Large-Format High Resolution X-ray Microcalorimeter Arrays

NASA has supported research programs developing x-ray microcalorimeters since the early 1980's. In spite of good progress and the realization of the first generations of this technology for space, there remains a huge potential for further progress. New innovations exist that can dramatically increase the number of pixels, increasing the field-of-view and angular resolution capabilities. Dramatically better energy resolution and higher count-rate capabilities are also possible, and there is the potential to incorporate a wide variety of different pixel designs within a single instrument that is optimized for a variety of different observation requirements. A new era of imaging high-resolution x-ray spectroscopy will begin with the launch of the Astro-H Soft X-ray Spectrometer in 2015. The 5 eV energy resolution of the 36-pixel microcalorimeter array in the energy band of 0.2-10 keV will provide new understanding in many areas of x-ray astrophysics, but represents just a first step toward what is needed for high-resolution imaging x-ray spectroscopy. The first mission concepts based on kilo-pixel scale x-ray microcalorimeters were formulated just before the turn of the century, and the development of the superconducting transition-edge sensor (TES) arrays established that technology as the reference for a series of mission concepts that could possibly start in the next few years. We can envisage x-ray microcalorimeter arrays with the millions of pixels that one usually associates more with charge-coupled devices than low temperature detectors. We could have large arrays with pixel sizes of just a few tens of microns all the way to having pixels on the centimeter scale. And the count-rate capability limits per pixel could be higher than ten thousand counts per second. The number of pixels in an x-ray calorimeter spectrometer is currently limited by a number of practical factors: (1) The number of room temperature amplifier channels; (2) the maximum density of wiring within the array and feeding through to the read-out amplifiers; (3) the maximum number of TESs that can be read-out by each amplifier channel utilizing the various multiplexing techniques; and (4) the accommodation of heat loads at cryogenic temperatures.

There are a number of technological alternatives we have identified that can dramatically advance this technology over the next 30 years that indeed have way-stations at the 10 and 20 year timescales. TESs have the potential for significant improvement in energy resolution through advanced techniques for engineering the properties of the transition.[1] Magnetically coupled calorimeters (MCCs) with either paramagnetic sensors or magnetic penetration depth sensors have the potential to push energy resolution limits significantly below 1 eV using a read-out that involves negligible heat dissipation within the pixels.[2] The area with perhaps the greatest potential for expansion is the read-out multiplexing. Code division multiplexing,[3] in particular, involving the steering of currents with superconducting switches and multiplexing at frequencies in the GHz range using microwave resonator circuits for each pixel[4] have the potential to take us to perhaps tens of thousands of TESs or MCCs per read-out channel. The use of multi-absorber sensors (Hydras[5]) can produce further increases in the number of read-out pixels that can be read out, with sensors attached to up to few tens of sensors of absorbers elements being possible.

Mission concepts already exist that can take advantage of a number of these innovations. On the 10-year timescale, Smart-X[6] is a mission that baselines a 90 thousand pixel microcalorimeter array with less than 4 eV energy resolution. There also exist a number of mission concepts developed that could also benefit from these innovations.[7] On the more ambitious 20-30 year timescale is the mission concept known as Generation-X. This mission is designed to observe the first black holes and stars at redshift z~10-20, and to trace the evolution through cosmic time of galaxies and their elements using x-ray spectroscopy. It has a goal of having a few million microcalorimeter pixels, and less than 1 eV energy resolution.[8]

1. J. Sadleir et al., "*Magnetically Tuned Superconducting Transition-Edge Sensors*", IEEE Trans. on Appl. Superconductivity, **99** (2013) doi: 10.1109/TASC.2013.2251391.
2. S.R. Bandler et al., "*Magnetically Coupled Microcalorimeters*", J. Low Temp. Phys. **167** (2012) 254-268.
3. M.D. Niemack et al., "*Code-division SQUID multiplexing*", Appl. Phys. Lett. **96**, 163509 (2010).
4. J.A.B. Mates et al., "*Demonstration of a multiplexer of dissipationless SQUIDs*", Appl. Phys. Lett. **92**, 023514 (2008),.
5. S.J. Smith et al., *"Development of position-sensitive transition-edge sensor X-ray detectors"*, IEEE Trans. on Appl. Superconductivity **19**(3) (2009) 451-455.
6. A. Viklinin et al., Smart-X, *"Square Meter, Arcsecond Resolution X-ray Telescope"*, Proc. of SPIE **8443**, 844316, (2012).
7. http://pcos.gsfc.nasa.gov/studies/xray/x-ray-mission-rfis.php - see responses for AXSIO (J. Bookbinder), Sahara (R. Mushotzky), EPE (M. Garcia) and Xenia (C. Kouveliotou).
8. S.R. Bandler, E. Figueroa-Feliciano, *"Generation-X Microcalorimeter Development Roadmap"*. White paper submitted to 2010 Astronomy & Astrophysics Decadal Review. http://www.cfa.harvard.edu/hea/genx/technology/xms/