

Beyond CCDs: CMOS image sensors for soft X-ray Astronomy and Beyond

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Historically, charge-coupled devices (CCDs) have been the detector of choice for soft X-ray astronomy, successfully deployed on numerous missions over several decades, including XMM-Newton, Swift XRT, Suzaku, Chandra, and the upcoming European Space Agency (ESA) SMILE mission. While highly successful over many years, CCDs are particularly susceptible to radiation damage and must be operated at cold temperatures, typically at or below $-100\text{ }^{\circ}\text{C}$.

For the upcoming ESA M7 candidate soft X-ray astronomy mission, THESEUS, it was determined that the focal plane of the soft X-ray imager (SXI) could only be cooled to approximately $-40\text{ }^{\circ}\text{C}$, rendering CCDs unsuitable and necessitating alternative detector technologies. A competing technology, CMOS image sensors (CIS) have already proven effective for optical instruments, as seen in ESA's flagship JUICE JANUS instrument. However, as of 2019, CIS technology lacked the full depletion and efficient charge collection required for high-performance X-ray spectroscopy, prompting further development.

In response, ESA engaged the Centre for Electronic Imaging (CEI) and Teledyne e2v (Te2v) to develop the world's first bespoke X-ray-optimised monolithic CIS. Between 2019 and 2024, the CIS221-X sensor was designed as a test structure, manufactured, and characterised. This $2 \times 2\text{ cm}^2$ device has $40\text{ }\mu\text{m}$ pixels and achieves noise $<2.5\text{ e-rms}$, with low dark current and image lag $<0.1\%$ providing an energy resolution (FWHM) of 126 eV at 5.9 keV at $-40\text{ }^{\circ}\text{C}$ operating in excess of 30 frames per second. Variants include an on-chip optical blocking filter (OBF). The soft X-ray quantum efficiency has been characterised at PTB over the $0.1\text{-}1.5\text{ keV}$ range for both with/without OBF variants. This test device meets all the Theseus SXI focal plane requirements except detector size. Testing has also been conducted at higher temperatures achieving 128 eV FWHM resolution for 1500 eV X-rays at $0\text{ }^{\circ}\text{C}$. This talk will present the world-leading performance of the current sensor and the development of the next-generation full-scale 3-sides butttable detector the CIS321 having $4.5 \times 9\text{ cm}^2$ detection area and capable of operation at 20 fps. The Theseus SXI focal plane array will comprise 2×4 of these sensors totalling an area of $18 \times 18\text{ cm}^2$ which will lead to one of the largest X-ray arrays ever flown.

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