Dark Matter Searches with Micro-X

Resolving the keV-scale Dark Matter Controversy with Sounding Rockets

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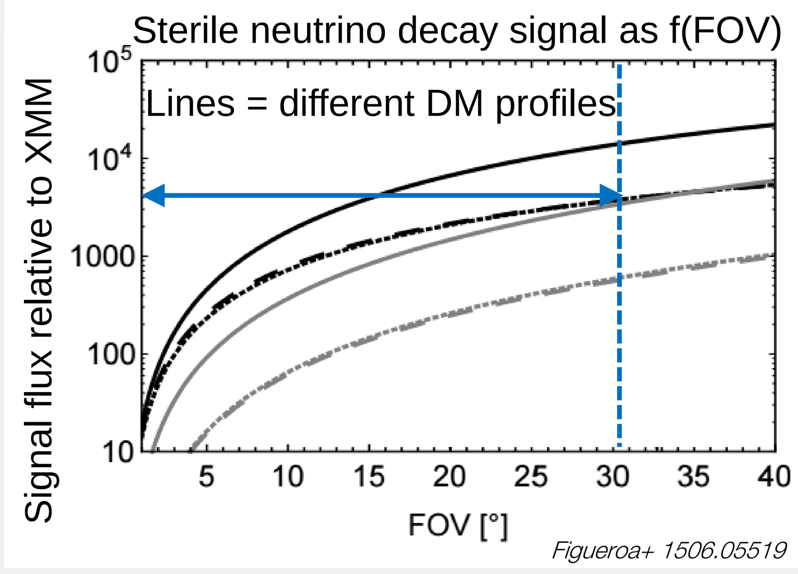
X-rays are a well-motivated dark matter detection signal

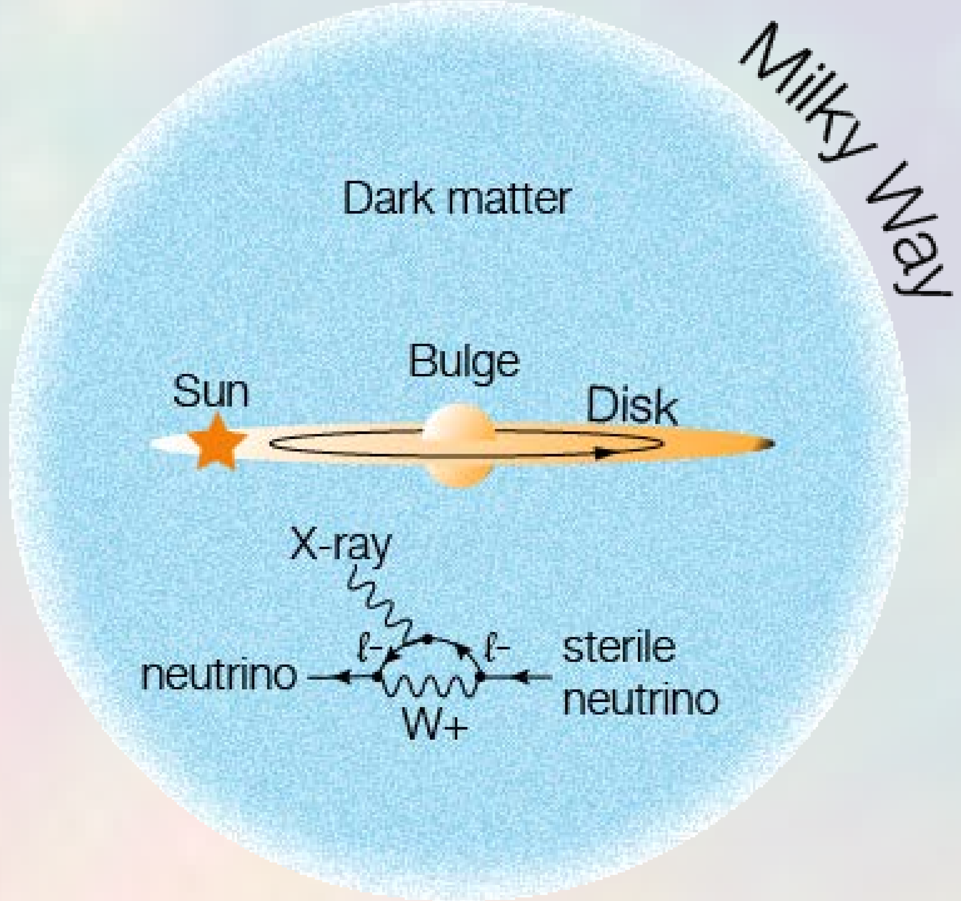
Dark matter makes up 26% of the known Universe, but its nature is still unknown. In the Milky Way, a spherical dark matter halo surrounds the plane of luminous matter. An extremely promising potential dark matter observation is in the X-ray band. The X-ray production mechanism depends on the dark matter candidate. One promising candidate, the sterile neutrino, can decay to an X-ray and an active neutrino in a loop-suppressed process, producing an X-ray at half the sterile neutrino mass.

X-ray satellites observe an X-ray anomaly at 3.5 keV that may be dark matter. Chandra, XMM-Newton, and Suzaku observe an excess at 3.5 keV that may be from secondary products of a dark matter interaction:

- The line does not appear to be instrumental.
- An atomic explanation requires an order of magnitude discrepancy with expectation.
- keV-scale dark matter candidates are well-motivated, including the sterile neutrino.
- The existence and nature of this line is under debate and require a high-resolution detector to be resolved.



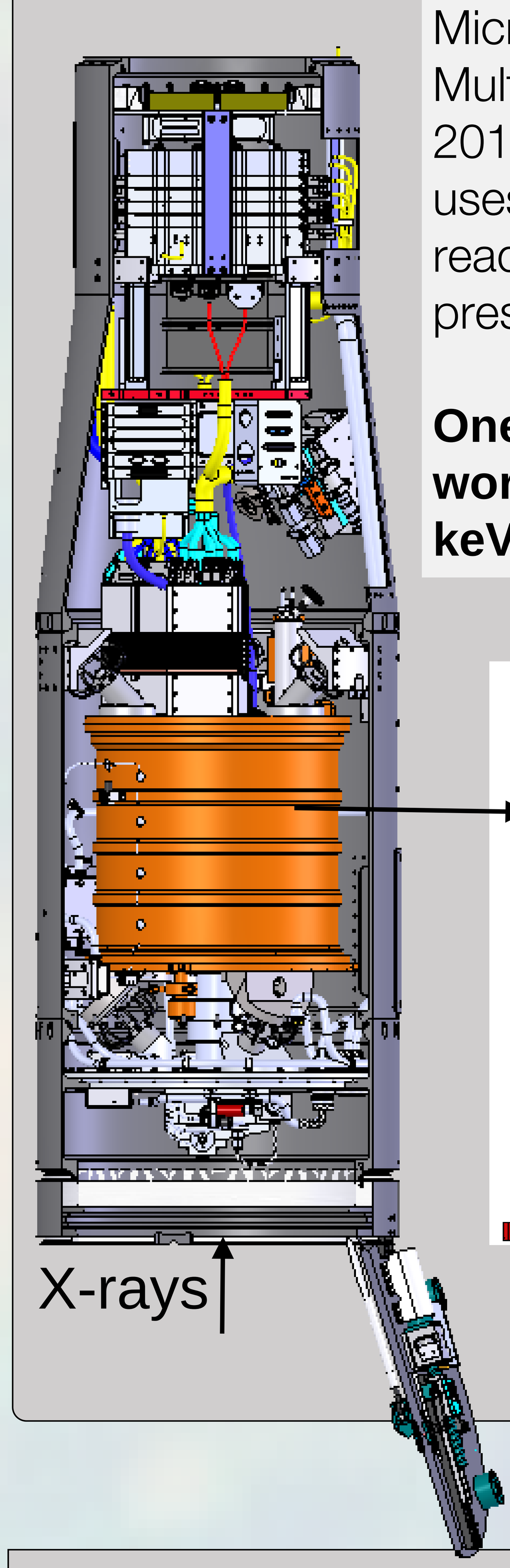
A 5 minute sounding rocket flight with high resolution detectors and a large FOV instrument is compatible with this observation. Galactic dark matter is an all-sky signal, so the incident flux scales as the FOV. Microcalorimeters provide the high resolution required to separate the monoenergetic signal from the background continuum and nearby atomic lines.

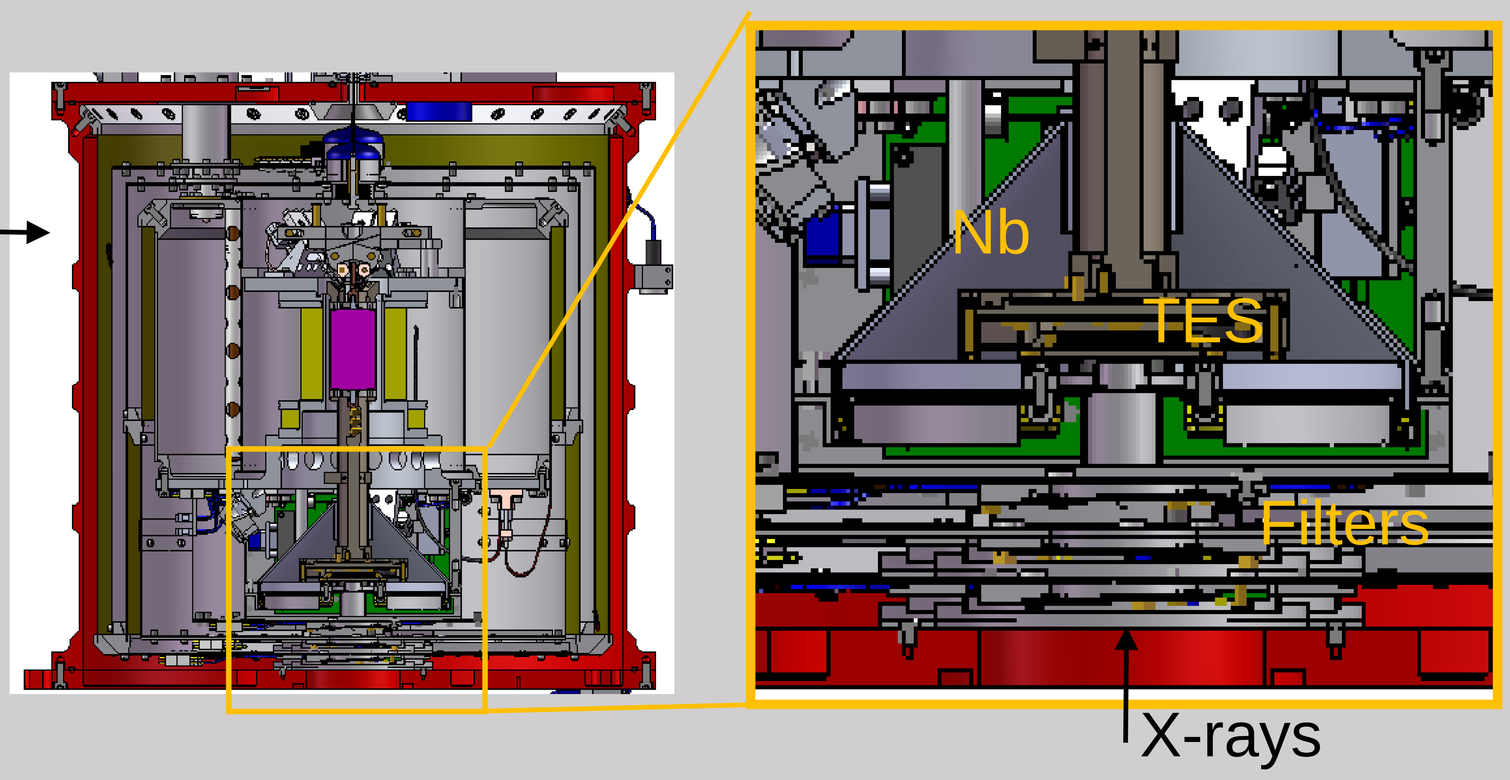


Micro-X TES Sounding Rocket

Micro-X became the first program to fly TESs and Time-Division Multiplexing (TDM) SQUID readouts in space with its first flight in July 2018. The TES array is placed inside an ADR-cooled cryostat and uses a 2-stage TDM SQUID readout. Room-temperature control and readout electronics are on-board. For first flight results, see presentations by N. Bastidon and D. Goldfinger.

One Micro-X flight will resolve the 3.5 keV controversy and set world-leading limits for any dark matter particle that produces keV-scale X-rays.





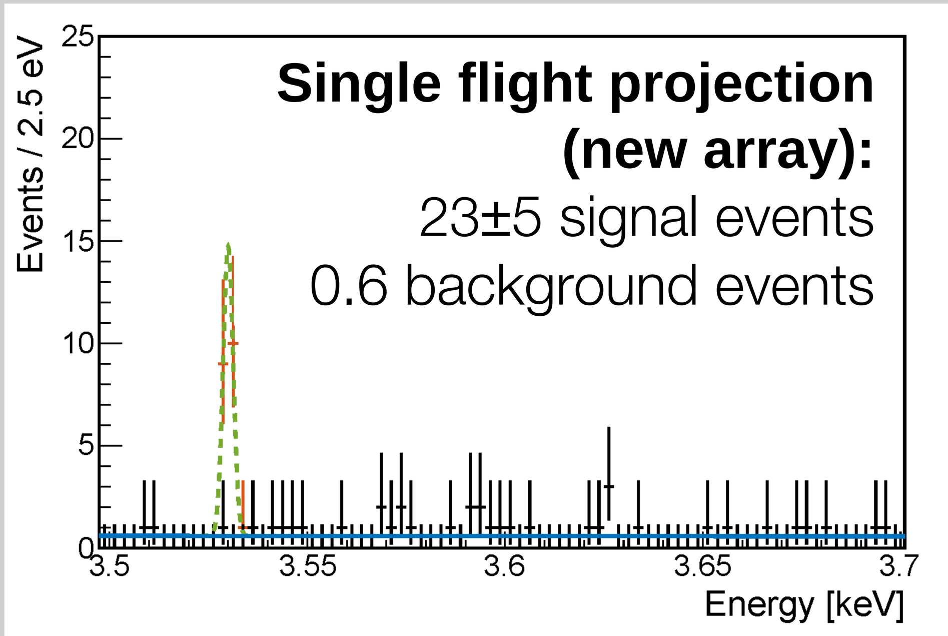
Dark matter payload upgrades

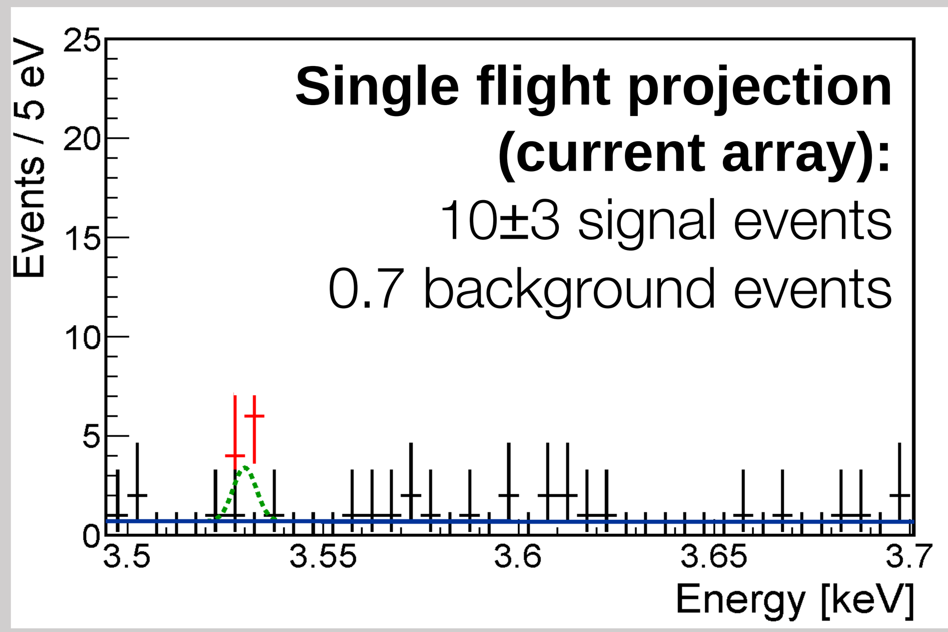
The dark matter science goals require a new TES array and modifications for a larger FOV:

- **New TES array:** The optimization of effective area to resolution is ongoing. Current models assume 128 pixels at 890 um x 890 um for an effective area of 1.1 cm^2. Detectors will be a Mo/Au bilayer TES with a Au/Bi absorber (3 um Bi, 0.7 um Au). The expected signal rate is <10 Hz across the array (<1 Hz/pixel); the rate will not be an issue.
- **Mechanical modifications** will widen all apertures between the detector array and space.
- **Magnetic shielding** from the ADR and external fields will be modified for the larger aperture. Current shielding uses: a bucking coil sits between the ADR and the detectors; a Nb shield encloses the TESs and SQUIDs; a field coil above the array rejects any remaining field.
- **Optical/IR Al-polyimide filters** will be made thicker. Athena and XQC filters can be used, but are operationally challenging.
- **On-board calibration source** will use ^{55}Fe to fluoresce NaCl (instead of the current KCl) to emit outside the region of interest.
- **Charged particle** rejection is in under investigation.

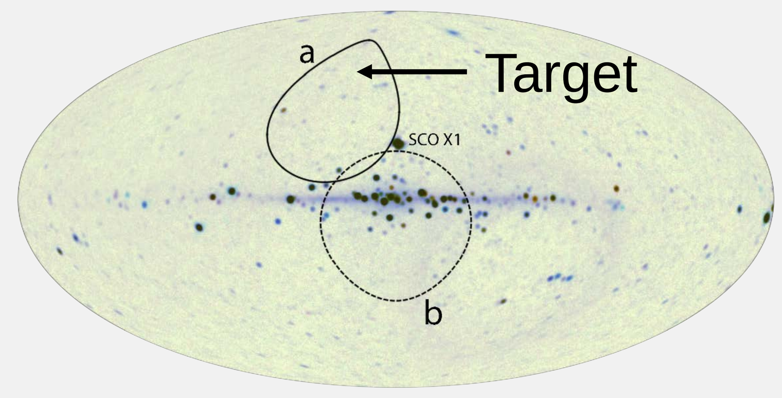
Configuration	Imaging (current)	Dark matter
Operating temperature	75 mK	75 mK
Energy resolution	4.5 - 10 eV	3 eV
Bandpass	0.2 – 4 keV	0.5 – 10 keV
Effective area	0.47 cm^2	1.1 cm^2
Pixel size	590 x 590 um^2	890 x 890 um^2
Field of view	11.8 arcmins	33 degrees
Observation time	300 s	300 s
Expected counts	13,000	2,400

Dark matter results in a single flight

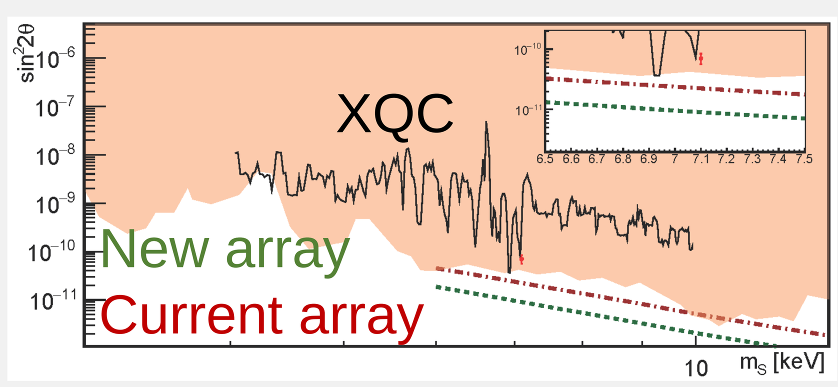




The target is a relatively quiet region near the Galactic Center. **A dark matter signal consistent with previous claims would yield an observation of >5σ significance with the new proposed TES array.** It would return a 2.5σ result with the current (first flight) array. The higher resolution of the new array keeps the background rate per bin low.



If a line is detected, it may be from a dark matter or an atomic interaction. Micro-X has the ability to discern between these two signals by mapping the Doppler shift of the line across the Galaxy with multiple flights. Dark matter is located in a stationary halo around the galaxy, while an atomic background will be co-moving in the galactic plane. **This "velocity spectroscopy" distinguishes dark matter, which is located in a stationary halo around the galaxy, from atomic backgrounds, which are co-moving in the galactic plane.**



The Micro-X observation is highly complementary with XRISM observations. Micro-X is optimized for the all-sky galactic signal, and its short flight precludes it from observing smaller targets that require a longer exposure with XRISM. XRISM will get excellent spectra from extragalactic sources like galaxy clusters and dwarf spheroidals. For Milky Way dark matter, XRISM would require 31 Ms of observation to accumulate the same signal flux as one Micro-X flight. Thus a combination of data from both experiments is an excellent way to enhance sensitivity to dark matter signals in this region.

White Sands Missile Range Blackhawk "The Rail"

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