Total Ionizing Dose effects on CMOS Image Sensor for the ULTRASAT space mission

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The ULTRASAT mission

ULTRASAT is a **wide-angle space telescope** that will perform a deep time-resolved all-sky survey in the **near-ultraviolet** (NUV) [1]. The science objectives are the detection of counterparts to gravitational wave sources and supernovae.
The mission is led by the Weizmann Institute of Science [2]. Launch is expected in early 2025 and 3 years of orbit operations are planned as a minimum. DESY will provide the **UV camera**, composed by the detector assembly located in the telescope focal plane and the remote electronics unit.

First results on pixel Total Ionizing Dose (TID) effects

We present **TID** results on Tower **test structures** with similar pixel to the final flight ULTRASAT sensor. Both sensors are Back Side Illuminated (**BSI**), **4T CMOS** Imaging Sensors made in the **Tower 180 nm** architecture. Due to the expected **similar photo-diodes** and technology node, we can use the conclusions from testing these test structures, to **optimize** the flight **sensor** performance. However, the final sensor is designed to be rad hard up to at least 20 krad TID and 60 MeV*cm²/mg Linear Energy Transfer Single Event Effects. Nevertheless, due to the similar photo-diodes and technology node, we expect that analysing the test structures' response to radiation will help us to gain a better understanding of the flight sensors.

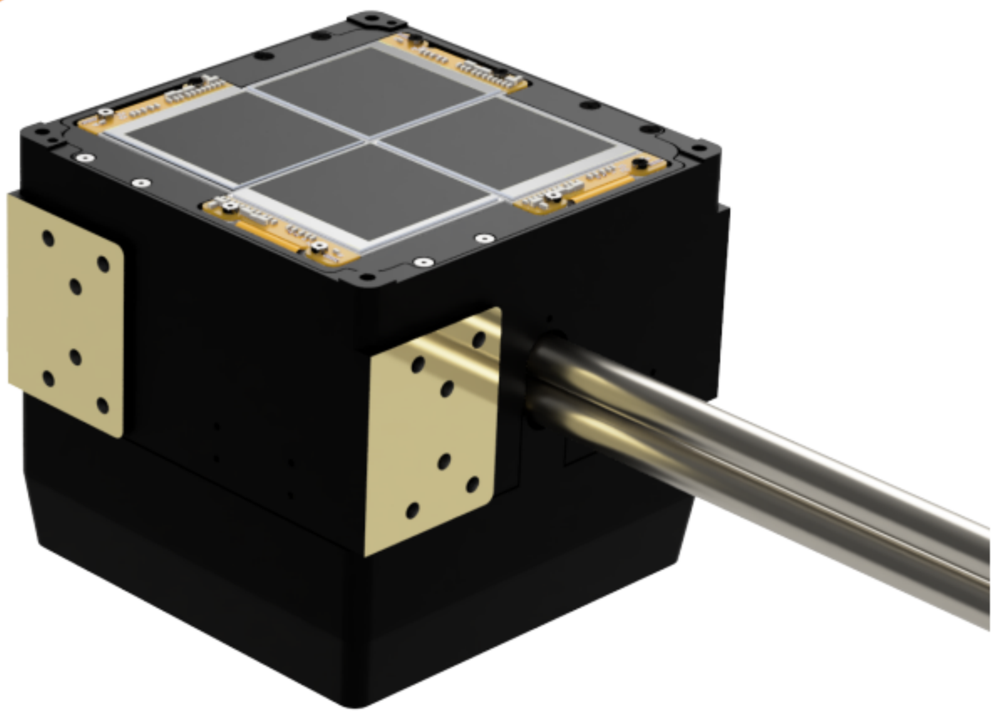

Figure 1: *Rendering of the ULTRASAT camera components that will be developed at DESY Zeuthen. The detector assembly (DA) is based on four 180 nm back-side illuminated (BSI) CMOS sensor arrays with a total of 90 Megapixels that are operated at -70°C*

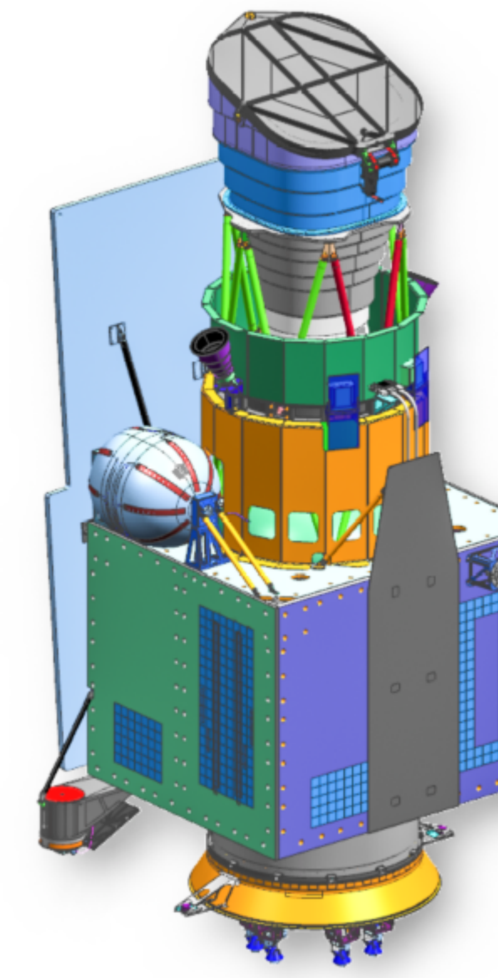

Figure 2: *Rendering of the ULTRASAT space mission [3]*

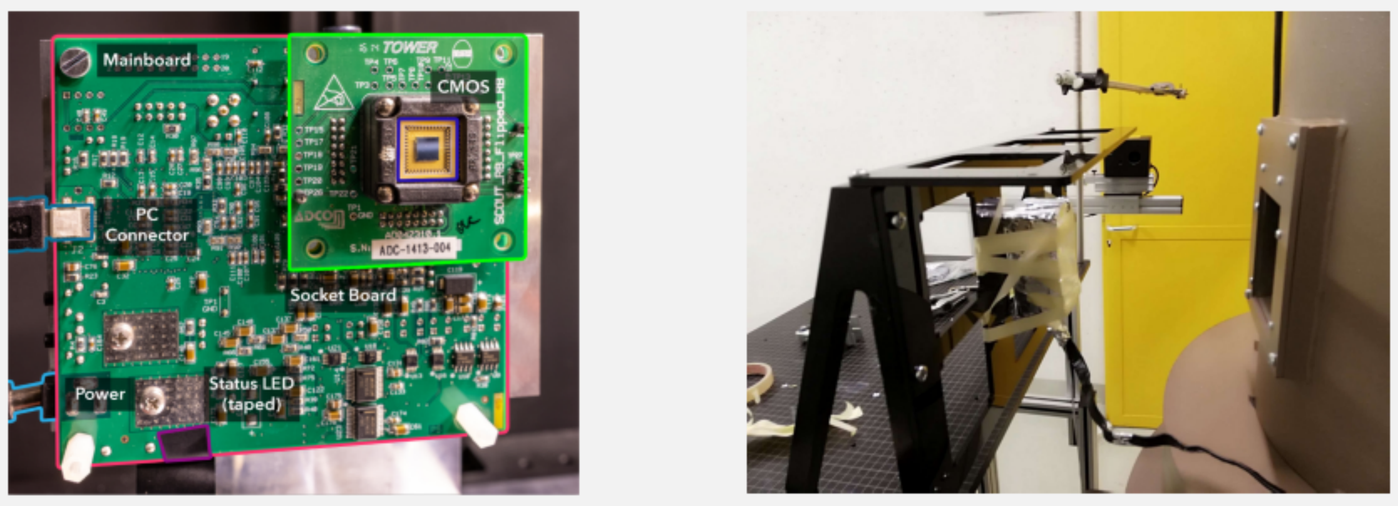

Figure 3: *Left: Scout test structure board set-up. Right: Experimental setup at the CC-60 irradiation facility at CERN*

Test structure (Scouts) experimental setup

- The Scouts readout chain is comprised out of a mainboard that acts as both a bias board and a read out board for the scout sensors and a daughterboard, in which Scouts can be socketed.
- Irradiations have been performed with a **Co-60** source at **CC-60, CERN** and at **HZB in Berlin**. The dark signal has been measured before and after irradiation at the same temperature.
- During irradiations, the sensors were **biased** at the highest bias configuration, at room temperature.

Dark Signal vs TID first results

Sensor noise

- An **increase in temporal pixel noise** is observed with elevated accumulated TID.
- The noise is elevated both in terms of distribution mean, caused by the increase in-pixel shot noise and distribution tail, which hints towards a **non-Gaussian noise** component.

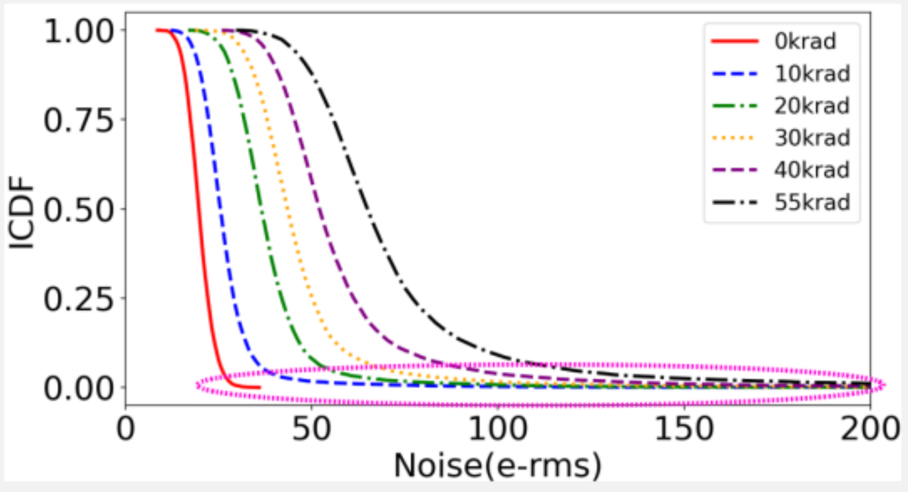

Figure 4: *Inverse Cumulative Distribution of total in-pixel temporal noise for multiple TID*

Sensor Dark Current

- **Elevated kurtosis** and **skewness** of the dark counts distribution is observed for higher TID values.

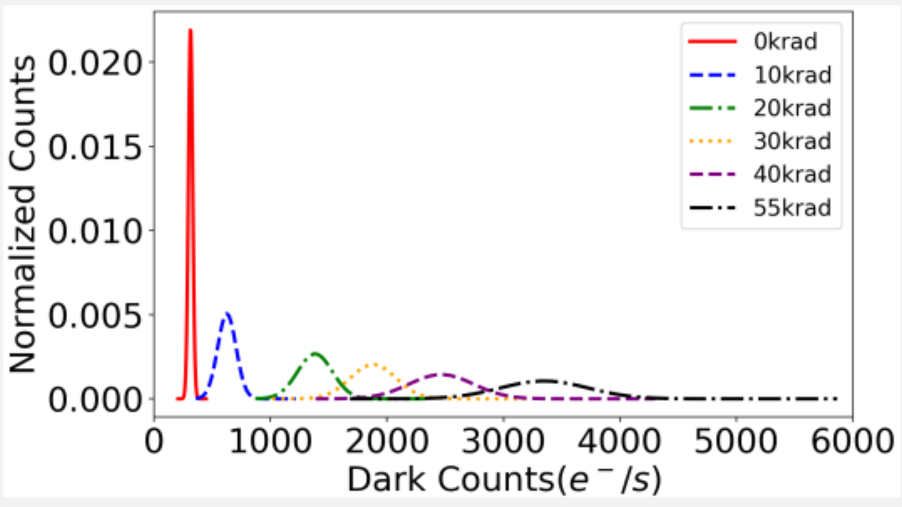

Figure 5: *Probability Distribution Function of dark counts for multiple TID*

These results hint towards an important **Dark Current – Random Telegraph Signal (DC-RTS)** contribution to the total post-irradiation noise.

Random Telegraph Signal detection

- In order to detect RTS jumps in signal, a **Real-time Auto-detection Method** for RTS is employed [4].
- The signal is first filtered with the following filter:

$$H(z) = \sum_{i=0}^{L/2-1} \left(\frac{2}{L} z^{-i}\right) - \sum_{j=L/2}^{L-1} \left(\frac{2}{L} z^{-j}\right)$$

- Triangles are formed at the leading edge, then are used to detect RTS jumps, based on a **dynamic threshold** for each noise segment.

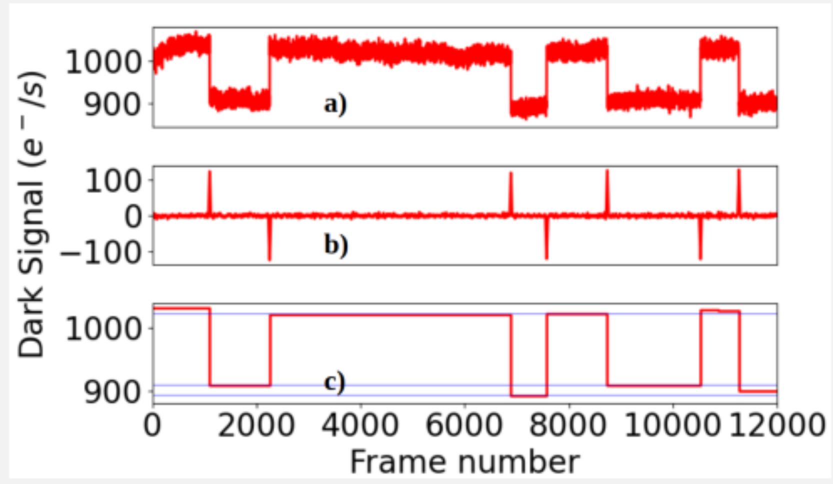

Figure 6: *(a) In pixel signal across multiple frames; (b) Filtered signal; c) Reconstructed RTS levels*

Random Telegraph Signal results

- Significant **RTS** is observed for relatively low doses **~1-5 krad**. This is most probably due to the **non-accumulated** operation mode of the Transfer Gate.
- **No RTS** was detected for **non-irradiated** samples.
- Distribution of RTS levels and amplitudes for multiple TID levels show an **increase** of TID induced **defects** in the **photo-diode**.
- The distribution of the maximum RTS amplitudes follow the same exponential decay, showing that the **same RTS mechanism** takes place at all TID values.

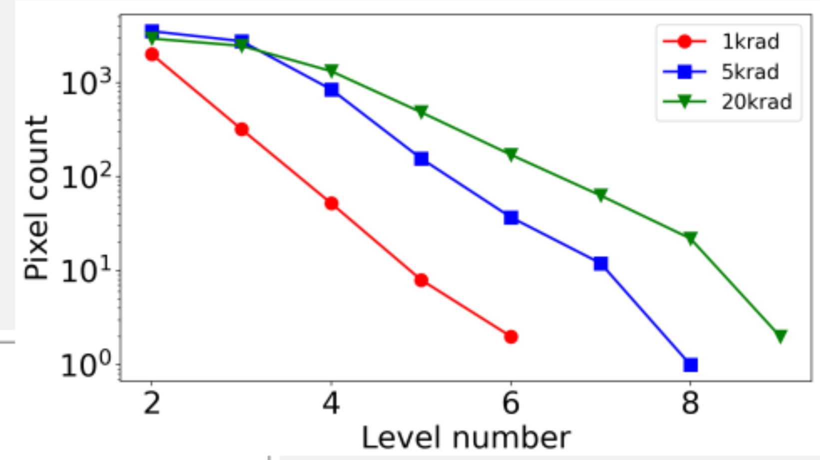

Figure 7: *Distribution of RTS level numbers for multiple TID values*

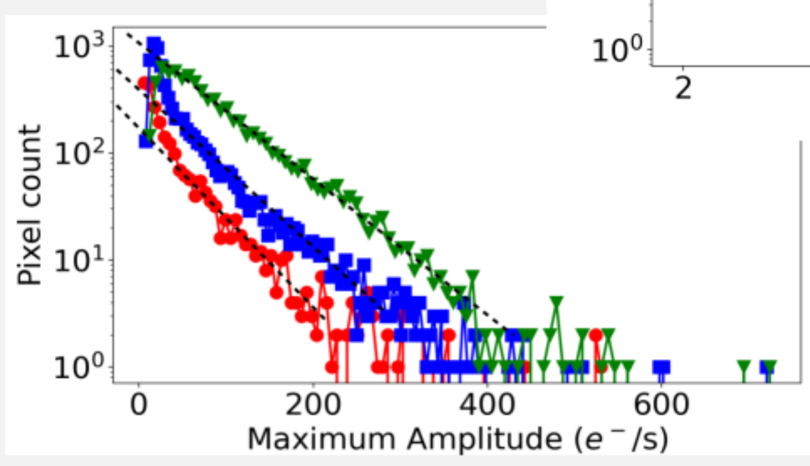

Figure 8: *Distribution of RTS maximum amplitudes for multiple TID values. Notice ~ the same slope in the exponential decay ~ 110 e⁻/s.*

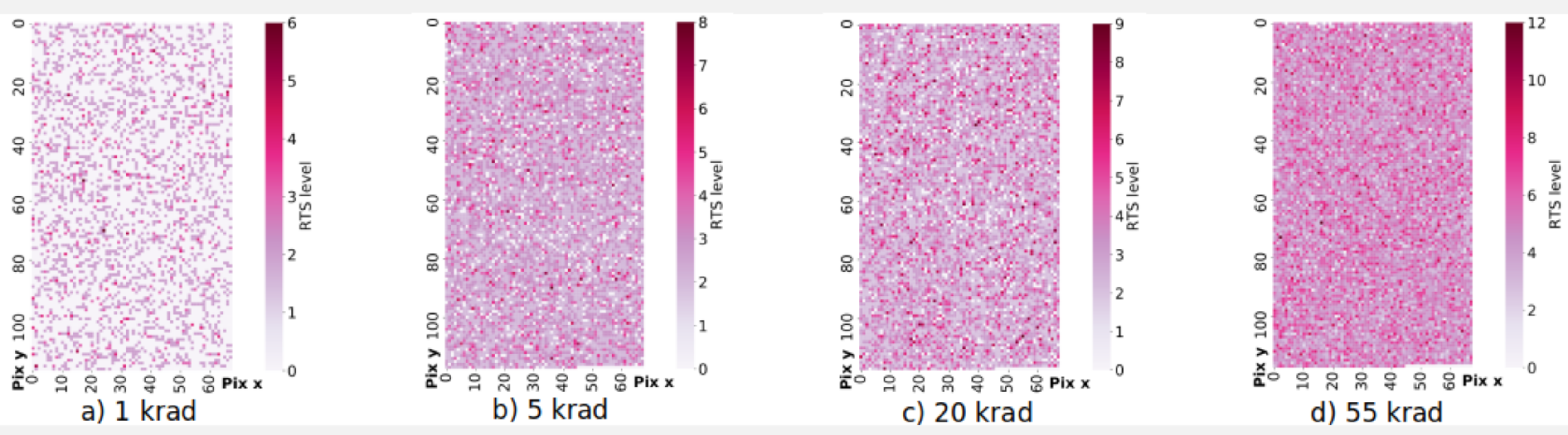

Figure 9: *Levels of RTS projected over the whole pixel array at: a) 1 krad TID; b) 5 krad TID; c) 20 krad TID; d) 55 krad TID.*

Summary

- The preliminary investigation on TID induced defects in the Scout test structures provided us with information on the expected response of the ULTRASAT flight grade sensors to radiation.
- The **lack of RTS in non-irradiated test structures**, shows a good isolation between the Space Charge Region of the photo-diode and the Silicon-Oxide interface.
- Due to TID and the **non-accumulated mode** in which the **Transfer Gate** operates, sensor performance degradation is observed.
- Further studies are planned in characterizing the RTS properties against the Low Transfer Gate Voltage and **accelerated annealing**, in order to showcase the source of these defects.
- This study will improve the understanding of the final operation of the flight sensor for the ULTRASAT mission and will help to streamline the **radiation characterization of the flight sensors**.

References:
[1] https://www.weizmann.ac.il/ultrasat/
[2] https://www.weizmann.ac.il
[3] https://www.iai.co.il/commercial
[4] Virmontois, C., et all, (2011). IEEE Transactions on Nuclear Science, 58(6), 3085-3094.

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