The First Two Flights of the Micro-X Rocket

LTD-18, Milano, 22-26 July 2019

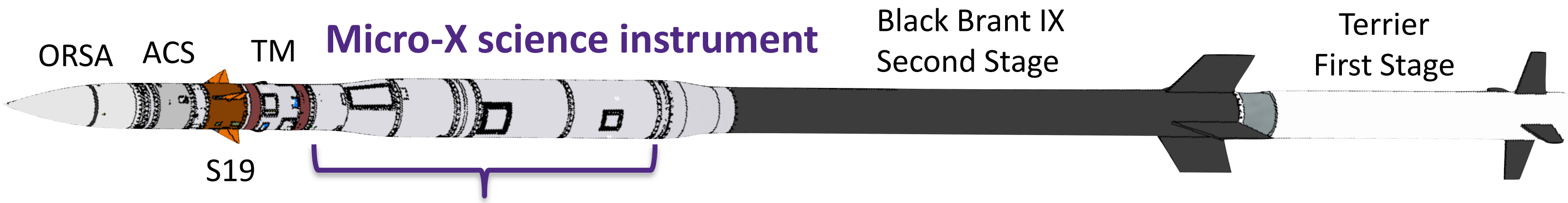
Noemie Bastidon on behalf of the Micro-X collaboration

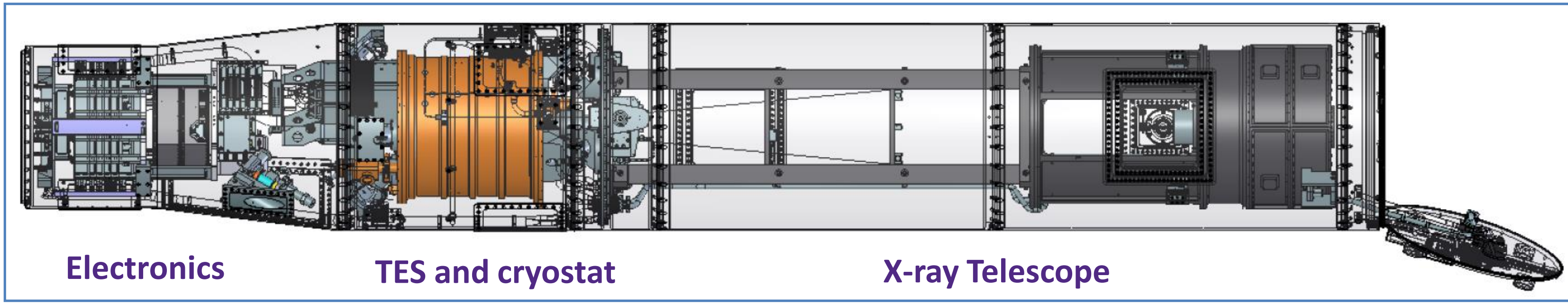
Micro-X sounding rocket was launched for the first time on the night of the 22nd July 2018 from the White Sands Missile Range.

⇨ First Flight of Transition-Edge Sensors and SQUID MUX in Space

⇨ Survey of Cassiopeia A (Spectrum 0.1 – 2.5 keV)

Micro-X sounding rocket



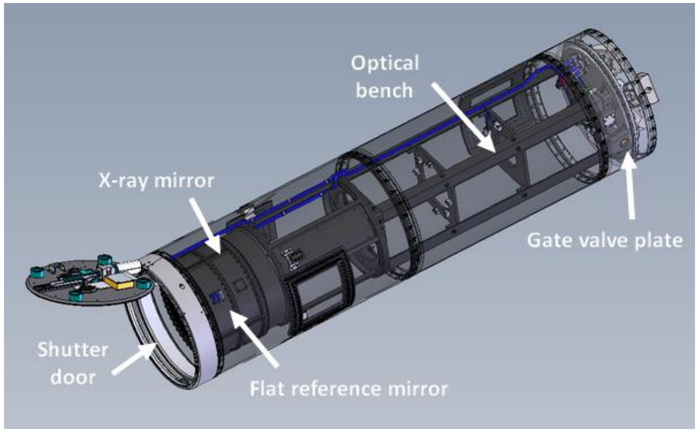


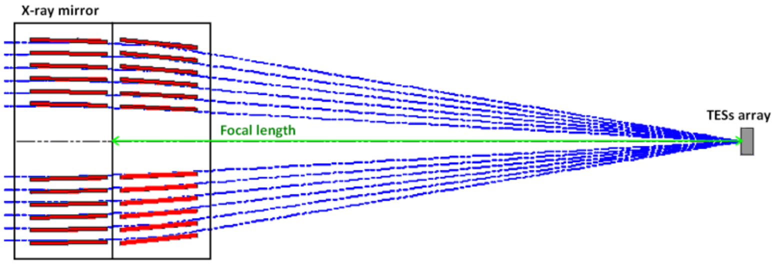
Payload	7.9 m long, 556 kg, 22”/17.3” diameter (56/44 cm)
Attitude Control System (ACS)	ST 5000 star tracker + bi-level cold gas thrusters
Telemetry (TM)	5.0 Mbit/s for housekeeping + 2x 20 Mbit/s for science data
Power	Batteries supplying science chains and ADR for the full flight
S19	Guidance system (gyros + accelerometers)
ORSA	Ogive Recovery System Assembly (parachute)

X-ray telescope

- Once in space, a shutter door opens and X-rays are focused along the 2.1m focal length of the mirror.
- A valve is then opened to expose the detectors to incoming X-rays.
- A star tracker uses an optical star map to identify direction, and compressed gas is used to control payload pointing (*DOI:10.1117/12.787917*).
- Pre-flight vibration testing indicated the X-ray optics maintain an alignment stability < 2.5' PSF under flight conditions.

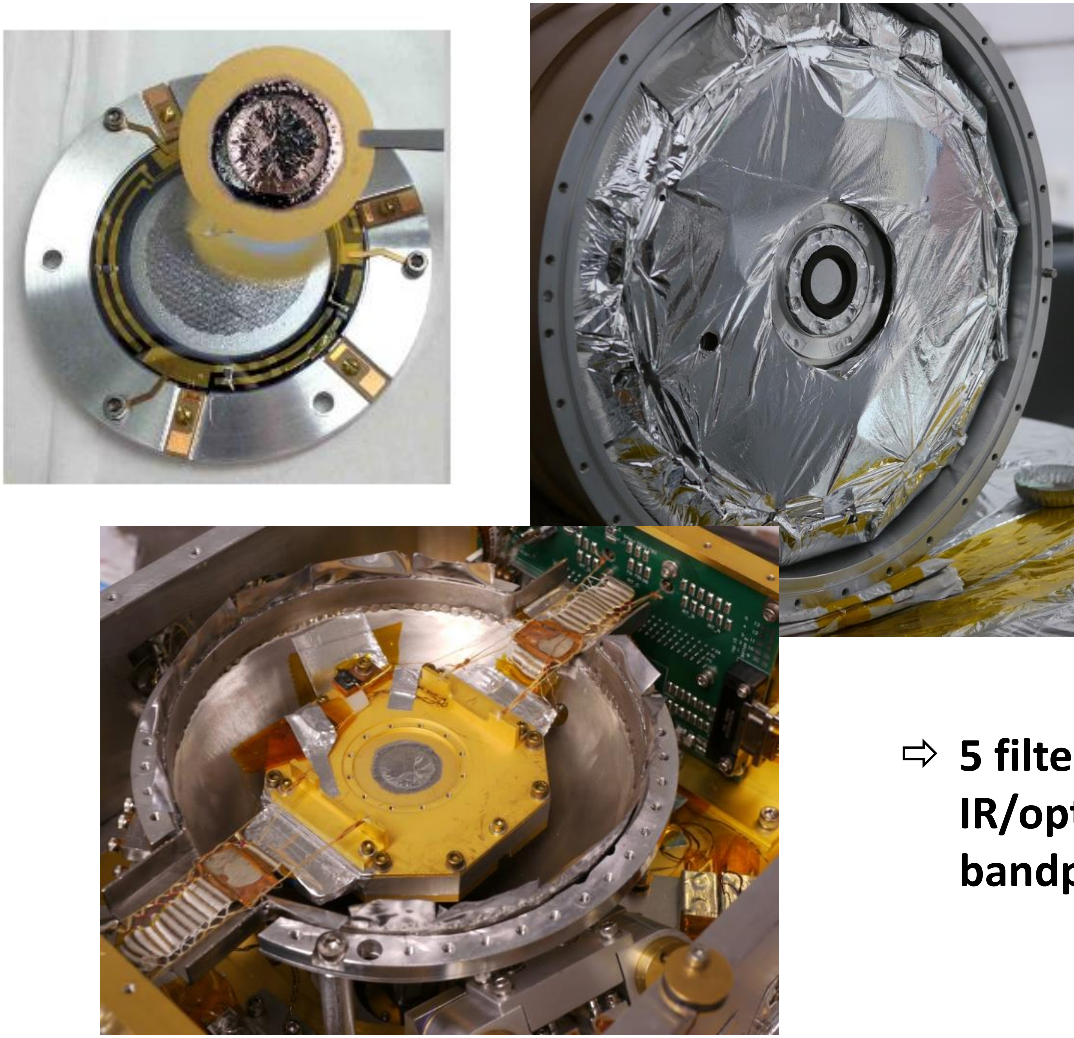
DOI:10.1007/s10686-009-9163-8
DOI:10.1155/2010/412323

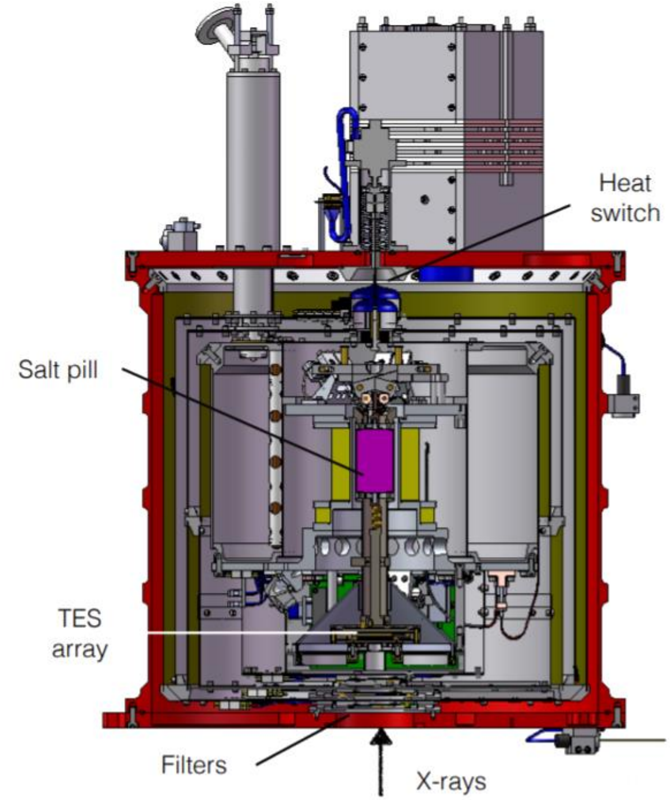




Two-stage conically approximated Wolter I mirror

Infrared filters

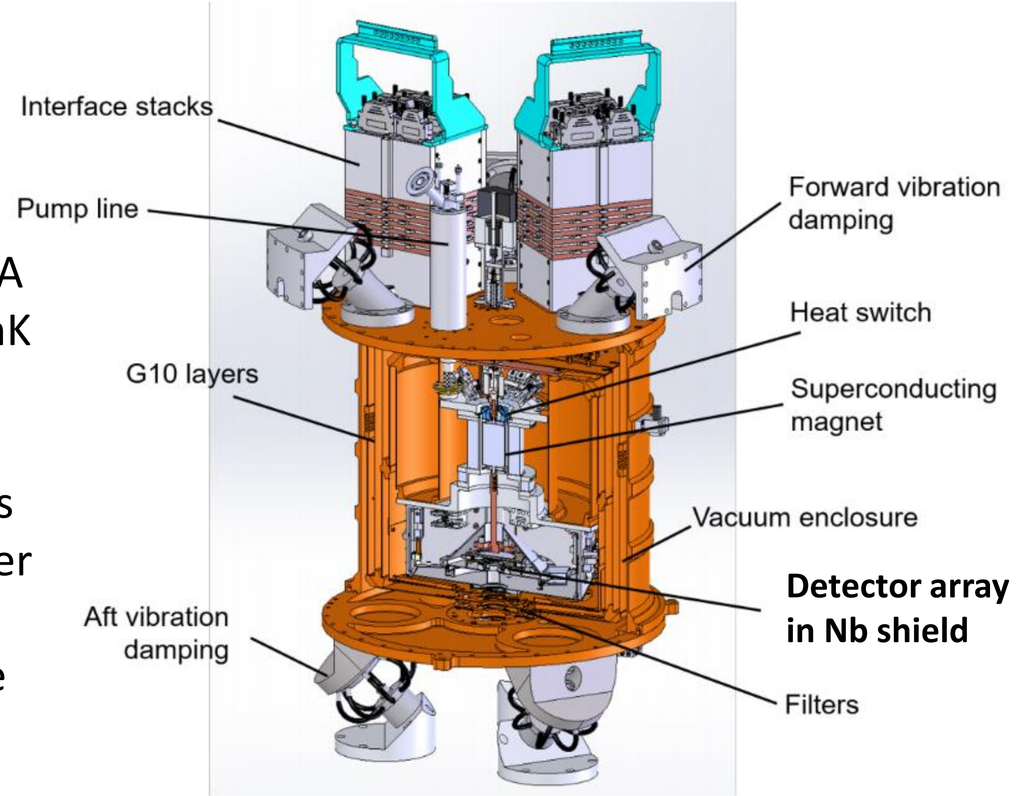




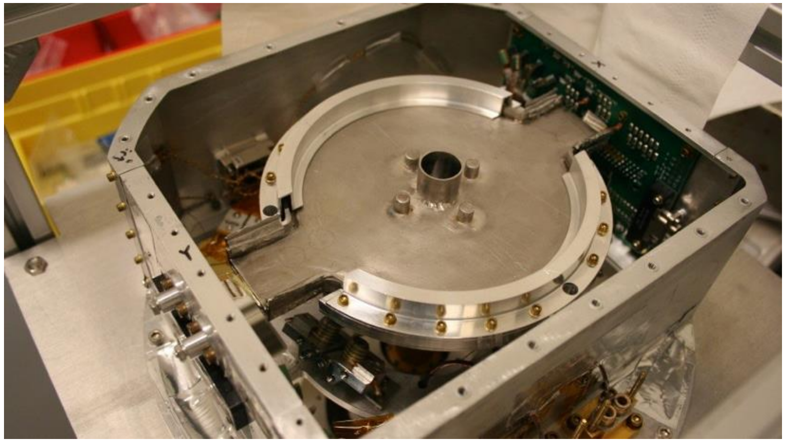
⇨ **5 filters allow X-rays in while blocking IR/optical photons (0.3 – 2.5 keV bandpass, aluminum + polyimide).**

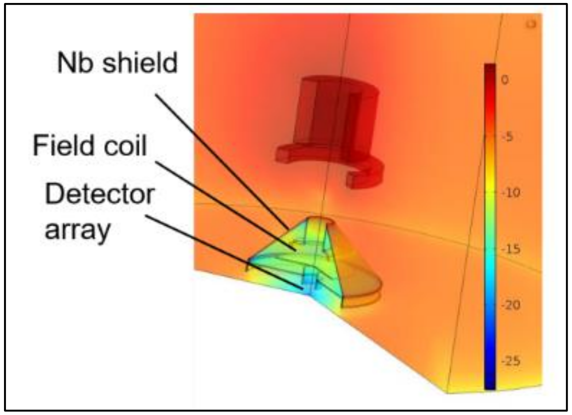
Cryostat

- The cryostat houses an Adiabatic Demagnetization Refrigerator (ADR). A stable operating temperature of 75 mK ±7 μK is achieved.
- The multiplexing SQUID readout passes through all temperature stages to minimize thermal noise and number of wires.
- A valve is opened in flight to let space pump on the He bath.

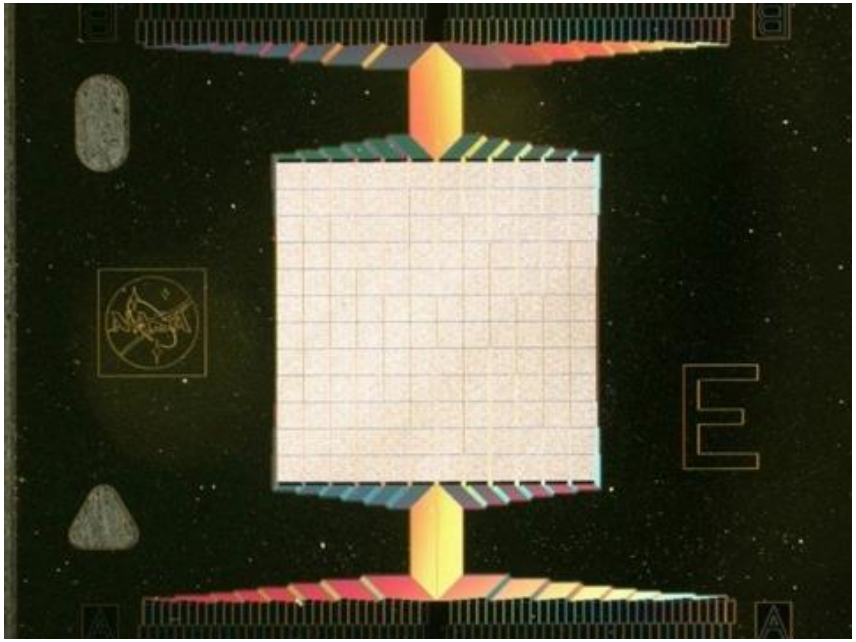


DOI:10.1007/s10909-016-1549-1



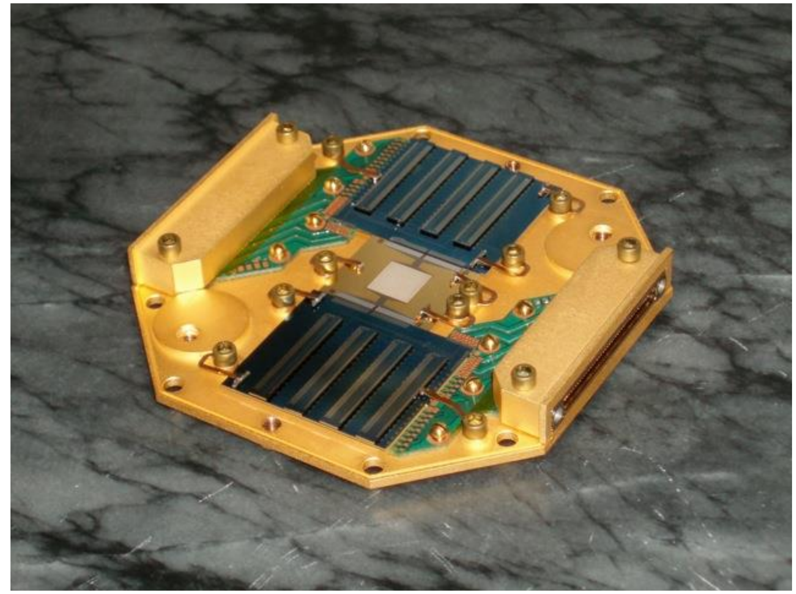


Detector system



128 pixels, 590 µm x 590 µm each
11.8 arcmin FOV
Bismuth/gold absorber
Molybdenum/gold TES

DOI:10.1063/1.3292437

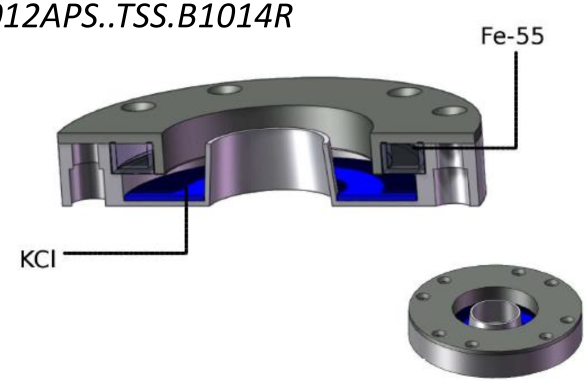


Time Division Multiplexing
8 columns of 16 rows each
2 science chains of 4 column each
NIST MUX06

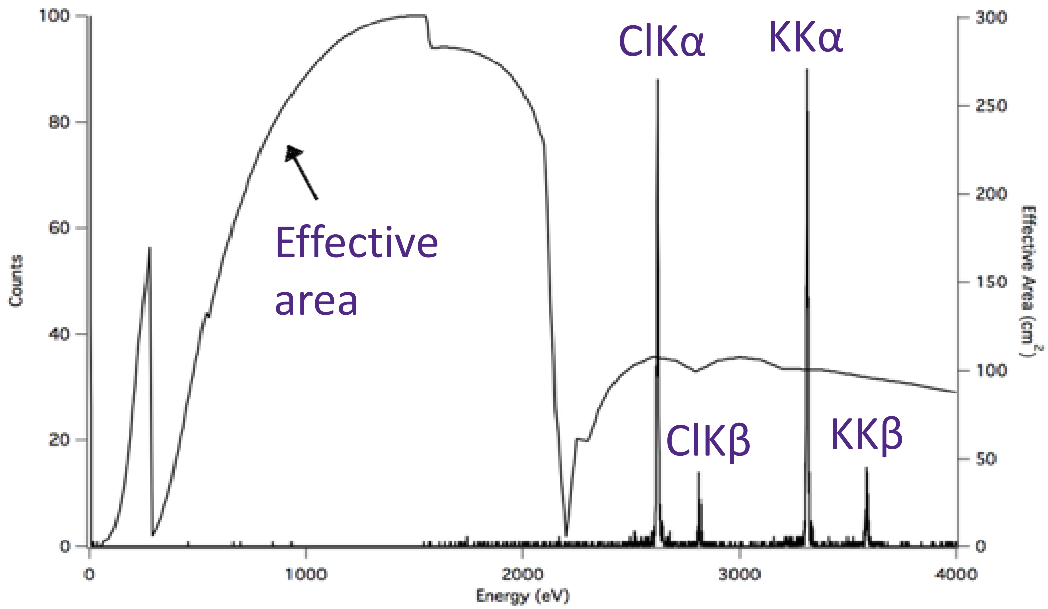
DOI:10.1063/1.1593809
DOI:10.1109/TASC.2010.2091483

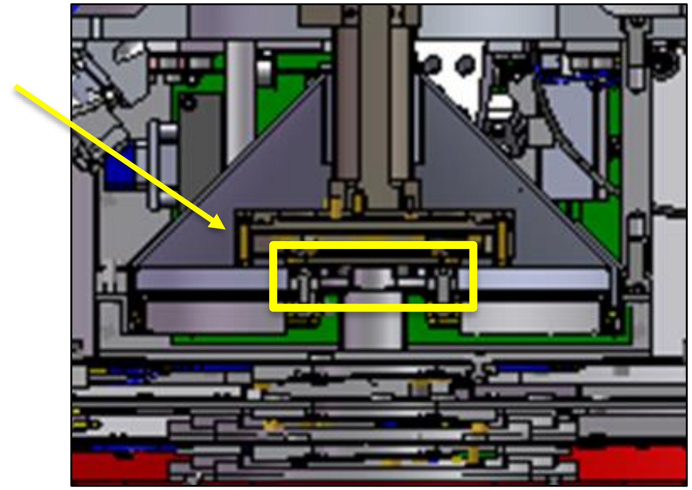
Flight calibration source

Ref: 2012APS..TSS.B1014R

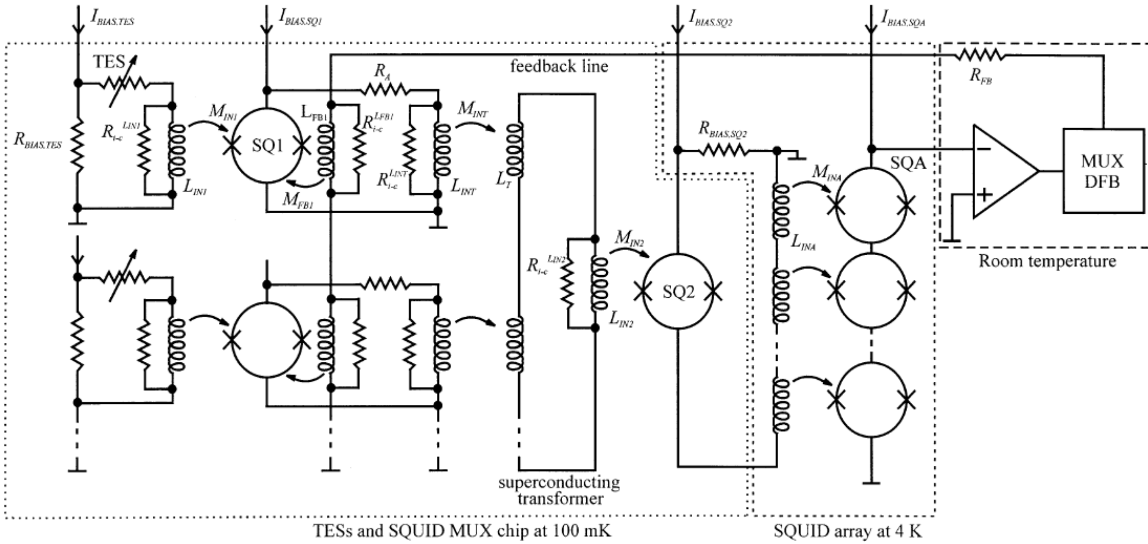


- Calibration source (KCl fluoresced by ^{55}Fe) directly adjacent to detectors track changes.
- These lines are just outside the region of interest (0.3 - 2.5 keV).
- Lines at 2.62 (ClKα), 2.81 (ClKβ), 3.31 (KKα), 3.58 (KKβ) keV.





SQUID MUX system



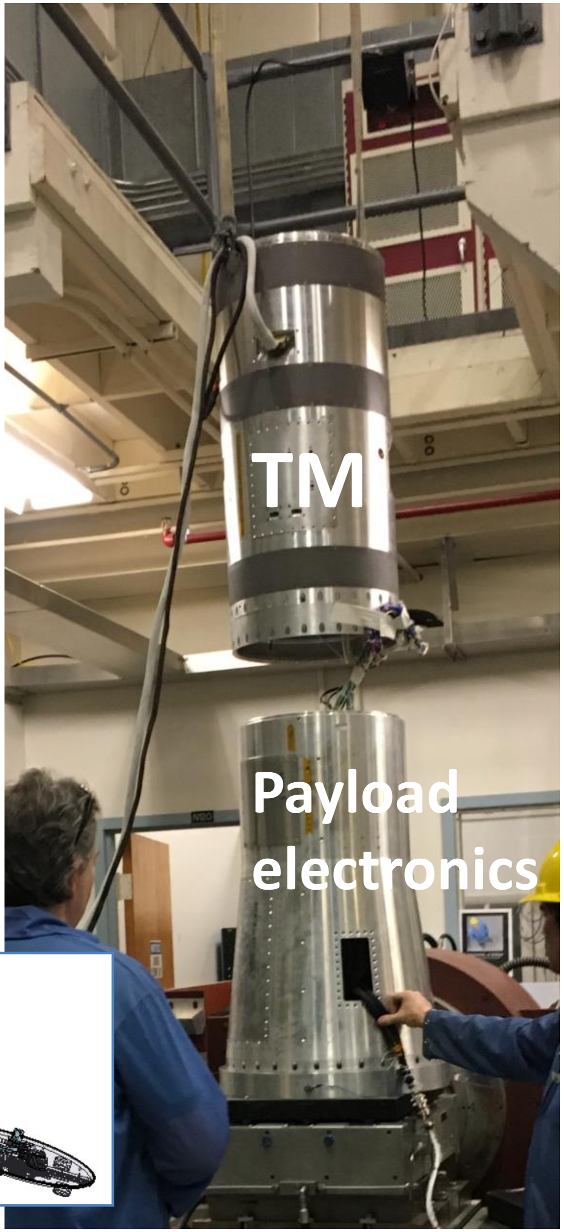
Read-out frequency of each pixel of 21.7 kHz.

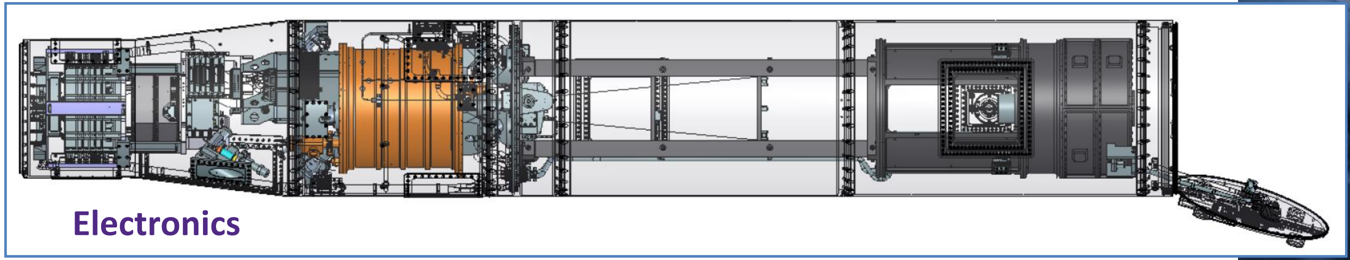
Time Division Multiplexing system, NIST MUX06a Series array SA4v4

4 MUX chips per science chain	Rsh,SQ2 = 90 mOhm
SQ1 turns ratio 8.53	TES Rn 9 mΩ, TES Rsh 0.5 mΩ
Feedback resistance 2100 Ω	Preamp is x100 amplifier
Master clock 50 MHz	Clock sampling/ pixel (lsync) 48
Low speed mode 2x 20 Mbit/s	High speed mode 2x 66 Mbit/s

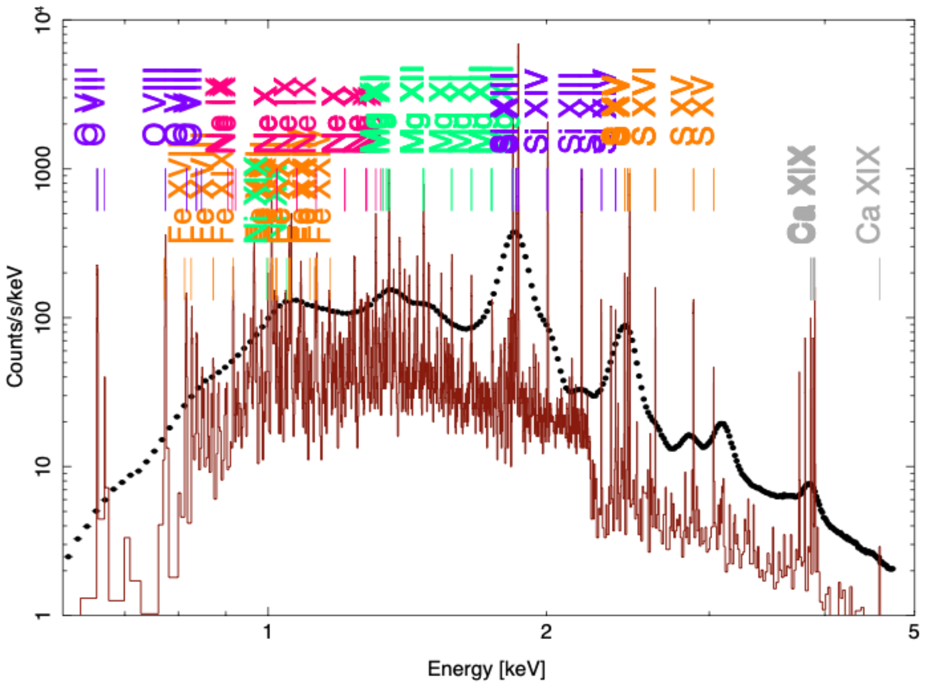
On board electronics

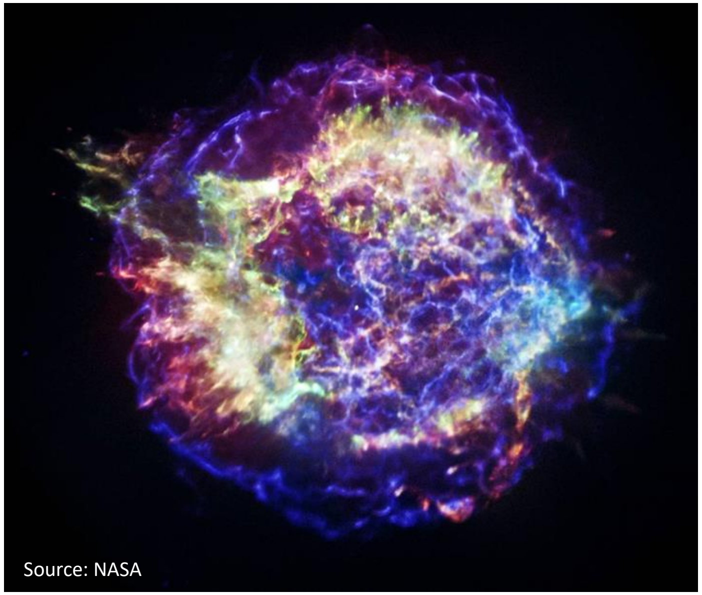
- All flight actions occur via timer (no uplink)
- On-board electronics control the ADR and process 132 Mbit/s science data
    - 30% of data is encoded and transmitted to the ground via antennae
- Ground Support Equipment reads out real-time data before and during flight
    - In the event of a bad landing, this is the full data set
    - Full data stream (32 GB) was recovered

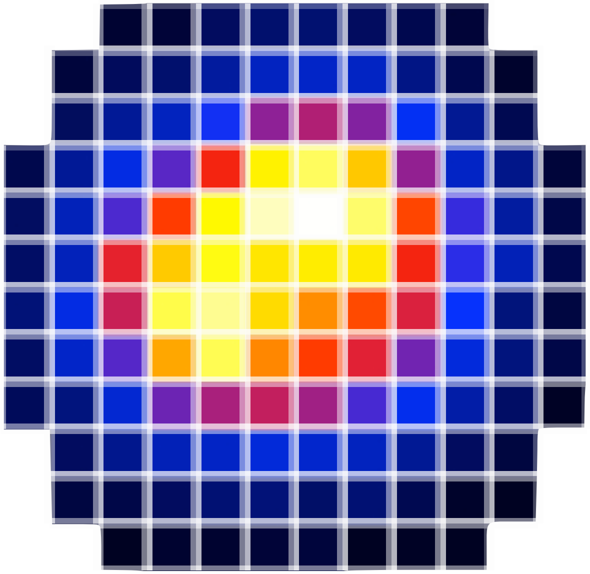




Cas A and Micro-X

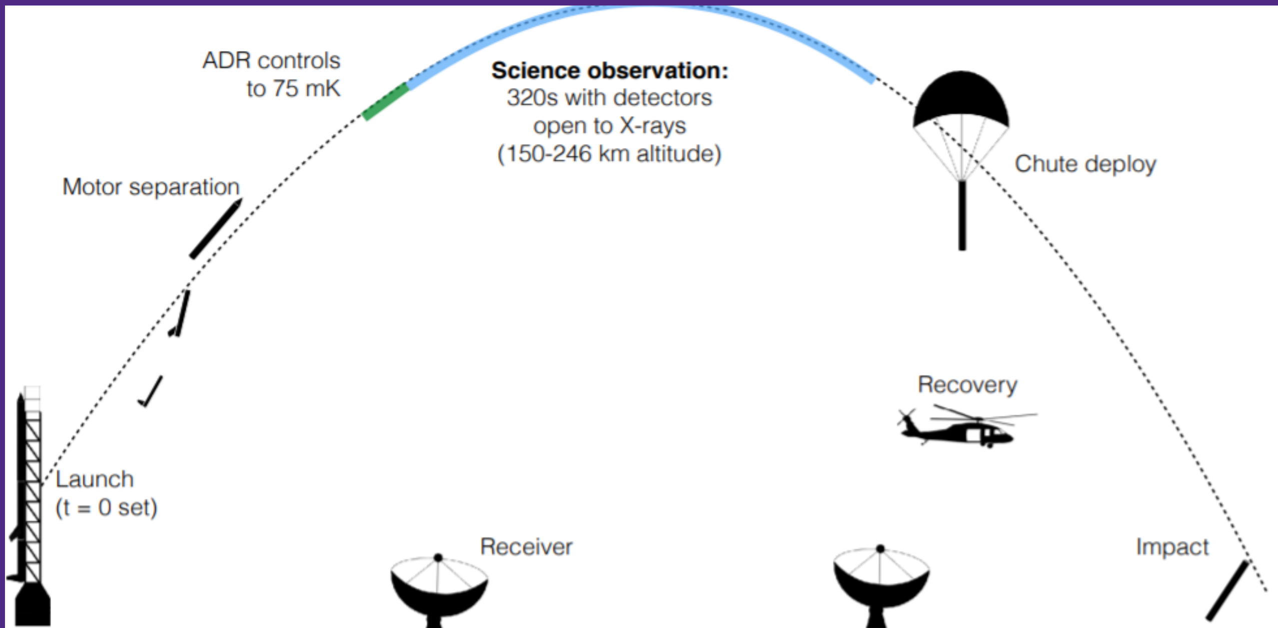






- Map emission lines provides an estimate of elemental abundances.
- Study of the plasma.
- Study of different nucleosynthesis models.

Flight timeline – 22nd July 2018



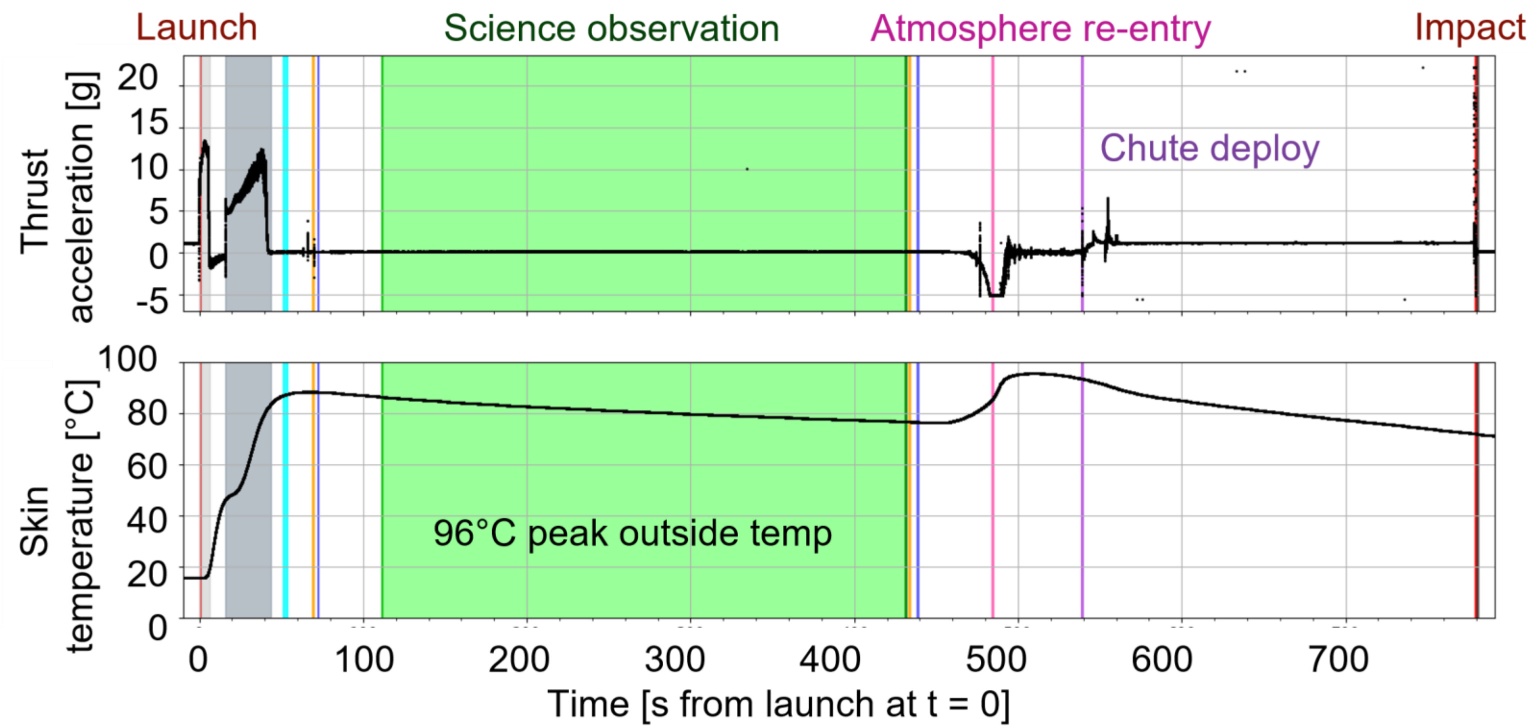
The rocket Attitude Control System (pointing) failed due to an in-flight software reboot that made the gas canisters eject all their gas, leading the payload to spin and not spend any time on-target.




Flight video

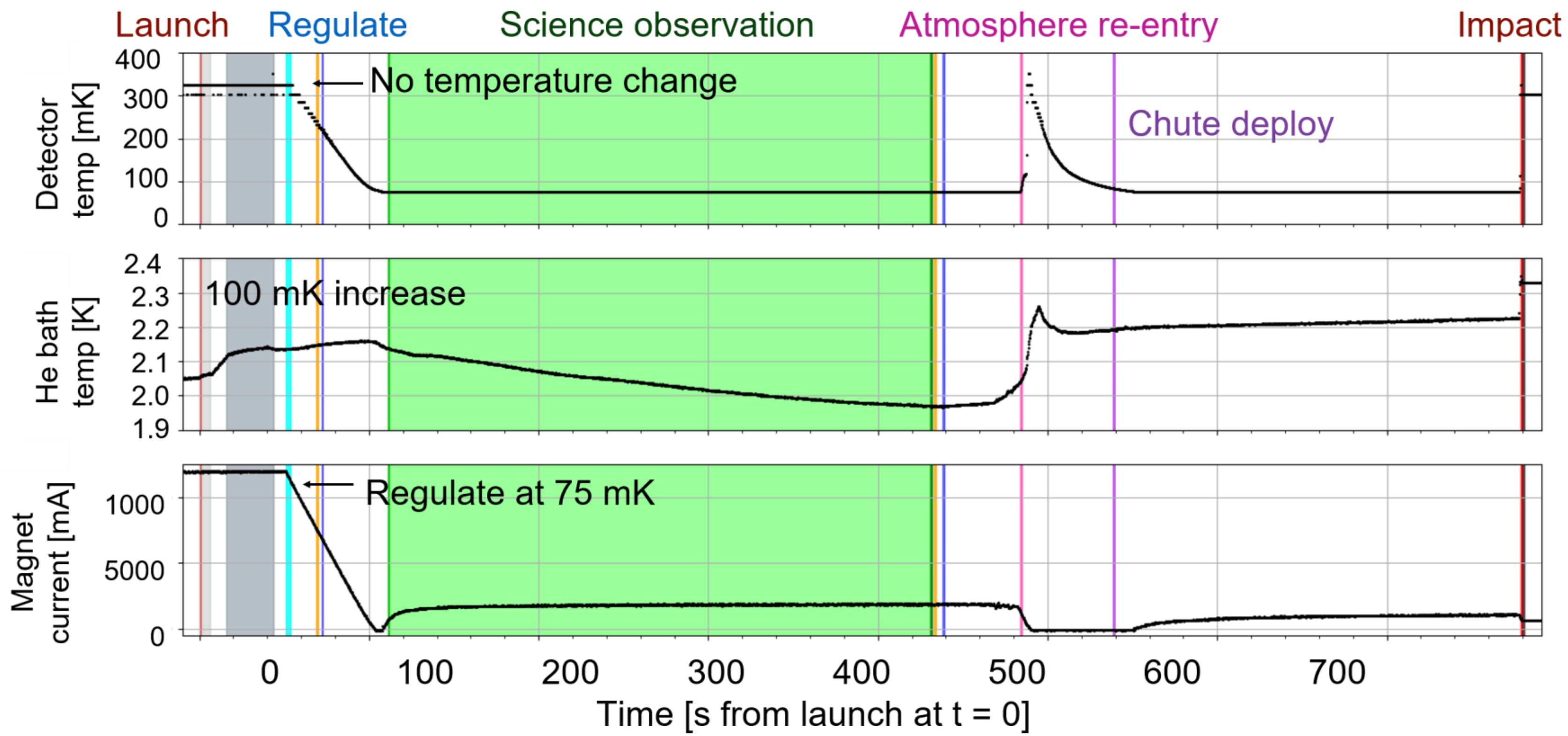
Flight performance – payload

- Timers successfully activated on time and components did not overheat.
- Full data recording, recovery and real-time data transmission were successful.
- The rocket experienced a peak 12.5 g vibration with external skin temperatures reaching 96°C.



Flight performance – ADR

- The ADR successfully achieved a stable 75 mK ±7 µK.
- The detectors did not see any temperature change during launch. Temperature regulation took 100 seconds.



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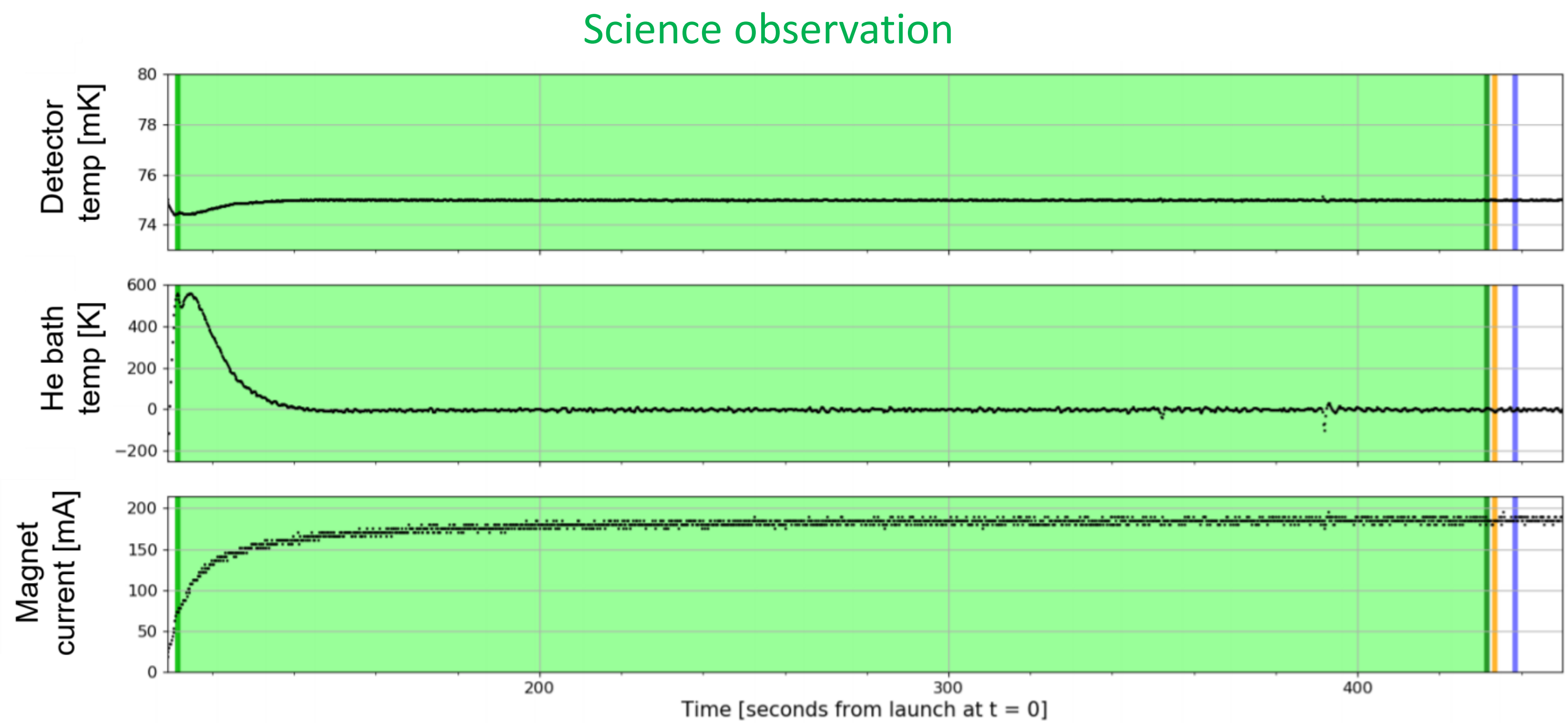
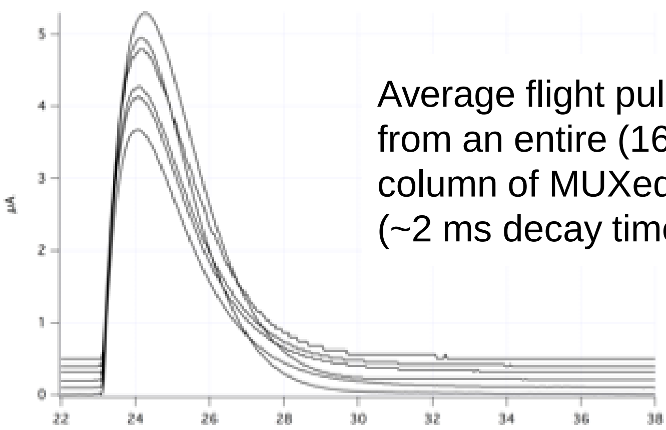


Flight performance – detectors

- 117 of the 128 pixels were operational at launch.
- Over 90% of the pixels achieved an integrated NEP (resolution metric) <10 eV at 3 keV in individual lab testing with flight electronics.
- 34% achieved an NEP <10 eV at 3 keV in flight configuration.

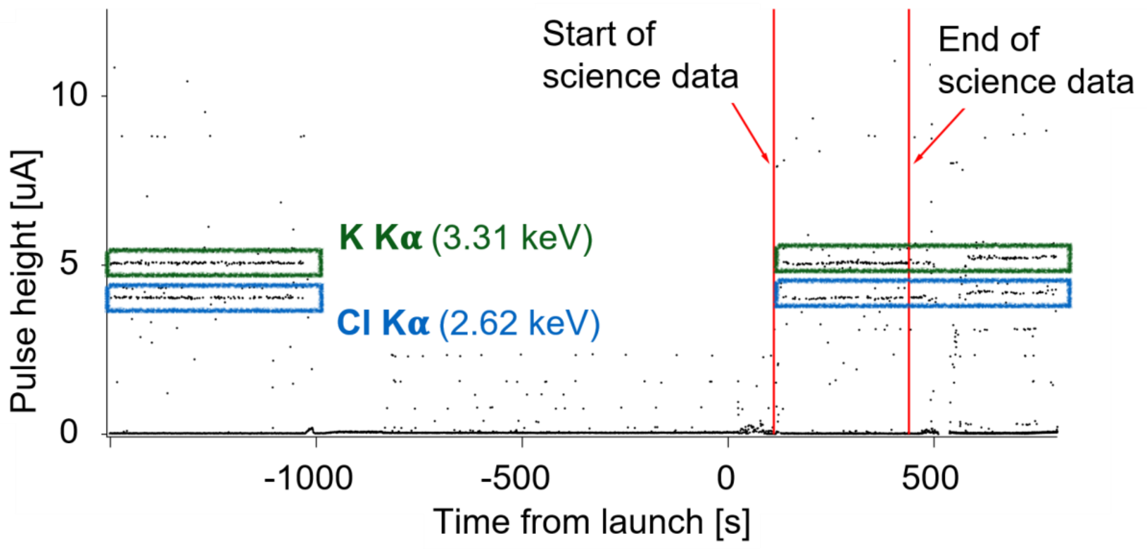
- All flight X-rays are consistent with coming from the on-board calibration source, as expected with the pointing failure.
- Brightest incident source has an expected rate of 0.19 counts / second for the array (J165749.6+352022).
- Calibration source rate was 2.881 ± 2.3 counts / second / pixel in flight.



Average flight pulses from an entire (16 pixel) column of MUXed pixels (~2 ms decay time)

See poster #166 "Detector Performance in the Micro-X Telescope", D. Goldfinger et al.

Flight performance – detectors



- Many detectors lost lock for periods of the flight.
- The cause is under investigation; possible hypotheses are a combination of using an older SQUID design known to be sensitive to magnetic fields (MUX06) and the pointing failure leading to the payload spinning in the Earth's field, susceptibility to RF noise.

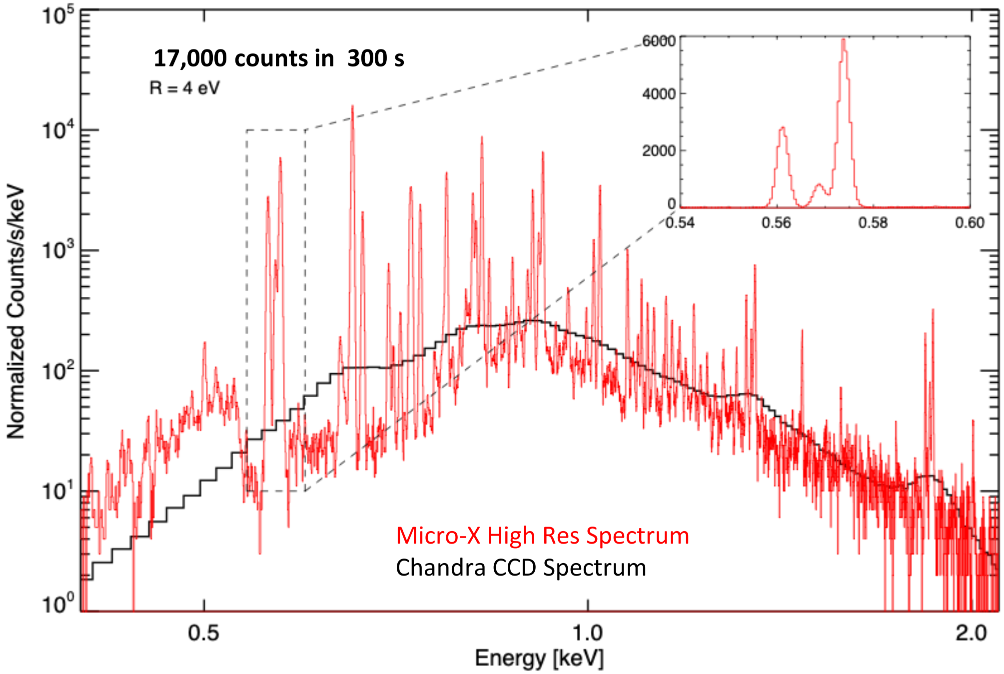
From flight 1 to flight 2

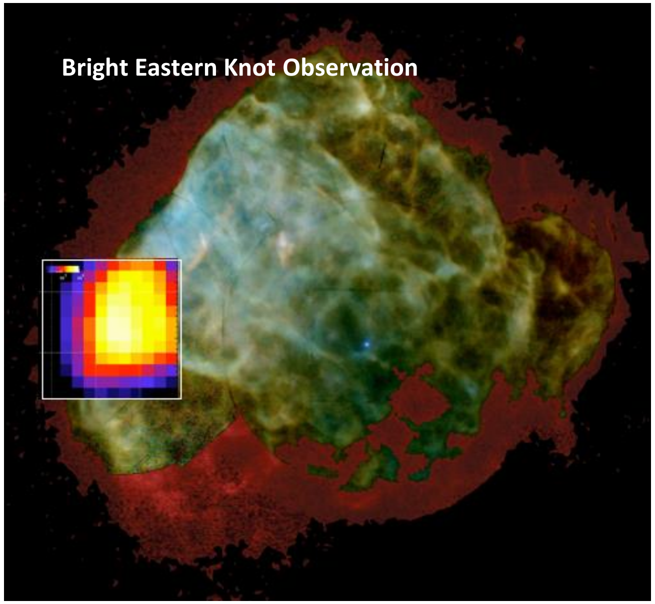
- The rocket pointing error means this first flight was effectively an engineering flight.
- Issues only observable in flight have been identified, with plans to improve them before the next flight.

Electronics upgrade	Improved RF shielding
Wire Rope Isolator replacement	Three broke during reentry (thermal effect)
New MUX system	Upgraded SQUID readout to two-stage gradiometric design.
Clock synchronization	Eliminate noise from beating

⇨ **Flight 2 planned for December 2019**.

Puppis A and Micro-X - simulations





Katsuda et al., 2010

- Measure the velocities and line structures of the various emission lines to obtain information about the dynamics and turbulence of the shock and surrounding plasma.
- Perform plasma diagnostics to obtain ion thermodynamic states for individual elements.
- Study the shock physics and look for potential connections to cosmic ray acceleration.

Conclusion

- The first flight of Micro-X saw the first operation of TES and MUX readout in space.

  See poster #166 "Detector Performance in the Micro-X Telescope", D. Goldfinger et al.

- The second flight (winter 2019) will target Puppis A in the same payload configuration.
- The payload will then be modified to look for dark matter.

See poster #182 "Towards Dark Matter Searches with the Micro-X Sounding Rocket ", A. Hubbard et al.

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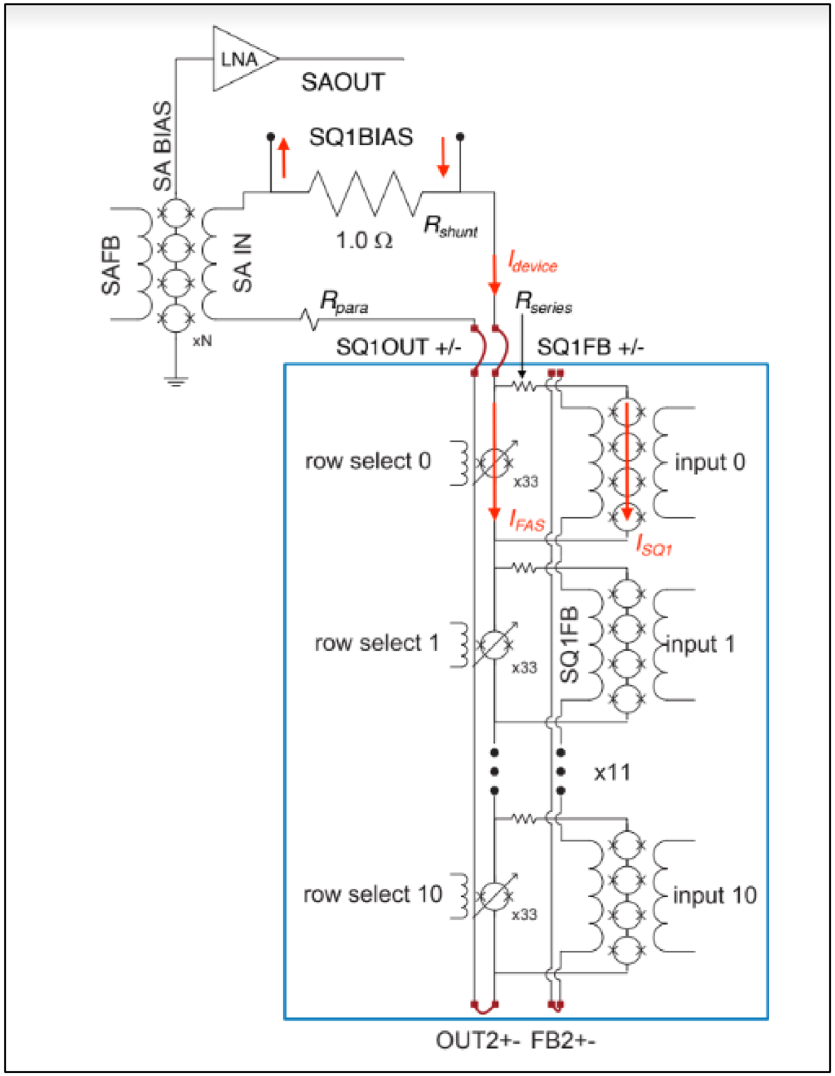
+ many undergrad students

New MUX system

- SA13 + MUX18
  - The loop area has been reduced to decrease the susceptibility to RF noise and ambient magnetic field.
  - MUX18 is a two stage MUX system while MUX06 was a three stage system.
  - MUX18 uses the gradiometric SQUID technology.

MUX18 (Min = 4.20 pH,Mfb = 29 pH, Rsh,SQ1 = 1.0 Ohm)
SA13 (Min = 107 pH, Mfb = 43 pH)



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