# Reading X-ray detector signals out in MHz frequency space

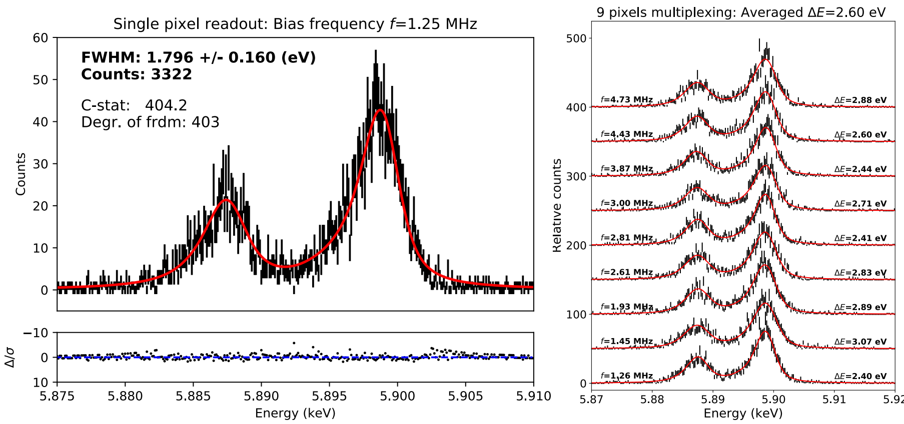
*Hiroki Akamatsu on behalf of the team developing the X-IFU detector readout technology*

*SRON, Netherlands Institute for Space Research, The Netherlands*

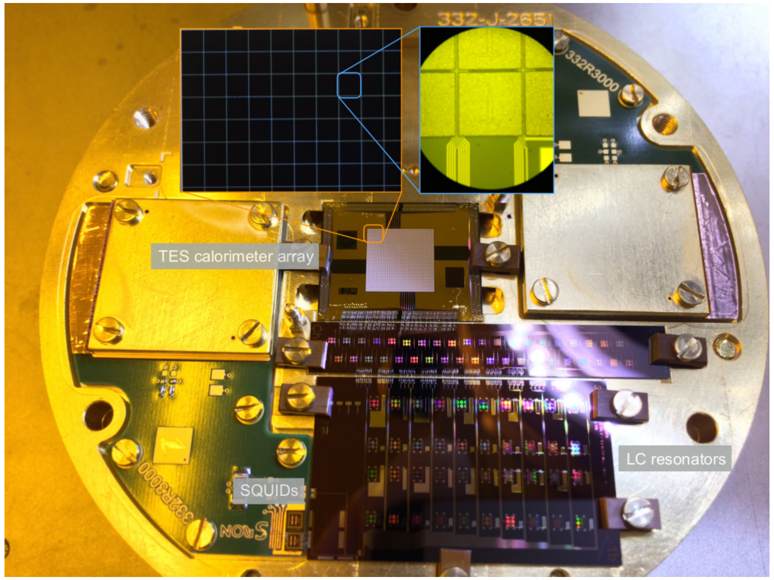
**T**he X-ray integral field unit (X-IFU) will revolutionize high-resolution X-ray spectroscopy thanks to its cutting-edge imaging spectrometer. This is an array of X-ray microcalorimeters using transition edge sensors to measure the deposited photon energies (TESs calorimeter), working at an extremely low temperature close to absolute zero (0.1 K). The instrument needs to satisfy severe constraints in terms of the electrical and cooling power available on the satellite. Therefore, multiplexed readout is a crucial technology for the TES microcalorimeter, the detector cooling system, and the X-IFU instrument as a whole.

**T**he readout technology that we are developing is called Frequency Domain Multiplexing (FDM). In the FDM readout scheme, TESs are coupled to LC resonators and biased with alternating current (AC bias) at MHz frequencies. By summing a set of pixels with different frequencies in a single read-out channel, the thermal load and electrical harness become manageable for X-IFU's large-format detector array. An X-ray photon event modulates the AC bias of a single pixel, which can be detected after demodulating the summed signal in the room temperature electronics. In practice, the optimization of this read-out scheme is challenging. Each LC resonator should be separated beyond its detector response (< 50 kHz) to avoid aliasing and crosstalk between neighbouring resonators. Thus, a wide bandwidth (~MHz) is necessary for the FDM scheme to read a large array of pixels. To satisfy the cooling requirement of the X-IFU, a multiplexing factor of 40 pixels/channel in a frequency range from 1 to 5 MHz is required. Using high-quality factor superconducting LC resonators and room temperature electronics developed at SRON in the Netherlands and low-noise two-stage SQUID (Superconducting Quantum Interference Device) amplifiers provided by VTT in Finland, we are currently demonstrating the FDM readout of Mo/Au TESs calorimeter arrays with Au/Bi absorbers from NASA/GSFC.

**S**ince the original proposal of the FDM readout concept, the team has made great progress. This included optimization of the system design (e.g. bandwidth, requirements on warm electronics, and thermal stability). Crucial for the ultimate system performance is understanding the physics that governs the properties of TESs under AC bias. With a new design of the NASA/GSFC pixels, we have now demonstrated that energy resolutions of 1.8 eV at 6 keV are feasible (figure, top-left). Similar performance with these improved TESs calorimeters has also been confirmed across 1-5 MHz, the desired readout bandwidth for the X-IFU instrument In addition, we successfully demonstrated the multiplexed readout of 9 pixels (of an earlier design) with an average performance of 2.6 eV, which should be significantly improved when we move to the newly optimized pixel designs. In parallel to this progress, we are developing a new set-up to demonstrate larger multiplexing factors (figure, top-right). This, together with a stepwise improvement of all key components such as the SQUIDs, LC filters, magnetic shielding, and harness) will bring us to a demonstration of a detector that meets X-IFU's requirements. Stay tuned for upcoming results.




Left: Spectrum of Mn Kalpha complex with a resolution of 1.8 eV FWHM at 1.25 MHz with improved GSFC TESs. Right: Results of the 9 multiplexing demonstration. Credit: Hiroki Akamatsu




Photograph of the detector plane, showing a kilo-pixel TESs array in the 2x40 FDM testbed. These results are a significant milestone for the development of FDM for the X-IFU.
Credit: Hiroki Akamatsu