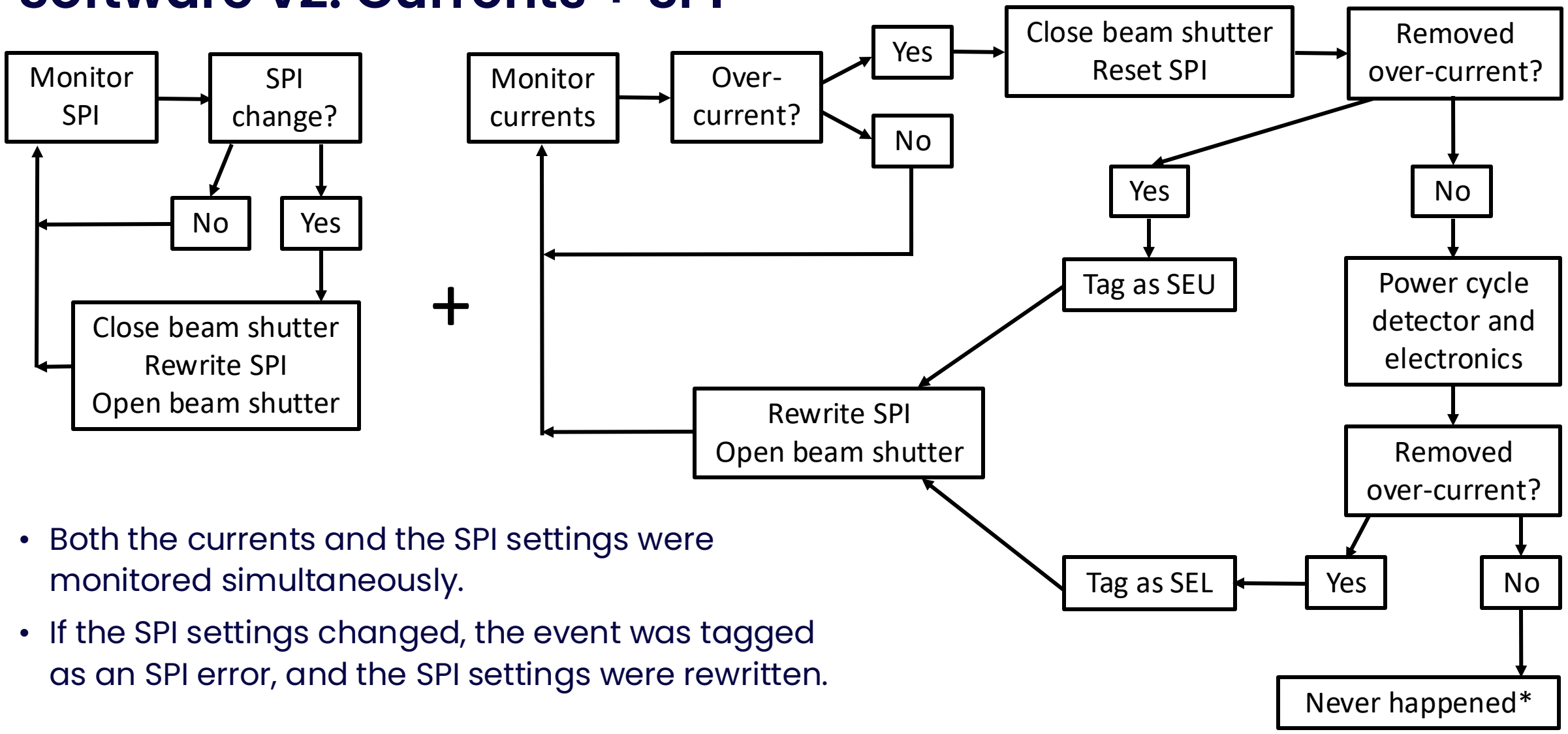
Software v1: Currents



- The currents were monitored continuously, and over-current events were tagged as SEU or SEL depending on how they were cleared.

*The power supplies would have been power cycled if it had happened.

Software v2: Currents + SPI

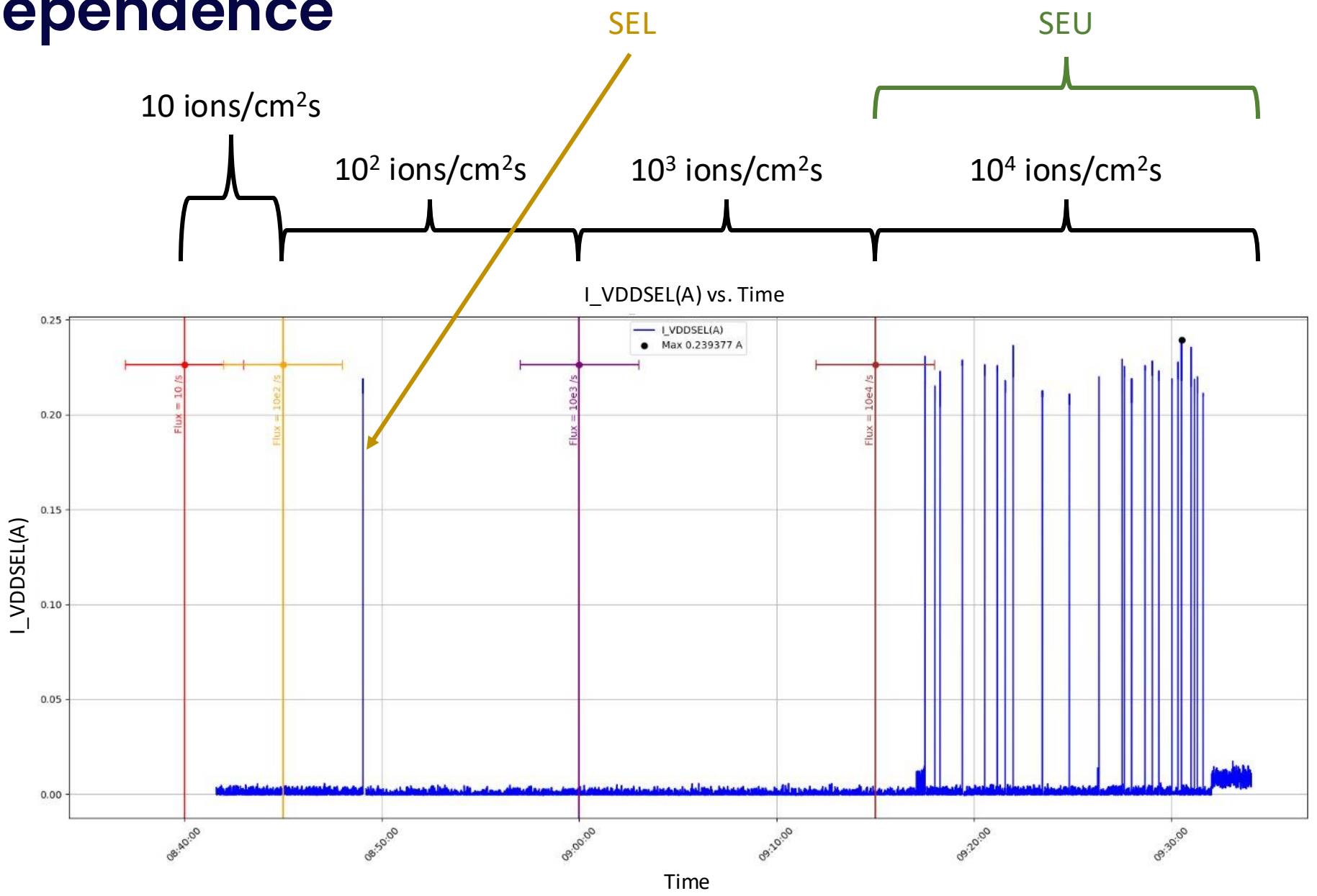


- Both the currents and the SPI settings were monitored simultaneously.
- If the SPI settings changed, the event was tagged as an SPI error, and the SPI settings were rewritten.

*The power supplies would have been power cycled if it had happened.

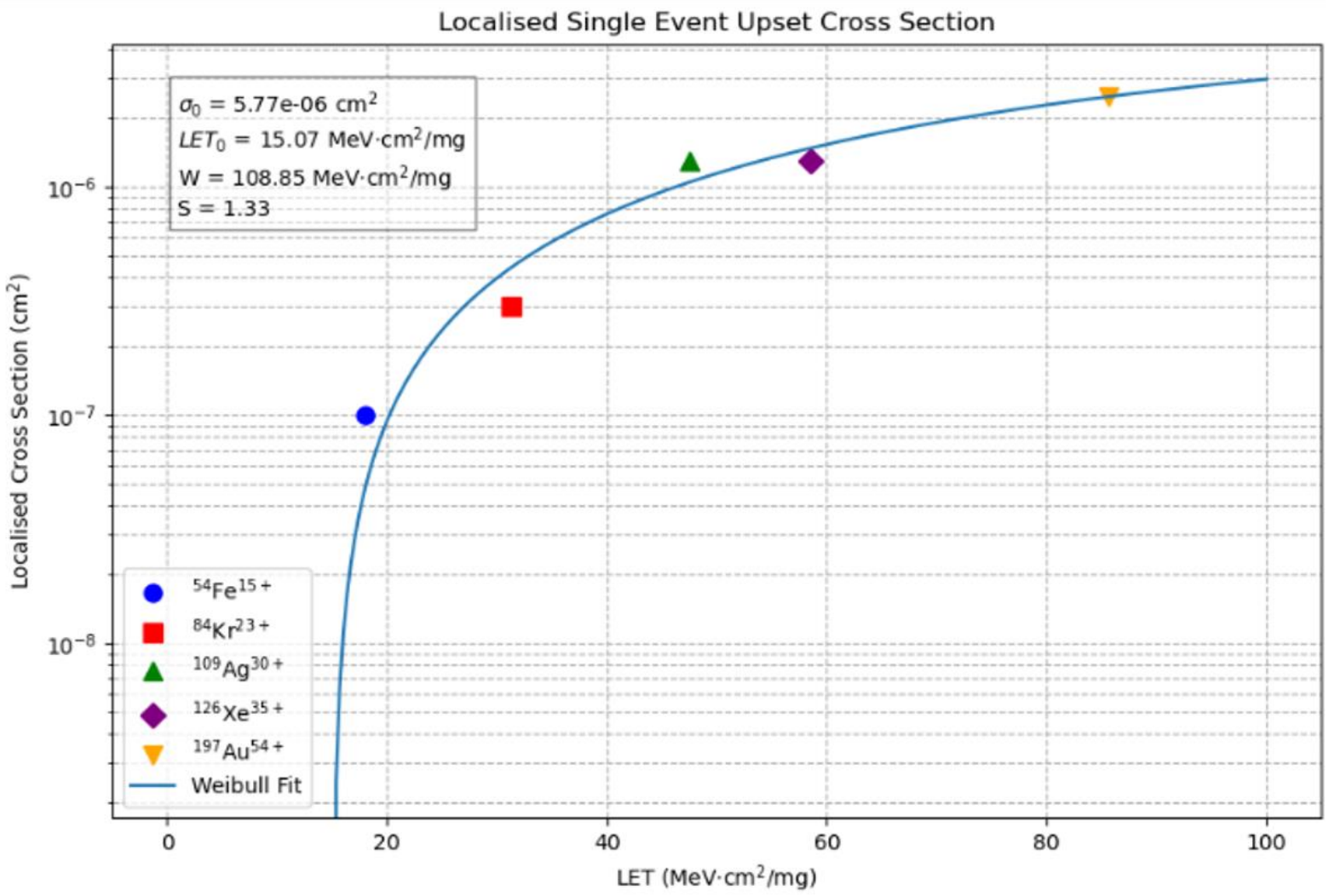
Results: Flux dependence

- The current spikes at the highest flux were identified as SEU.
- The current spike at low flux was identified as SEL.
- This behavior is consistent with triple mode redundancy breaking down at higher flux.



Results: SEU and SEL

- Observed a maximum of 25 SEU at the highest LET and highest flux.
- Obtained a localized SEU cross-section by normalizing the number of SEU by the fluence.
- Only two SEL were observed across all runs, occurring at the highest LET.
- All SEE were recoverable.



Results: SPI errors

- Two runs at the highest LET and flux, with the beam pointed at the bottom center of the detector.

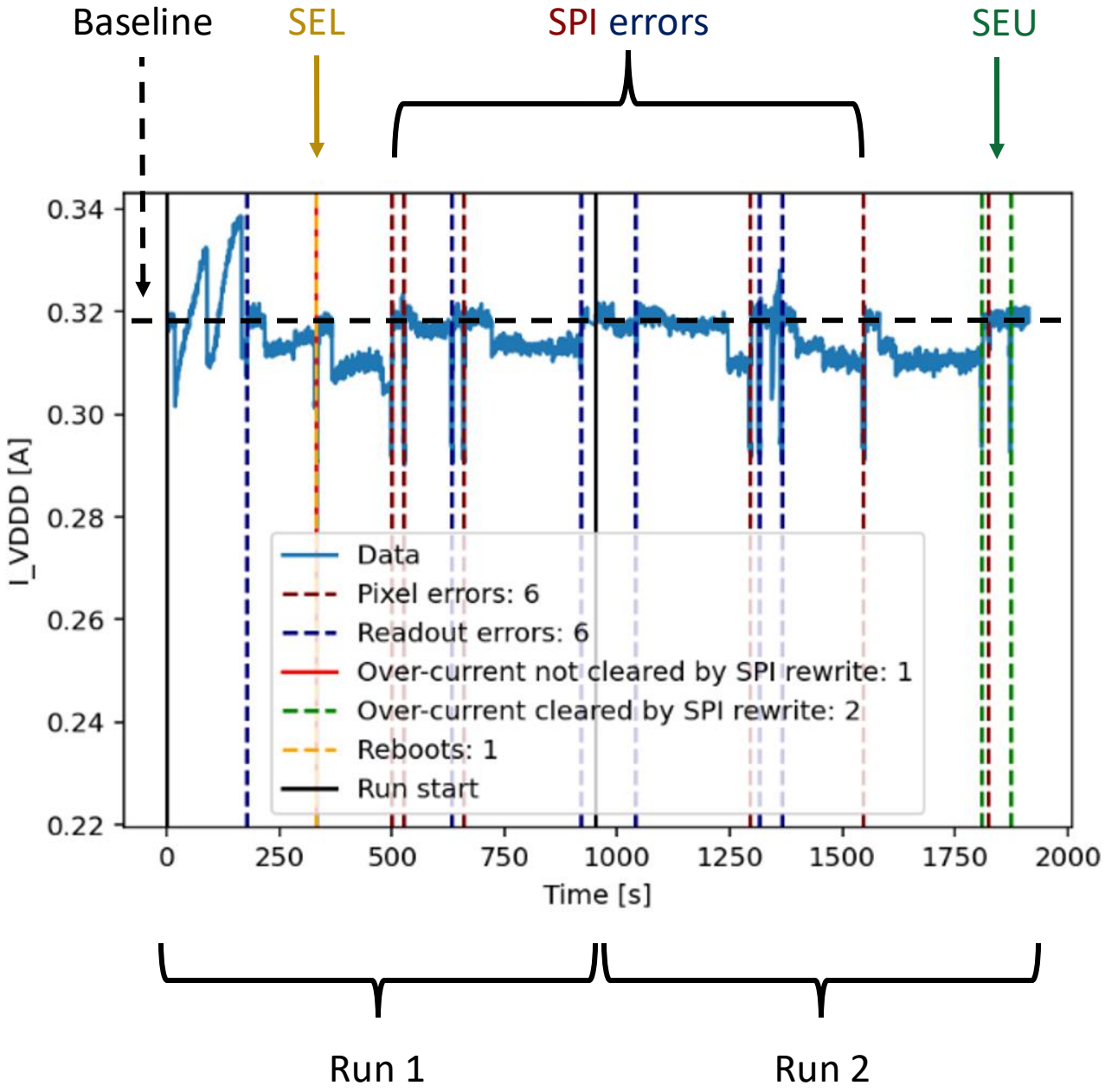
- SPI settings were monitored at the same time as the currents.

Events:

- Various SPI errors, cleared by an SPI rewrite.

- Two SEUs, cleared by SPI resets.

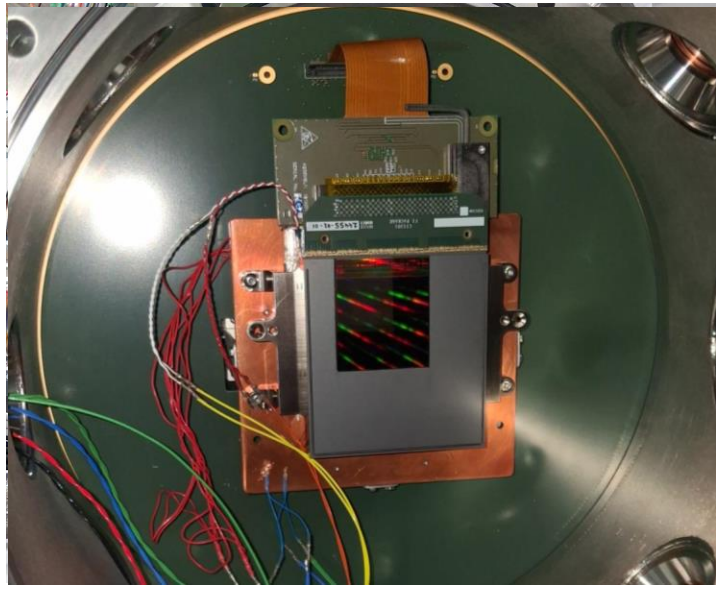
- One latch-up, cleared by a reboot.



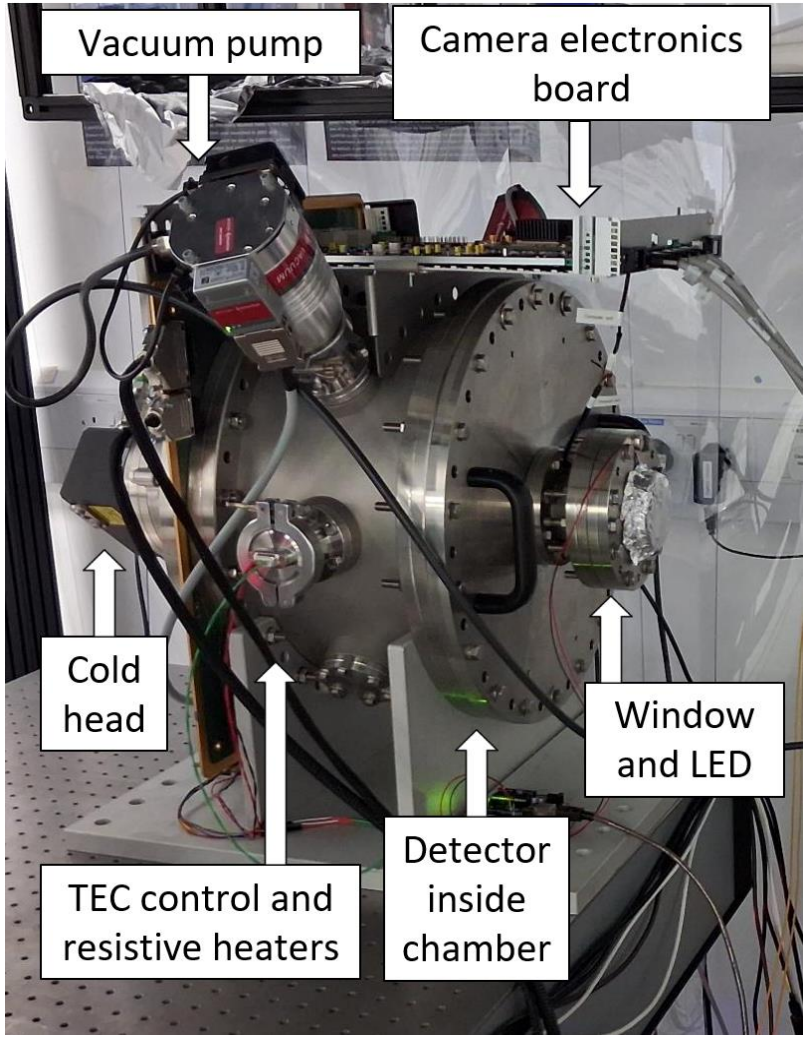
Ongoing work at the Open University

Versatile setup to further test CIS300 detectors:

- Clean tent environment.
- Temperature range: -120 to 50 °C.
- Wavelength range: 100 to 1000 nm.



CIS303 detector inside vacuum chamber



External view of setup

Clean tent

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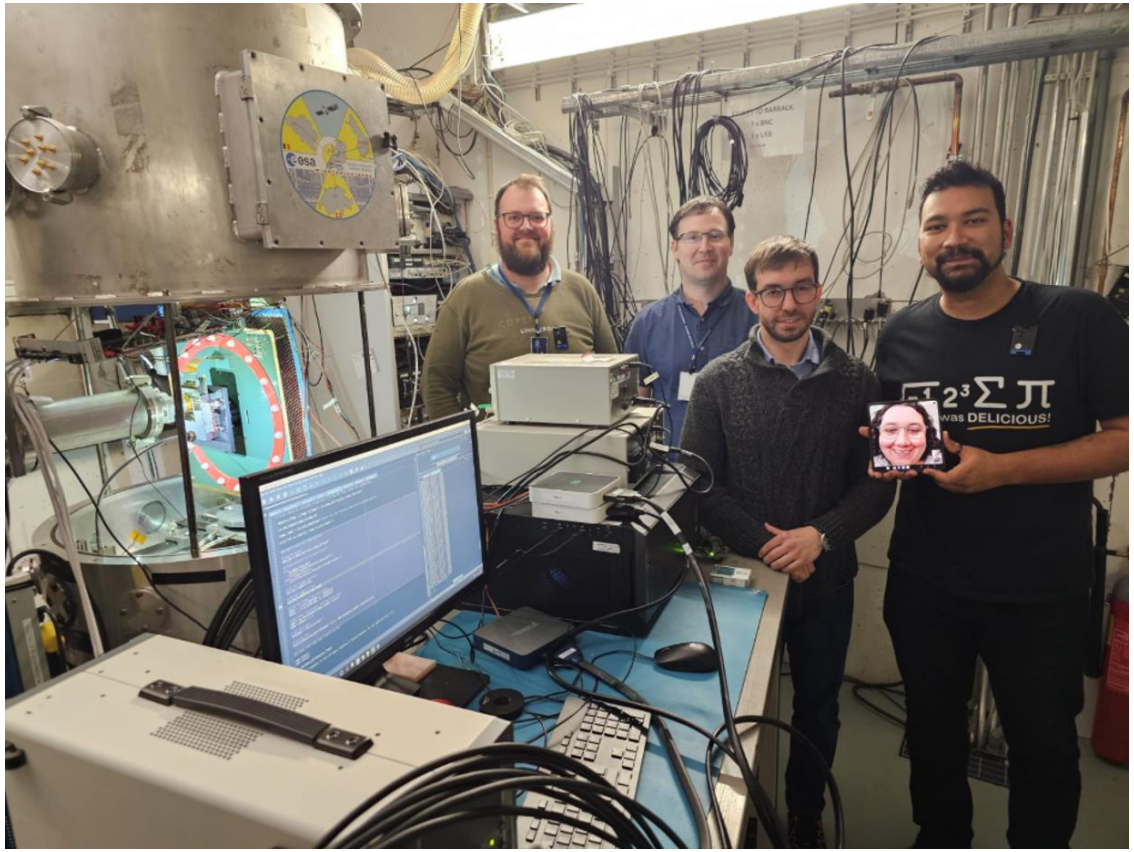
Summary

- Habitable Worlds Observatory is a future space telescope that will require state-of-the-art detectors like Teledyne e2v's CIS300-series.
- A heavy ion test was done on a CIS303 detector, for space qualification purposes.
- The detector was irradiated with a heavy ion beam with LET ranging from 18.1 to 85.6 MeV and a flux of 10^4 ions/cm^{2}s.
- The CIS303 detector shows considerable immunity to SEE.
- A few SEE were observed but they were cleared without damage to the detector.
- Further testing of CIS300 detectors is being done at the Open University.



Team and setup at the heavy ion test

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Backup

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