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Status of the Micro-X Sounding Rocket X-ray Spectrometer

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ABSTRACT

Micro-X is a sounding rocket borne X-ray telescope that utilizes transition edge sensors to perform imaging spectroscopy with a high level of energy resolution. Its 2.1m focal length X-ray optic has an effective area of 300 cm², a field of view of 11.8 arcmin, and a bandpass of 0.1–2.5 keV. The detector array has 128 pixels and an intrinsic energy resolution of 4.5 eV FWHM. The integration of the system has progressed with functional tests of the detectors and electronics complete, and performance characterization of the detectors is underway. We present an update of ongoing progress in preparation for the upcoming launch of the instrument.

Keywords: Microcalorimeter, Sounding Rocket, Transition Edge Sensors, Micro-X, X-ray astronomy, Cryogenics

1. BACKGROUND

Micro-X is a sounding rocket borne X-ray telescope that will perform imaging microcalorimetry [1]. The sounding rocket flight will reach an apogee of 270 km and will have 300 seconds for science observations after the gate valve opens at 160 km. It utilizes transition edge sensors (TESs) for its detectors, and will be the first instrument to use these in space. It has a Wolter imaging optic with a 11.8 arcmin field of view and a 2.4 arcmin point spread function. The detector has 128 pixels and an effective area of 300 cm², with a bandpass from 0.1 to 2.5 keV. The cryostat contains an adiabatic demagnetization refrigerator (ADR) which uses a ferric ammonium alum salt pill to cool the system down to 75 mK.

The Micro-X TES detectors are Mo/Au proximity-effect bilayers with Au/Bi absorbers, read out through three stages of superconducting quantum interference device (SQUID) amplifiers. TES microcalorimeters are devices biased into the superconducting transition so that they can act as very sensitive thermometers. A small temperature change within the transition manifests as a significant change in resistance, so the magnitude of the resistance change can be related to the energy of an incoming photon with excellent precision. The TESs are biased at constant voltage, so the change in resistance manifests as a change in current. This current is picked up by a three-stage SQUID readout system which amplifies the signal before it reaches the room temperature readout electronics. The SQUIDs are operated in a flux-locked mode, where a variable feedback is applied to the first SQUID in the chain in order to keep the total error fixed at zero. This keeps the input to all of the SQUIDs centered so that their gains remain constant, and the feedback is recorded as the output of the readout chain.

In addition to signal amplification, the SQUIDs also enable multiplexing between pixels. Each of the 16 pixels of a single “column” shares a single second-stage SQUID, whose input is the sum of the current from each pixel

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in in the column. In this time-division-multiplexing implementation, one first-stage SQUID per column is biased at a time, thus only one pixel is being read out on a column at any time. Since the switching happens fast enough that several samples can still be taken on each pixel during the rise time of an X-ray pulse, the multiplexing system reduces the number of needed wires, and therefore the heat load, without significantly decreasing the signal fidelity. These sensitive detectors are capable of producing high-resolution spectra which can be of great utility for astronomy.

The first flight of Micro-X will observe the Puppis A supernova remnant. Specifically, Micro-X will be observing the Bright Eastern Knot region of the remnant, to study the physics of a shock front interacting with very dense clouds of material [2]. Observing this object with an imaging microcalorimeter will enable better resolving emission lines than with CCD imaging (because of improved energy resolution) or gratings spectroscopy (because this is an extended source). The mapped out emission lines will provide better measurements of elemental abundances, allow for comparing plasma diagnostics between different species and determine the dynamics of the system from Doppler shift measurements. The complex interactions taking place at the Bright Eastern Knot may also lead to the first solid detection of charge exchange processes outside of the solar system. Cassiopeia A has been chosen as a secondary target if the flight schedule does not coincide with Puppis A's window of visibility (late November - March). For future flights, the system will be repurposed to explore other areas of science as well, including searches for potential signals of Dark Matter decay in the X-ray from the Milky Way [3].

2. PAYLOAD STATUS

After three years of redesigns and upgrades to the cryogenic system, Micro-X successfully passed launch-level vibration tests in July 2015, enabling a shift in focus towards the detector performance [4,5]. In February 2016, the Micro-X payload was moved to the Goddard Space Flight Center (GSFC) to begin full detector systems integration. The multiplexing (MUX) electronics have been integrated onto the readout and have accelerated both detector calibration and the characterization and elimination of electrical noise. Previously, the detectors had been mainly run with analog readout that permitted making single-channel measurements but did not have the high speed multiplexing capabilities of the digital MUX electronics. The switch to using the MUX electronics have made tests more flight-like and greatly improved the speed of tests intended to characterize performance across the entire array instead of on single channels.

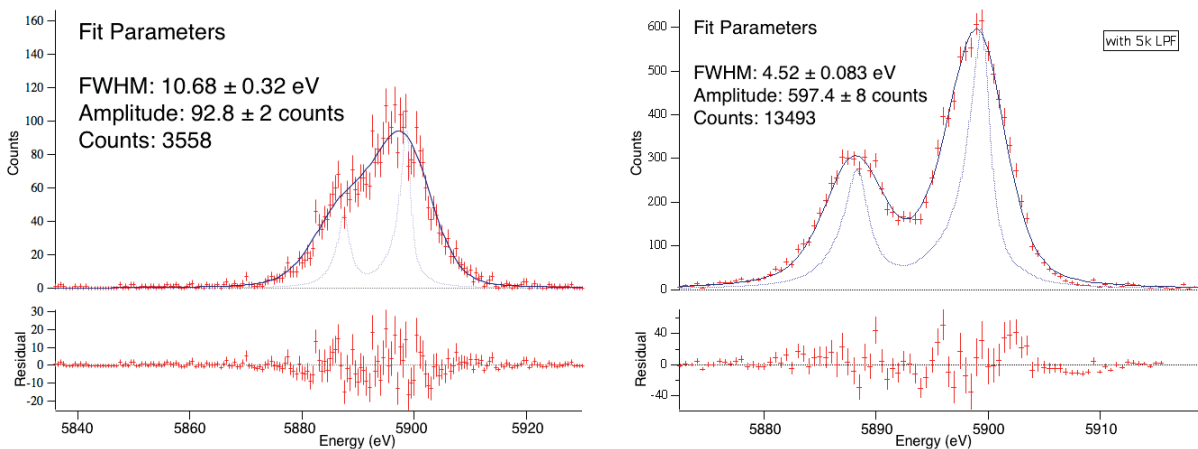


Figure 1. Spectrum of the 5.9 keV Mn $K\alpha$ line obtained with one of the Micro-X detector array pixels. The black curve represents the fit two our collected data and the blue curve represents the fundamental line shape. The left figure is a measurement taken in the flight cryostat with the flight electronics, while the right figure was taken in a laboratory cryostat with analog electronics for initial testing [6]. The flight-system energy resolution is currently affected by various sources of noise and crosstalk from the flight electronics, which we have mostly identified and for which fixes are in the works.

The achieved resolution of the Micro-X detectors in the flight system has improved substantially over the last five months as we integrated of the cryogenic and electronics systems at NASA Goddard Space Flight Center. As of this writing, Micro-X detectors have achieved 10 eV resolution using the flight cryostat and readout electronics (Fig. 1). They were originally tested in mature ground based cryostats at GSFC in 2010. In that apparatus, a spectrum of the Mn $K\alpha$ line was measured with a resolution of 4.5 eV, representing the optimal performance of these particular detectors with a Tc of 120 mK (Fig. 1). We expect that the implementation of various noise-reducing modifications will allow the detector resolution to continue to improve towards their best achievable performance.

3. ELECTRONICS NOISE STUDIES AT THE GODDARD SPACE FLIGHT CENTER

While integrating the flight electronics, we discovered a variety of electronic noise sources. Many have already been eliminated to produce the detector performance discussed above, and progress with the other noise sources will narrow the gap between the performance in the flight system and in the laboratory cryostat. These sources of noise are described in the table below.

| | |
|----------------------------------|--|
| Digital Housekeeping | The digital housekeeping electronics in the ADR controller and the MUX electronics operate by switching between different signals and compressing them into a single data stream. That switching is picked up by the science chain readout and appears as detector noise. By filtering the inputs to the housekeeping multiplexer and eliminating the housekeeping from the most sensitive channels entirely, the impact on the detectors has been reduced. |
| Multiplexing System Clock | The digital commands that control the SQUID array readout carry the system clock for the multiplexer into the cold stage electronics. By passing these commands through an opto-isolator, the clocking noise can be separated out. Design of a flight worthy installation of the opto-isolators is underway. |
| MUX Electronics Power | The MUX electronics derives its power from a converter card, which has a collection of DC/DC converters to generate the necessary voltage rails from the onboard 28 V batteries. This converter card produces significant white noise, which is seen on the detectors. For laboratory testing, this board has been replaced with commercial power supplies. Installation of superior shielding and filtering to eliminate the noise from this card is underway. |
| ADR Control Thermometer Stimulus | We found that when the ADR controller was powered, a significant amount of noise appeared at all stages of the science chain. This was produced by the electronics that generate the sine wave of current that is used as stimulus for the control thermometers on the detector plane. The noise on the detectors and the underlying digital clock on that board are correlated in Fig. 2. Changing the grounding configuration on this board to match the same board used for XQC rocket payload [7] cleaned up this effect. Adding a power line filter to the magnet current also eliminated this noise and is still in use. |

4. PATH FORWARD

With functional tests successfully completed, optimization has become the main focus of Micro-X. The payload was moved to Northwestern University to continue the optimization and integration efforts in August 2016. For the detectors, full measurements of system noise and energy resolution have been made on a single column, and those tests will need to be repeated over the entire array. It is also necessary to measure the uniformity of optimal SQUID tuning parameters for different pixels to better characterize the performance of the full array. These parameters vary with the magnetic field across the detectors, and a field coil has been integrated into the detector setup to minimize the magnetic field across the detector plane. This field must be optimized for performance across the array.

In addition to detector characterization, the readout timing must be optimized. The rocket flight version of the multiplexing electronics has a slower response time than other, less constrained versions of the system. While it is preferable to multiplex between channels as quickly as possible, it is necessary to ensure that the system doesn't multiplex so quickly that the switching time is shorter than the settling time for the electronics to reach its new state. SQUID tuning parameters will be further optimized to obtain the best MUX performance.



Figure 2. Comparison of noise spikes seen at the output of the unlocked science chain readout (green and yellow) with the square wave passing between the digital sine generator board and the germanium thermometer readout board in the ADR controller stack (pink). That these signals are correlated shows that the sine wave was ultimately responsible for the noise on the SQUIDs.

Following detector optimization, the remaining subsystems will be integrated into the system. The radioactive source for in-flight calibration and the optical blocking filters will be added to the inside of the cryostat. The X-ray mirror, which has already been calibrated, will be aligned with the detectors. Finally, full integration and testing at the Wallops Flight Facility will follow.

5. CONCLUSIONS

The Micro-X project has been making significant progress towards flight. The detectors have been operated inside the flight system with flight electronics and obtained an energy resolution of 10 eV FWHM at 6 keV, approaching the design sensitivity. This was achieved by identifying the sources of system noise and developing effective mitigation strategies. Further work will provide additional improvements to the energy resolution and complete the preparations for the upcoming flight.

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