Sterile Neutrino Dark Matter Searches with X-Ray Sounding Rockets

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Micro-X Science

1st flight: February 2018

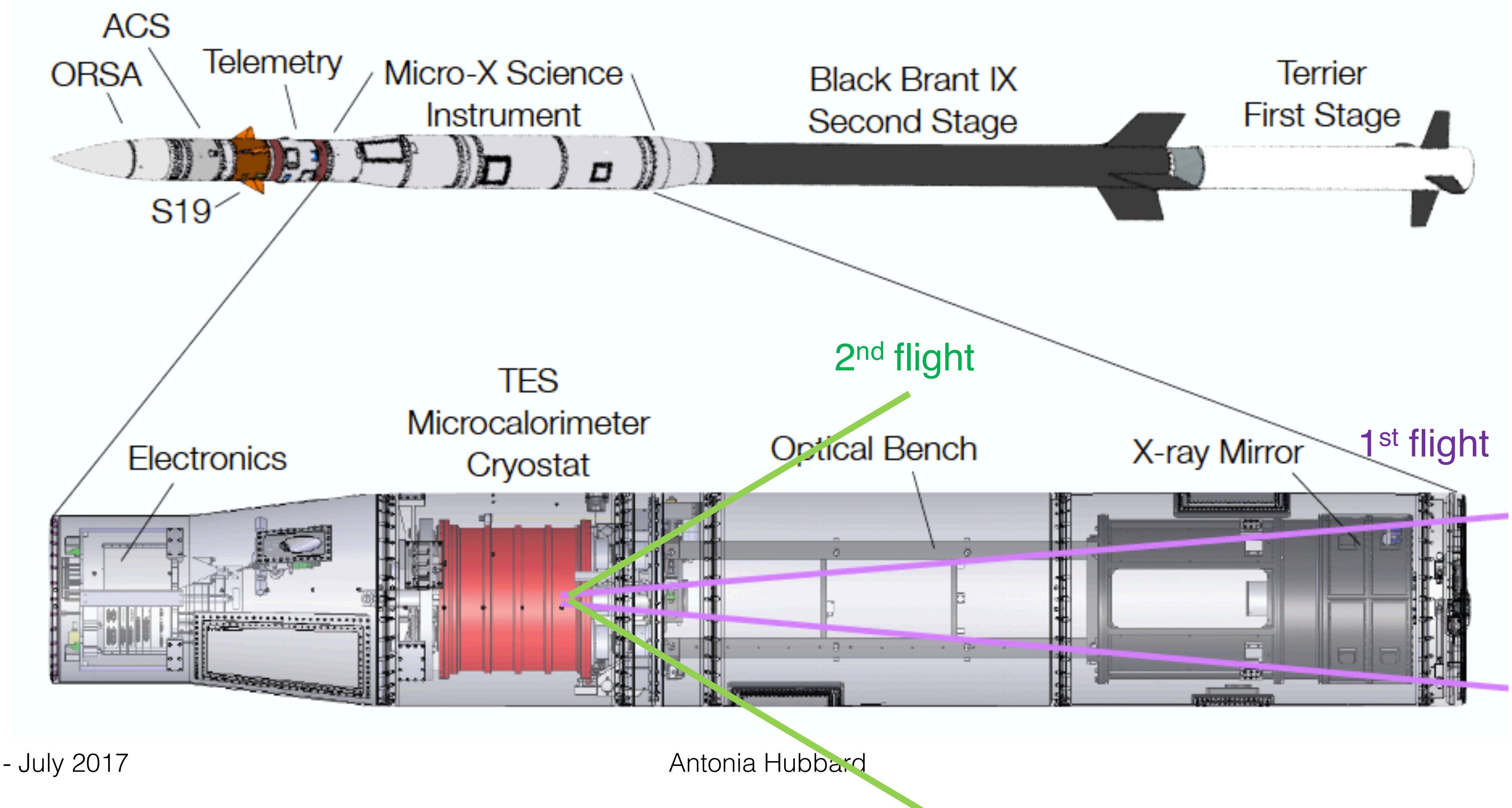
Puppis A SNR observation

- Energy and spatial information
- 2.5’ PSF

2nd flight: August 2019

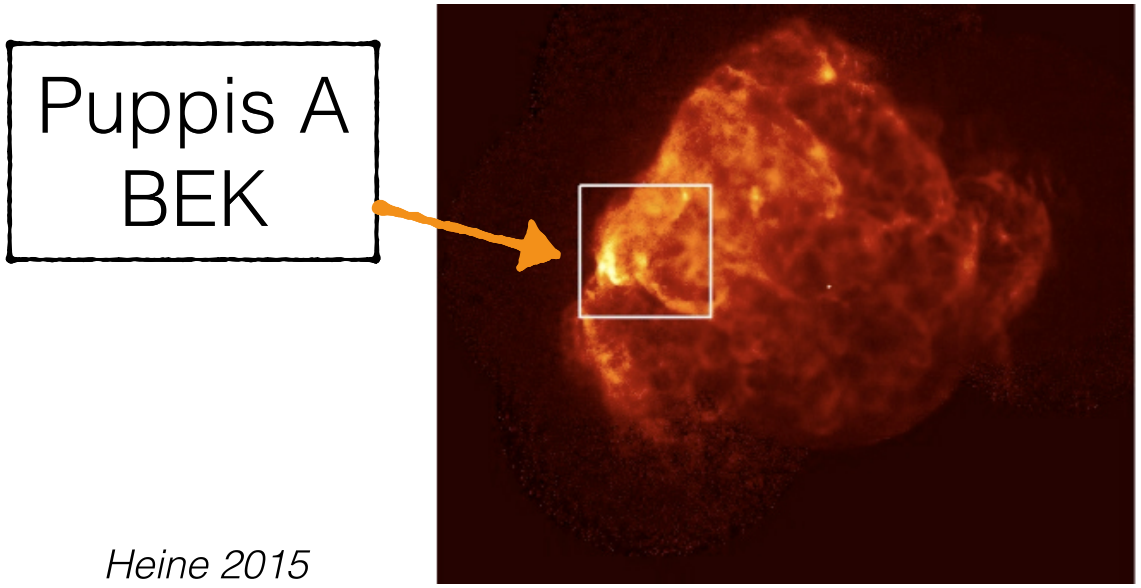
Sterile neutrino search

- Photon bucket
- 20° FOV

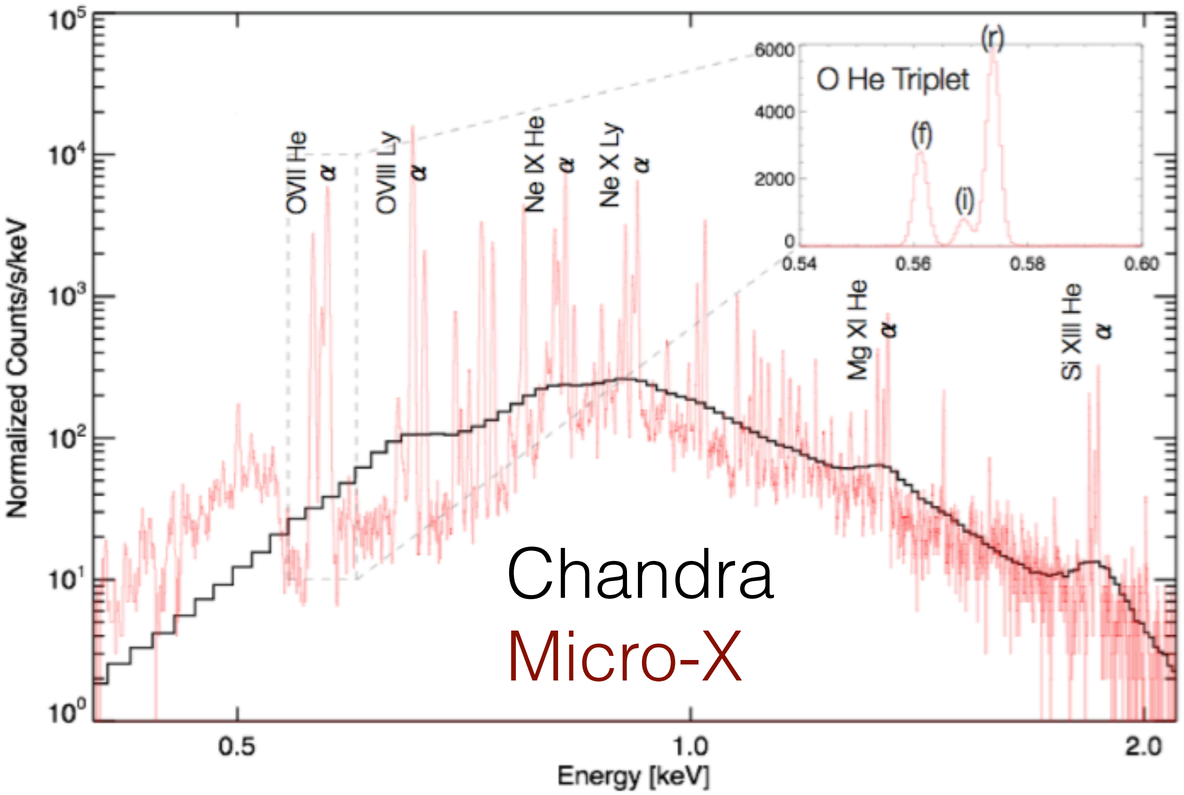


Up first: SNRs

- High spectral/angular resolution observation of extended X-ray sources with unique combination of bandpass, collecting area, resolution
    - SNR size makes high spectral resolution observations with grating instruments challenging
- Microcalorimeters can study detailed atomic physics of the plasma
    - Determine temperature, turbulence, elemental abundances
    - Look for evidence of charge exchange
    - Look for clues to gamma-ray emission from shock regions



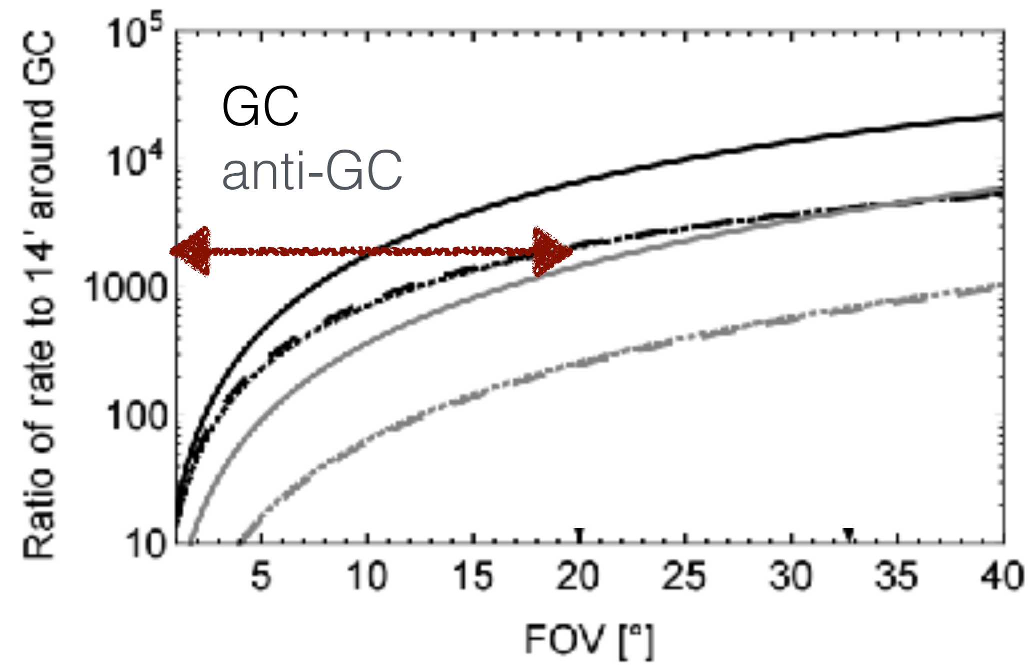
Heine 2015

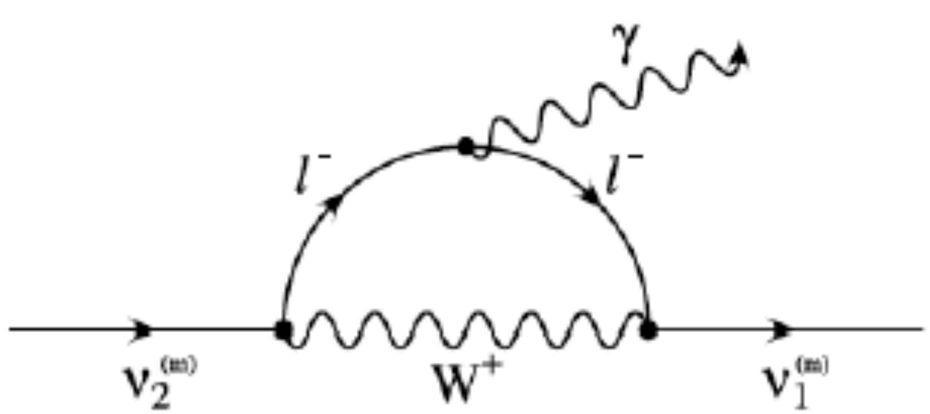


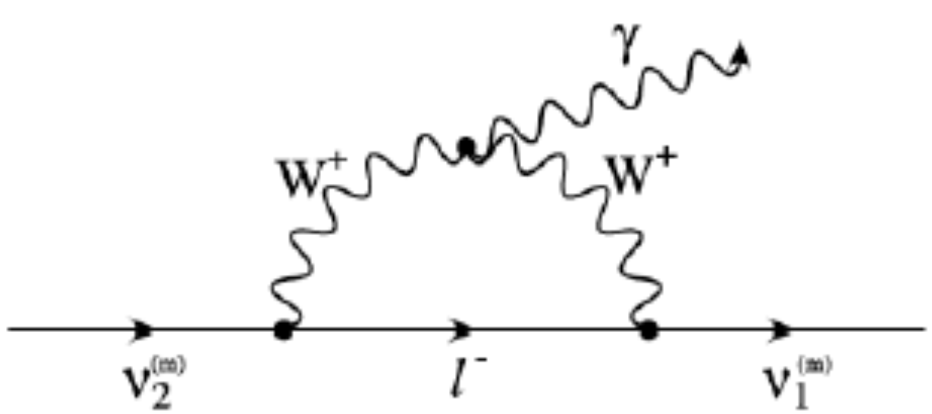
Detecting Sterile Neutrinos

- **Indirect detection:** decay to a photon and active neutrino in a loop-suppressed process mediated by oscillation between the active and sterile states
  - X-ray line at half the neutrino mass
- All-sky signal due to our location within the dark matter halo of the MW
  - Signal depends on flux along line-of-sight
  - Sensitivity improved by increasing FOV

Figueroa+ 1506.05519

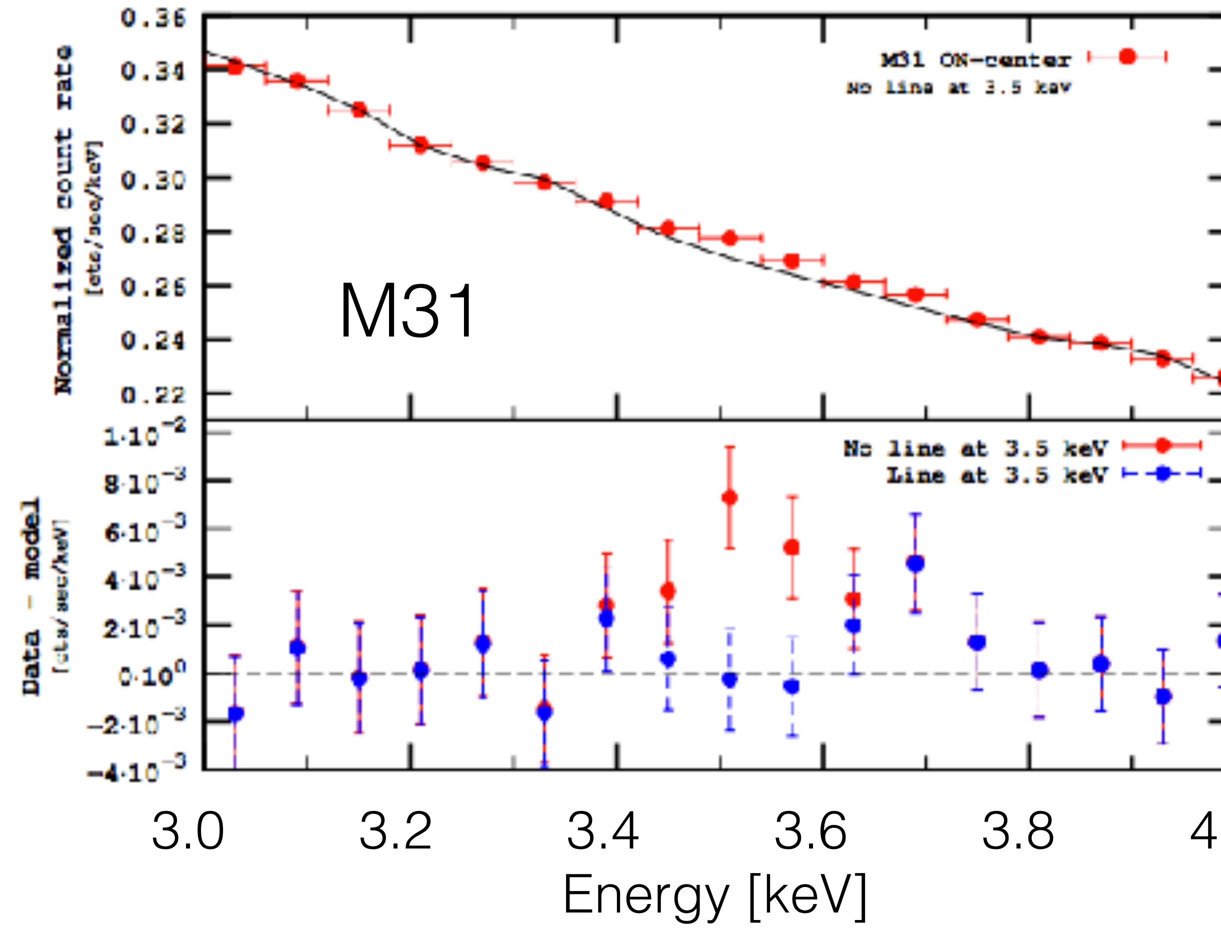




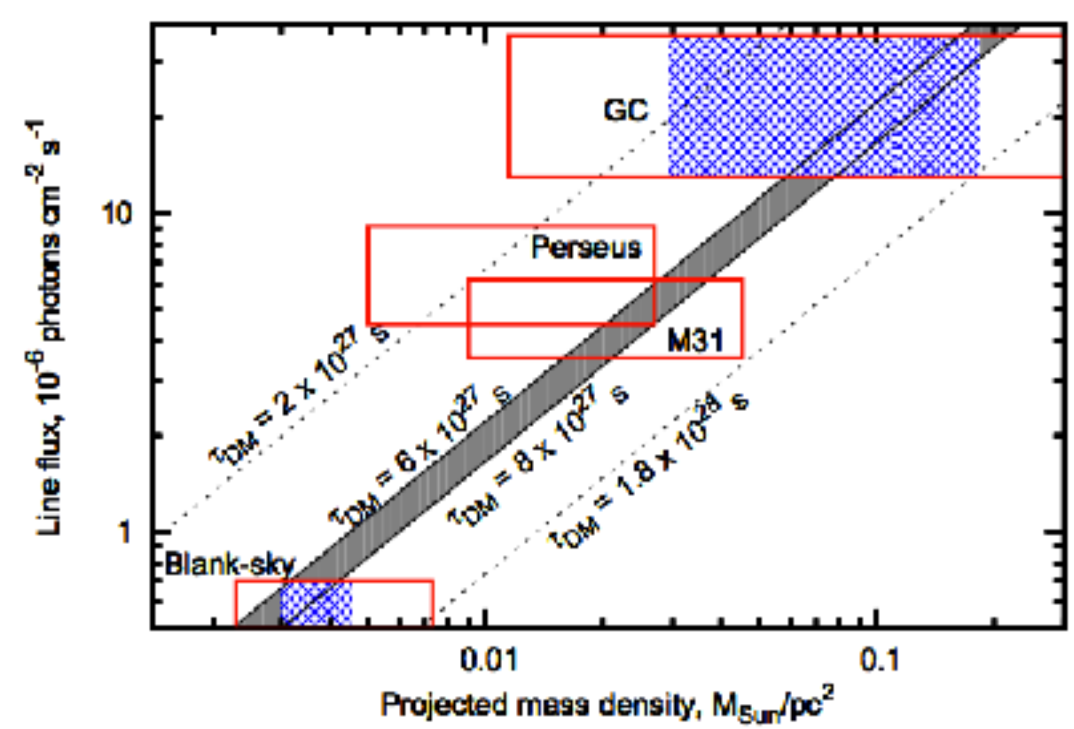


Have we found dark matter?

- Sterile neutrino in the keV range is a good dark matter candidate
- Anomalous line at 3.5 keV detected in XMM-Newton, Chandra, Suzaku, and NuSTAR data to high significance
- Instrumental explanation is unlikely
  - Observed across 6 detectors
  - Proper redshift
- Atomic explanation is not trivial
  - Must explain observations and non-observations
  - Anomalous line ratios of 10-20x required
  - Varying line flux contradicts atomic data



Boyarsky+ 1402.4119



Status of the field

	XMM-Newton	Chandra	Suzaku	Hitomi
Stacked clusters	+			
Andromeda	±			
Perseus	+	+	±	-
Coma, Virgo, Ophiucus	+	-	-	
MW GC	+	-		
Other clusters	+			
Stacked galaxies	-	-		
MW dwarfs	-			
Draco	±			

Riemer-Sorenson (1405.7943)
Jeltema & Profumo (1408.1699)
Boyarsky et al (1408.2503)
Malyshev et al (1408.3531)
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Cappelluti et al (1701.07932)

Status of the field

These observations are systematics-dominated -
we need higher resolution detectors!

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Andromeda	±			
Perseus	+	+	±	-
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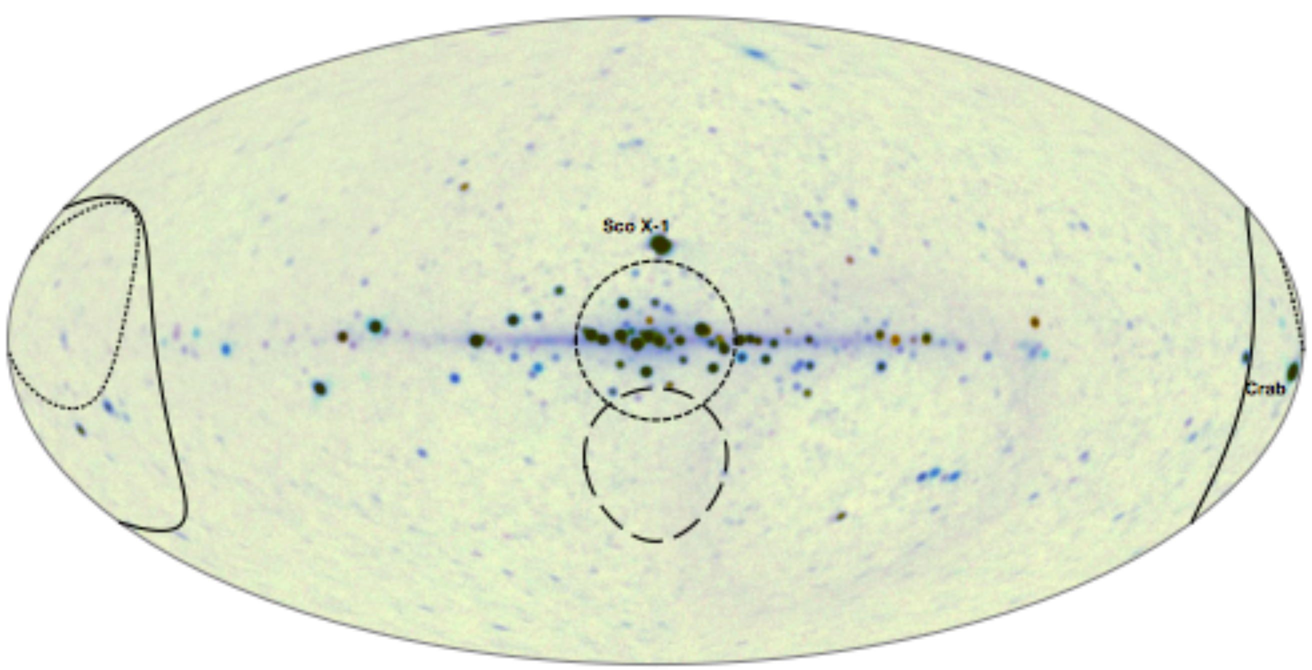
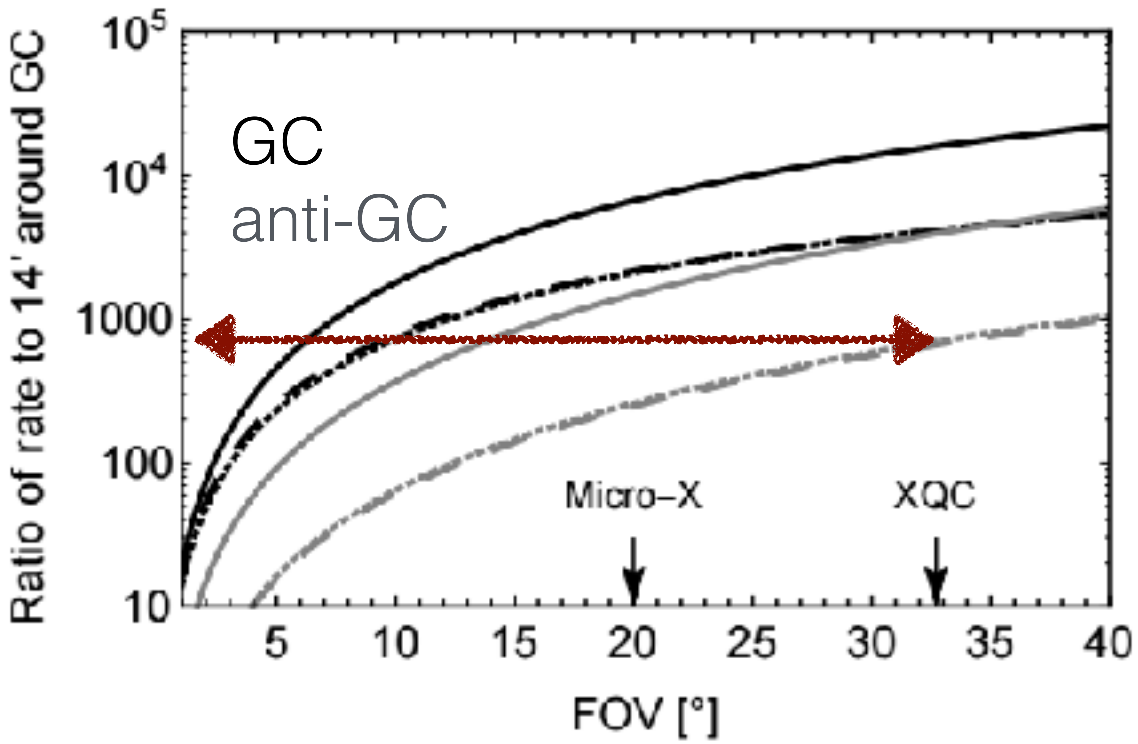
Microcalorimeter Sounding Rockets

- XQC (Wisconsin): 6 flights from 1995 - 2014
    - Si thermistor array with a ~50 mK operating temperature
    - High resolution (23 eV FWHM at 3.3 keV) and wide FOV (32.3° radius)
- 2011 anti-GC observation (l = 165° , b = −5°) with an effective exposure of 106 s
    - Large FOV observations of the GC have better signal-to-noise since the signal is all-sky while backgrounds are dominated by GC/GR (±5° from the plane) rather than CXB

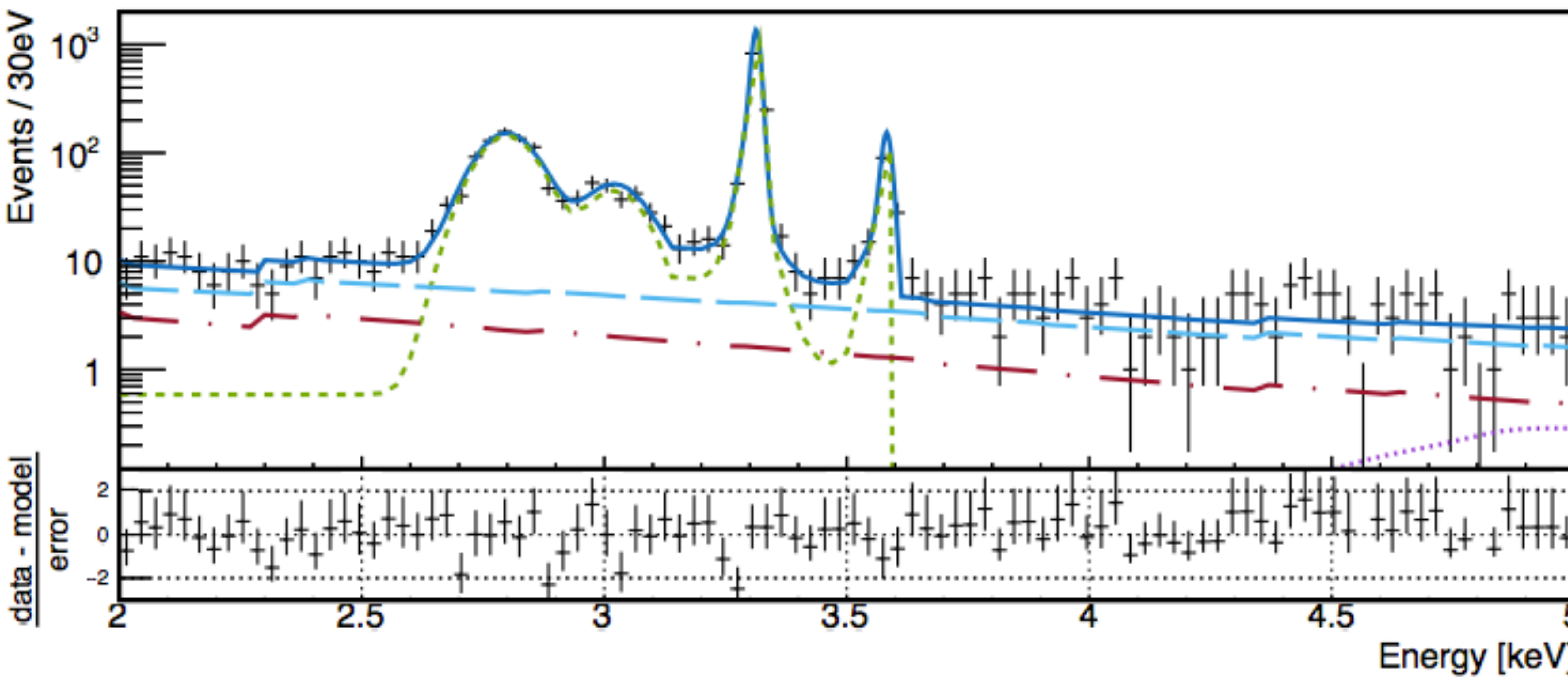




XQC Sterile Neutrino Results

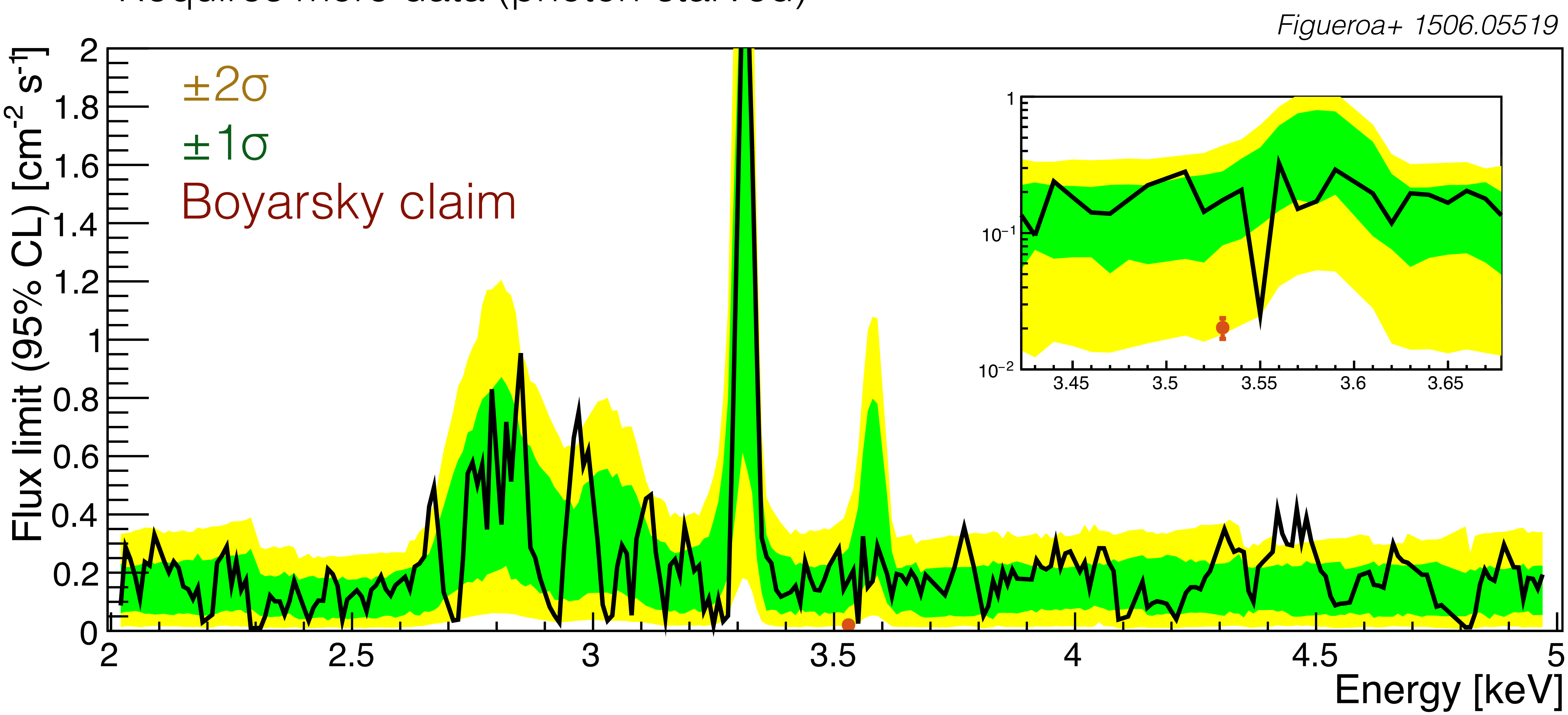
Data
Total background
Diffuse X-ray background (Hickox & Markevitch 2006)
Crab (Mori et al 2004)
Cosmic rays (GEANT simulation)
^{41}Ca calibration source

Figueroa+ 1506.05519



XQC Sensitivity

- Unbinned maximum likelihood set the upper limit for an unidentified line above the background model
- Upper limit on the flux of 0.17 counts/cm^2/s at 95% CL
  - Not sensitive enough to rule out Boyarski's MW detection
  - Requires more data (photon-starved)



The Micro-X Concept

Fly a 128-pixel TES microcalorimeter array in a vibration-isolated ADR on a sounding rocket

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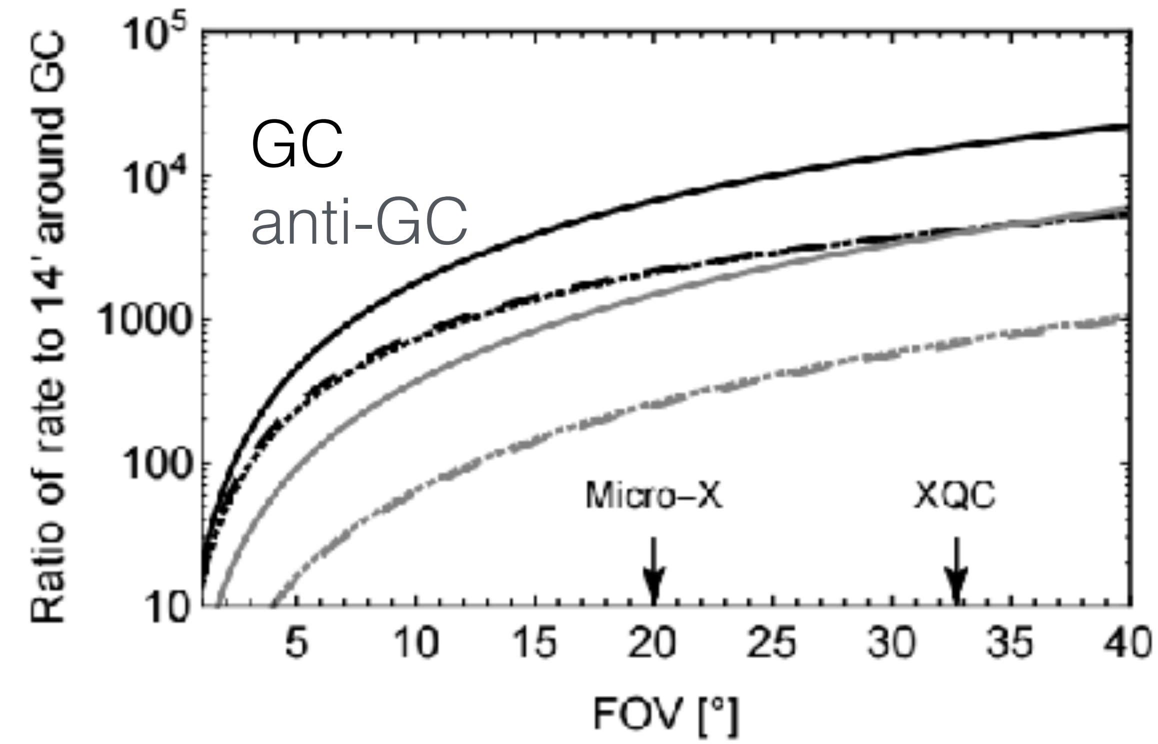
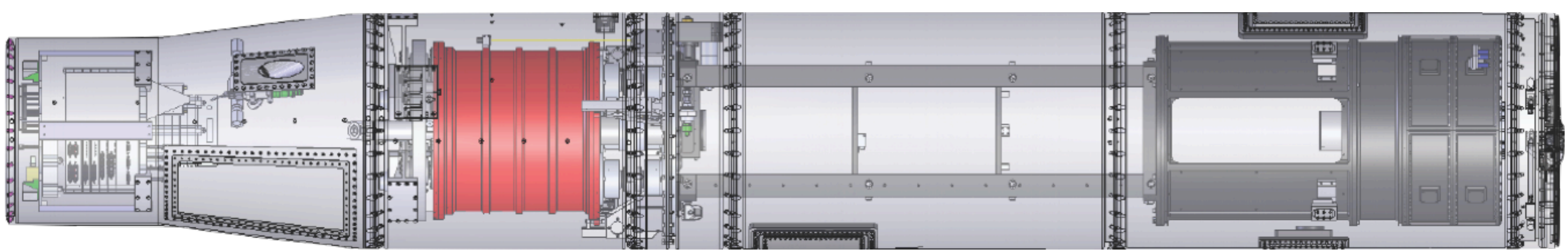


Electronics Cryostat Optics



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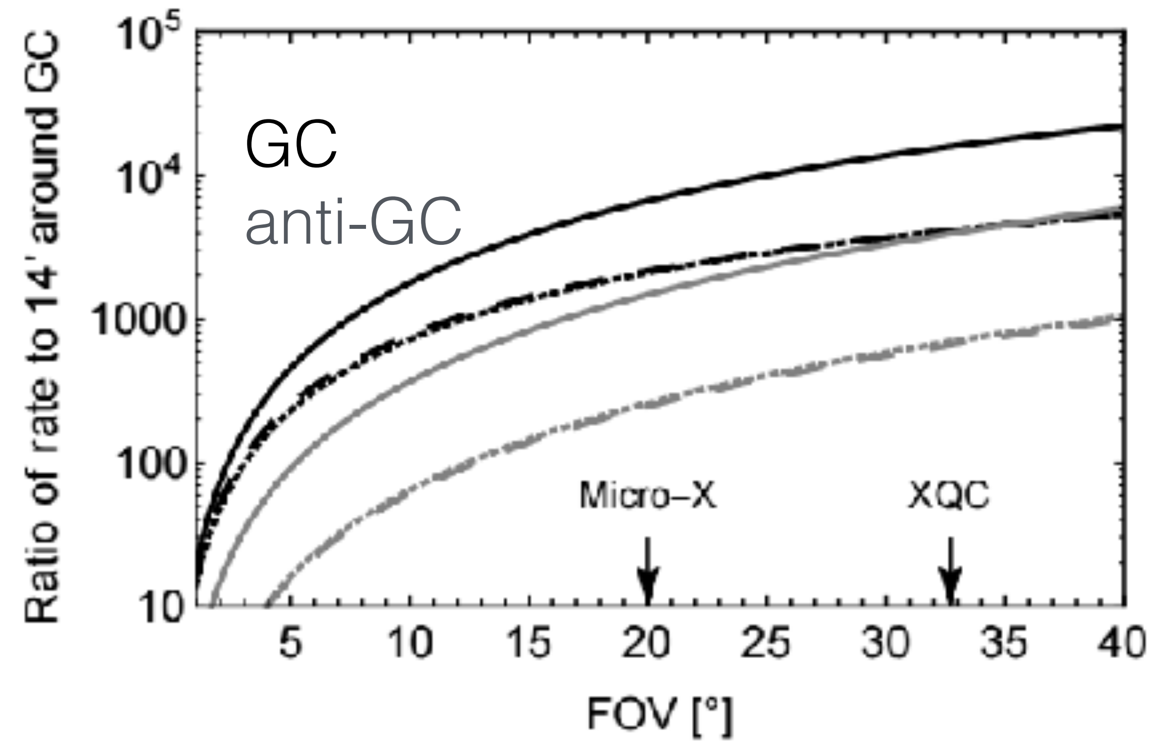
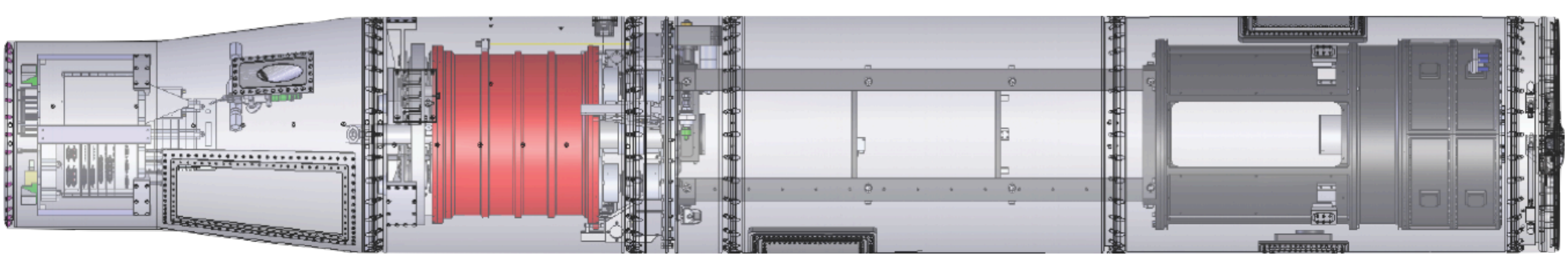
4 eV at 3 keV

Figueroa+ 1506.05519





The Micro-X Concept

Fly a 128-pixel TES microcalorimeter array in a vibration-isolated ADR on a sounding rocket

4 eV at 3 keV

75 mK

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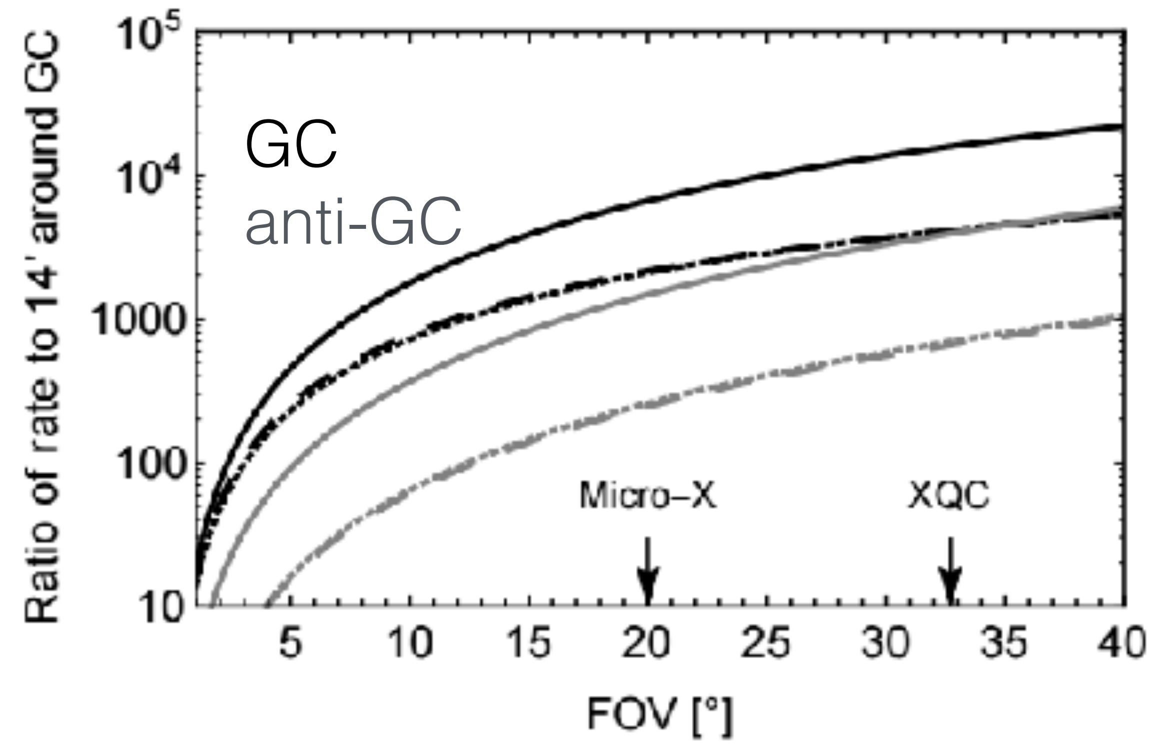

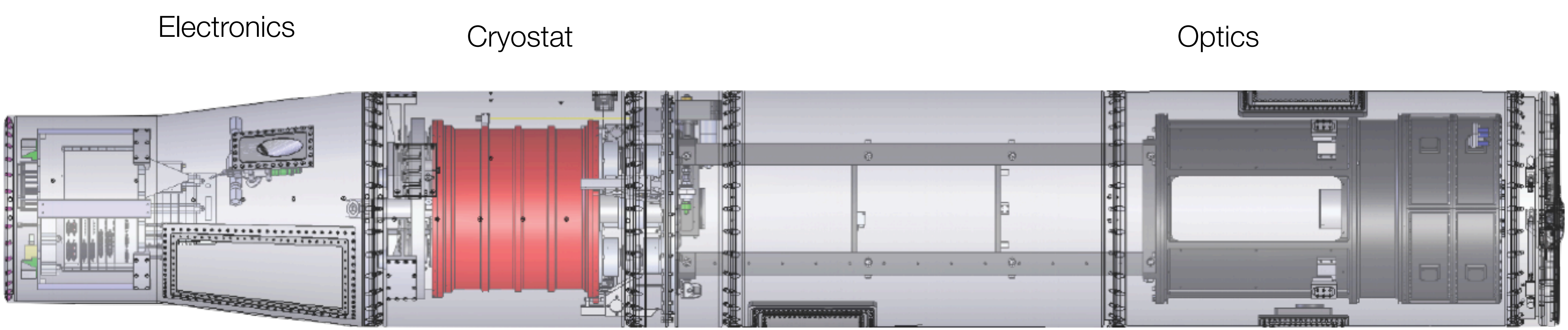

The Micro-X Concept

Fly a 128-pixel TES microcalorimeter array in a vibration-isolated ADR on a sounding rocket

- TES → 4 eV at 3 keV
- ADR → 75 mK
- sounding rocket → 5 minutes of data in the upper atmosphere

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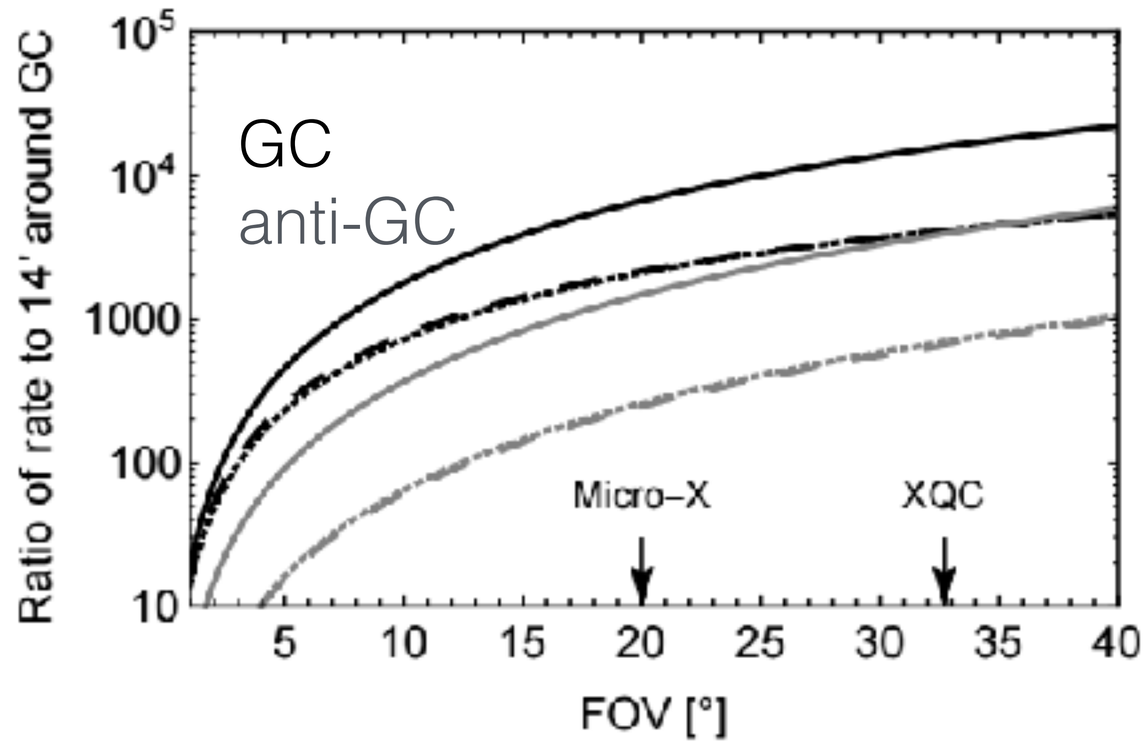

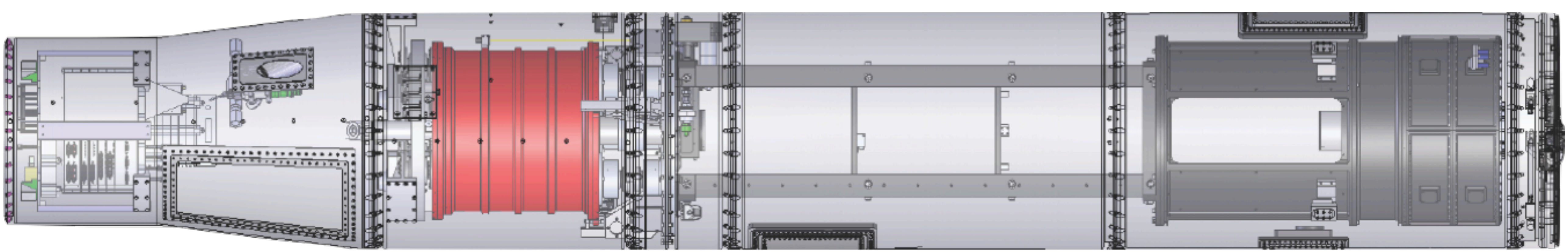

The Micro-X Concept

12' - 20°

Fly a 128-pixel TES microcalorimeter array in a vibration-isolated ADR on a sounding rocket

4 eV at 3 keV

75 mK

5 minutes of data in the upper atmosphere

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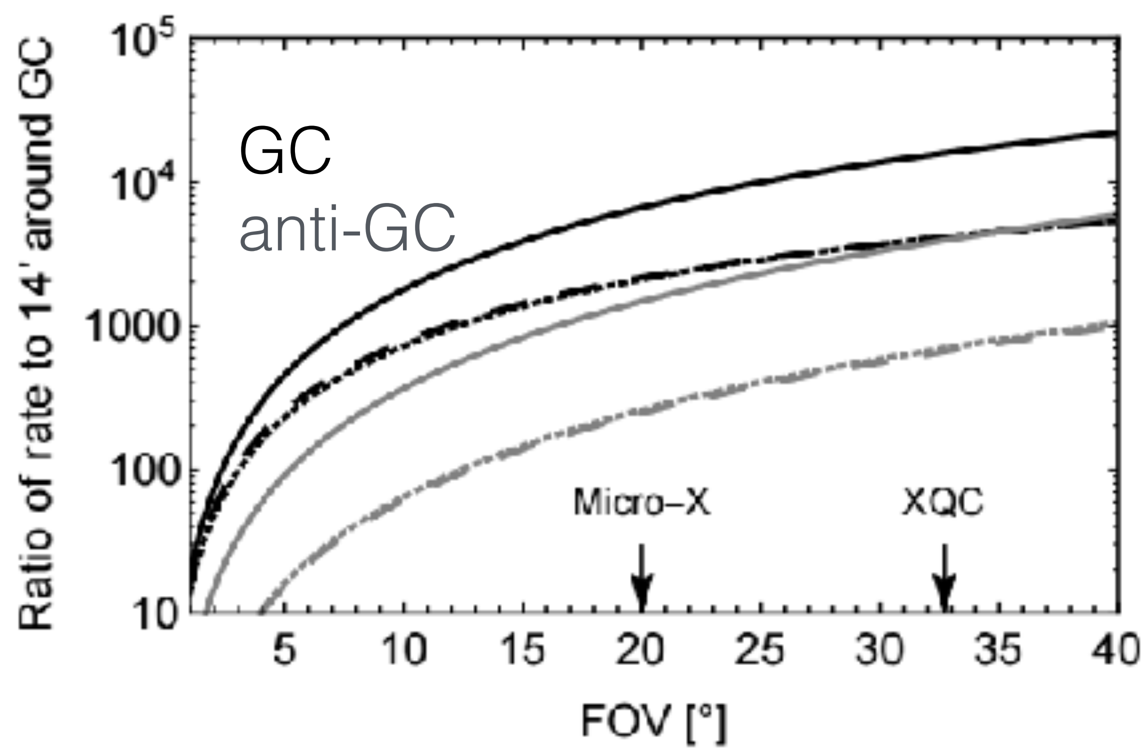
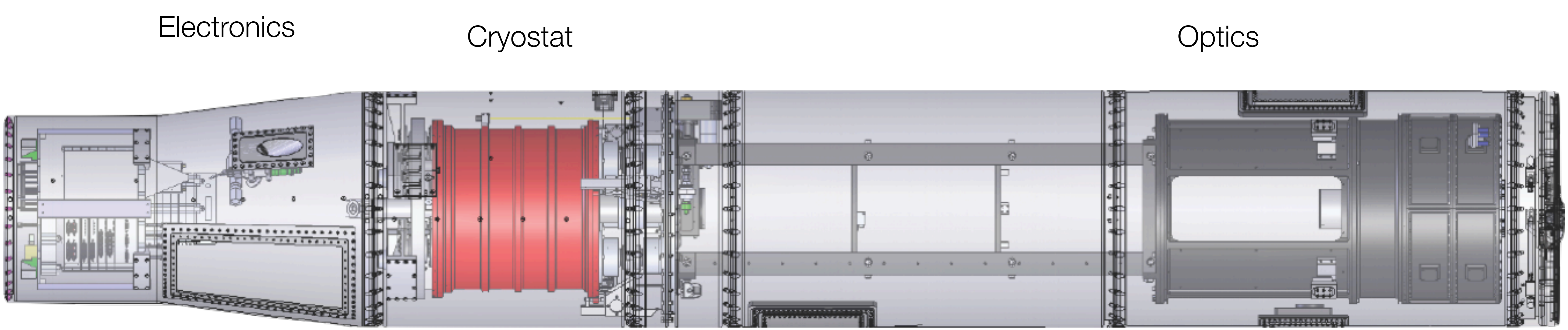
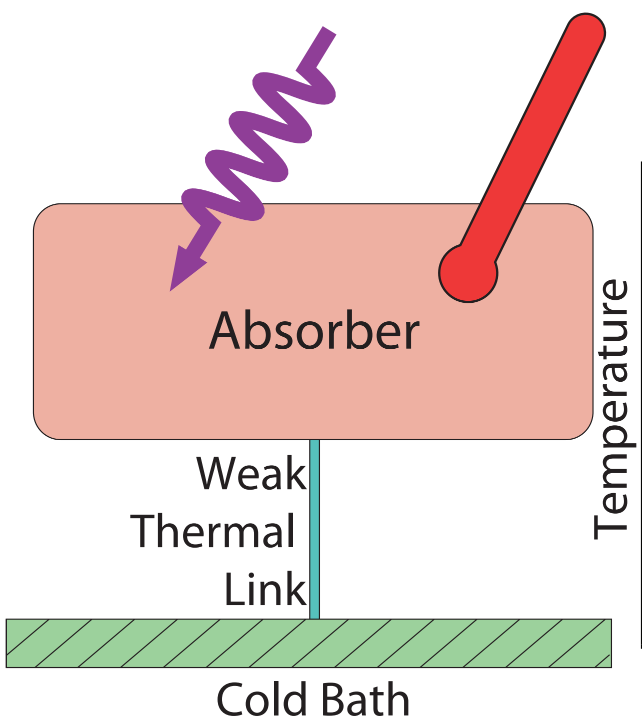
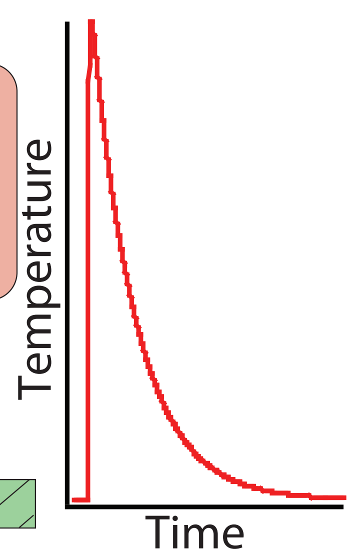


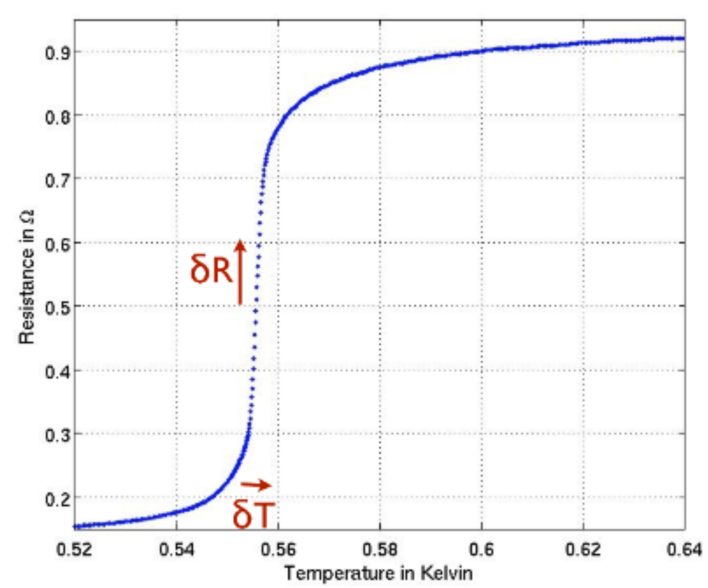


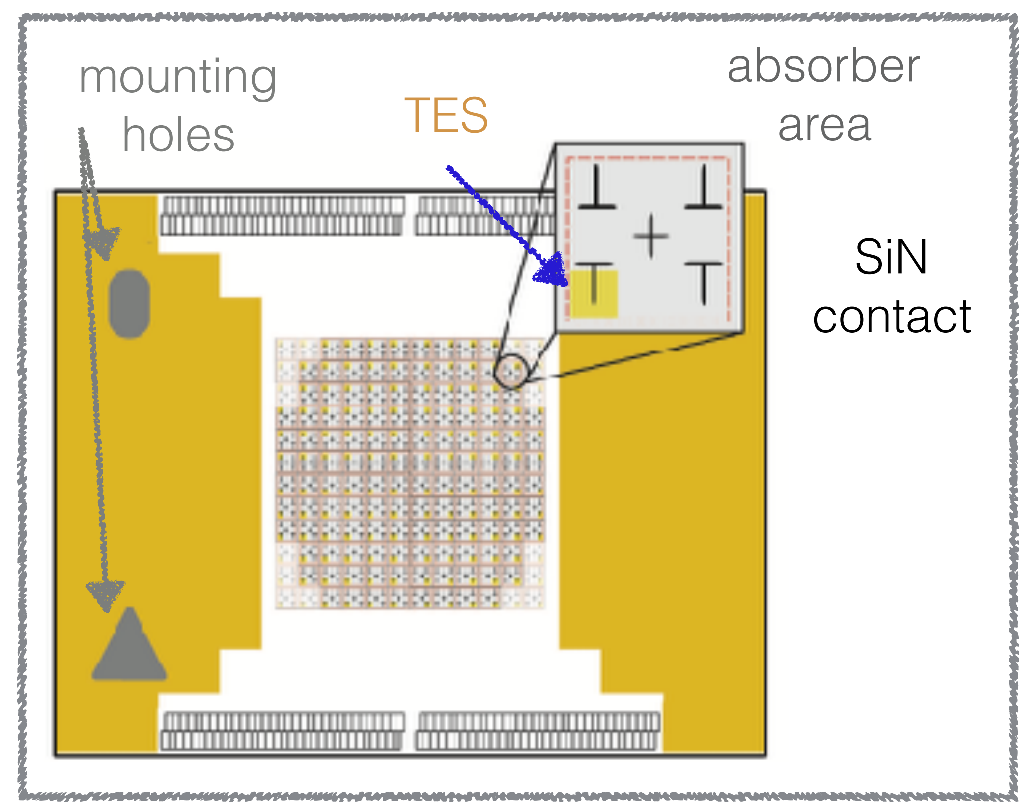
Micro-X Detector: TESs

- X-rays hit an absorber weakly connected to a cold bath and create a “pulse”
- TESs use a superconducting film biased into the transition to yield large resistance changes for small temperature changes
  - Demonstrated 2 eV (FWHM) resolution at 6 keV
- The Micro-X array: 128 590 μm x 590 μm pixels
  - Au/Bi absorbers with a Mo/Au TES



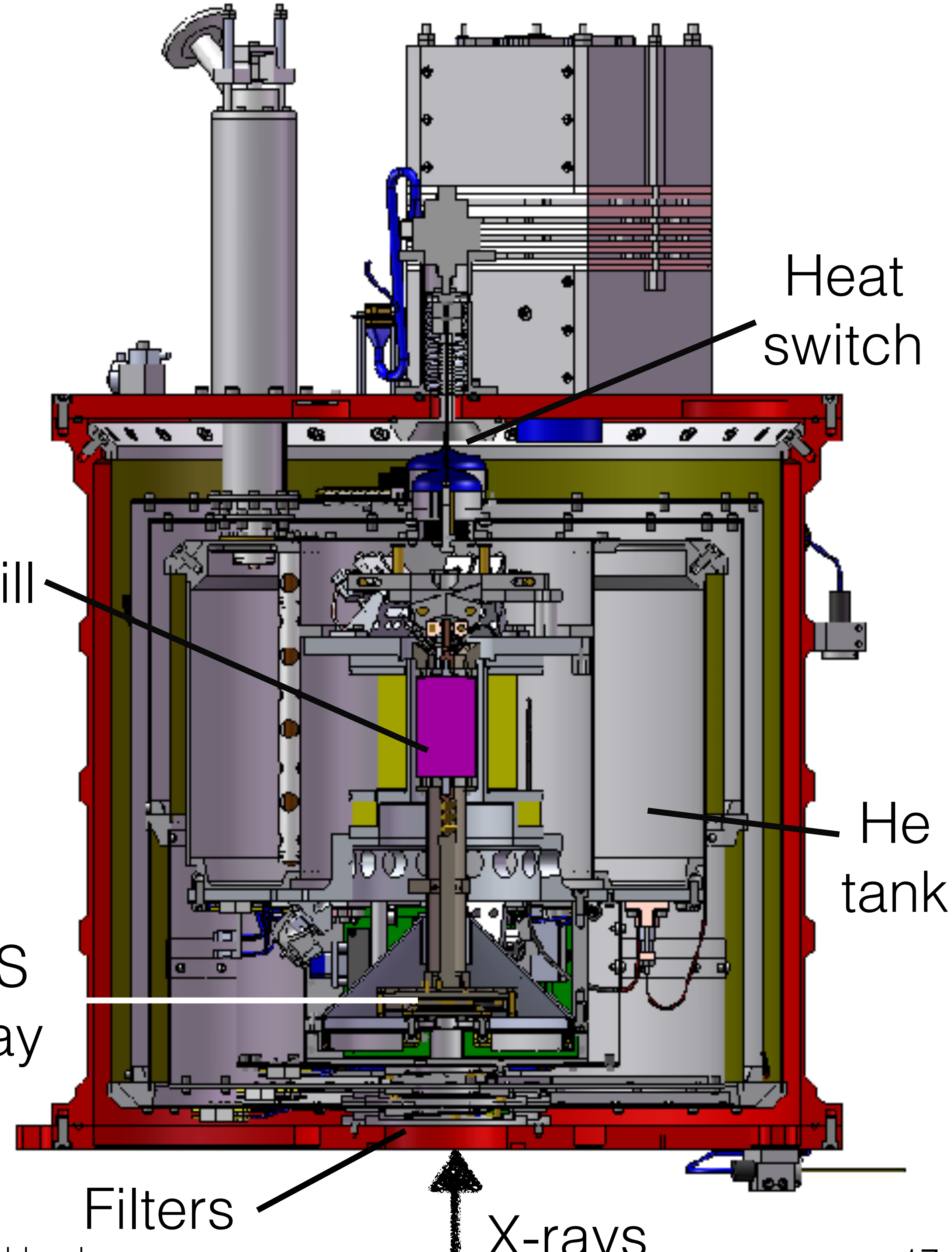






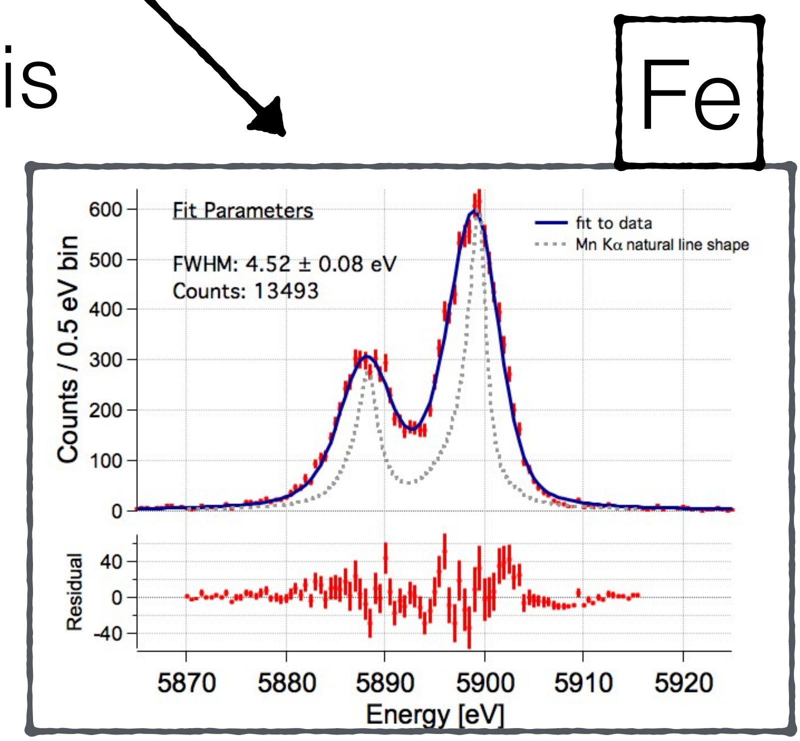
Micro-X Detector: Overview

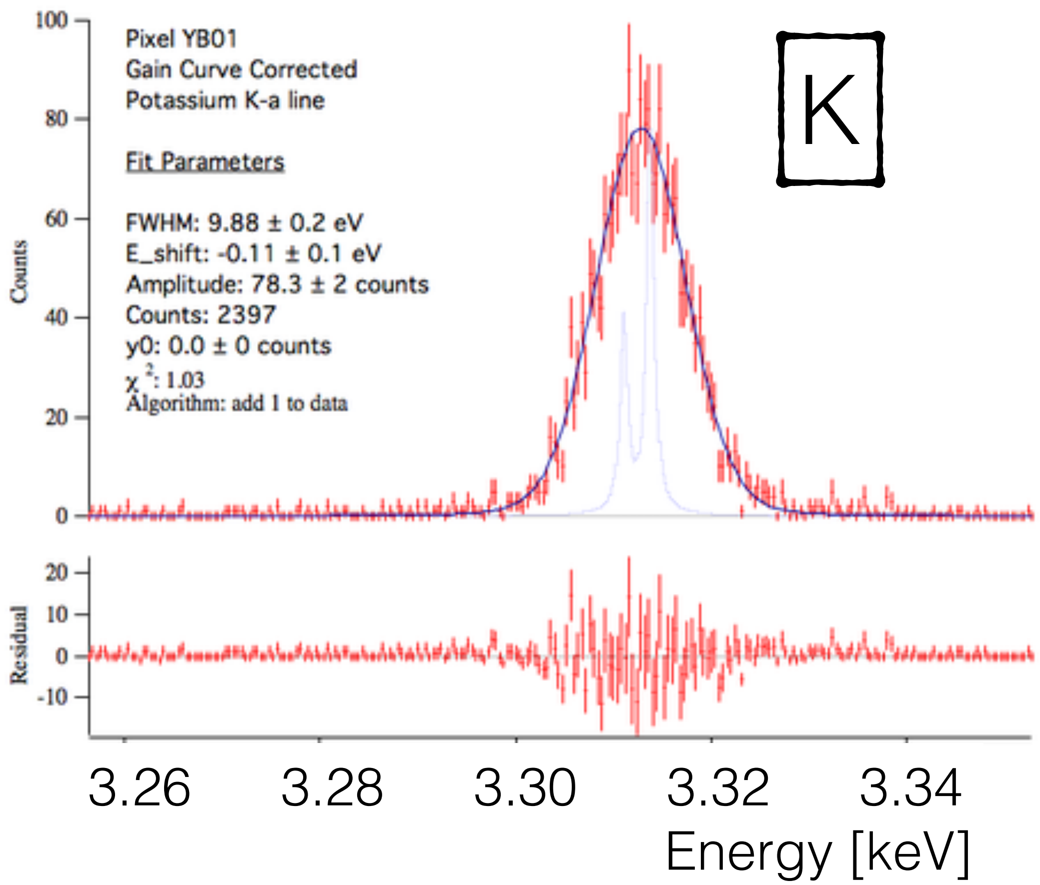
- X-rays enter the telescope through a gate valve
- 5 filters allow X-rays while blocking IR/optical photons
- Calibration source (KCl fluoresced by Fe-55) directly adjacent to detectors tracks changes
- 2 readout chains store data (16 GB) and transmit 30% in-flight (44 Mbit/s)

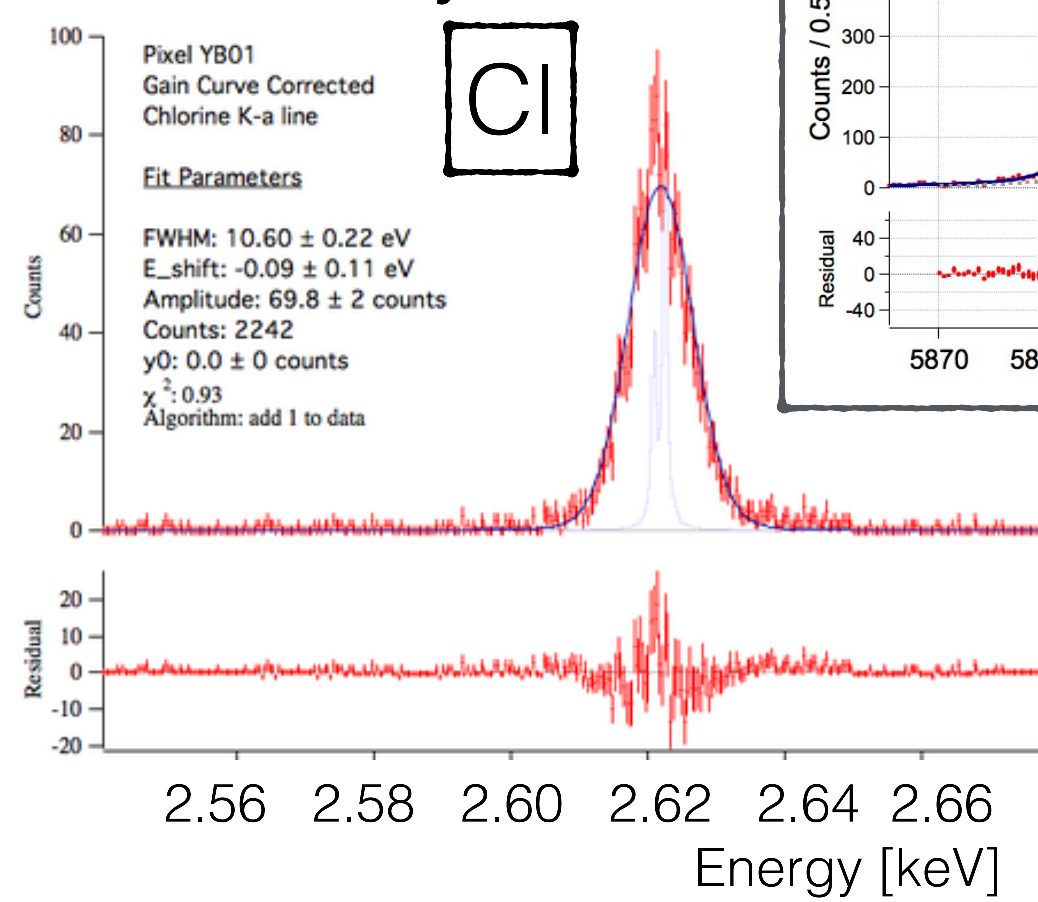


Micro-X Data: Resolution

- Best current resolution is 9.88 eV at 2.6 keV
    - These detectors hit 4.5 eV in lab setting
- Noise mitigation is underway to improve this
    - RF shielding, electronics stability

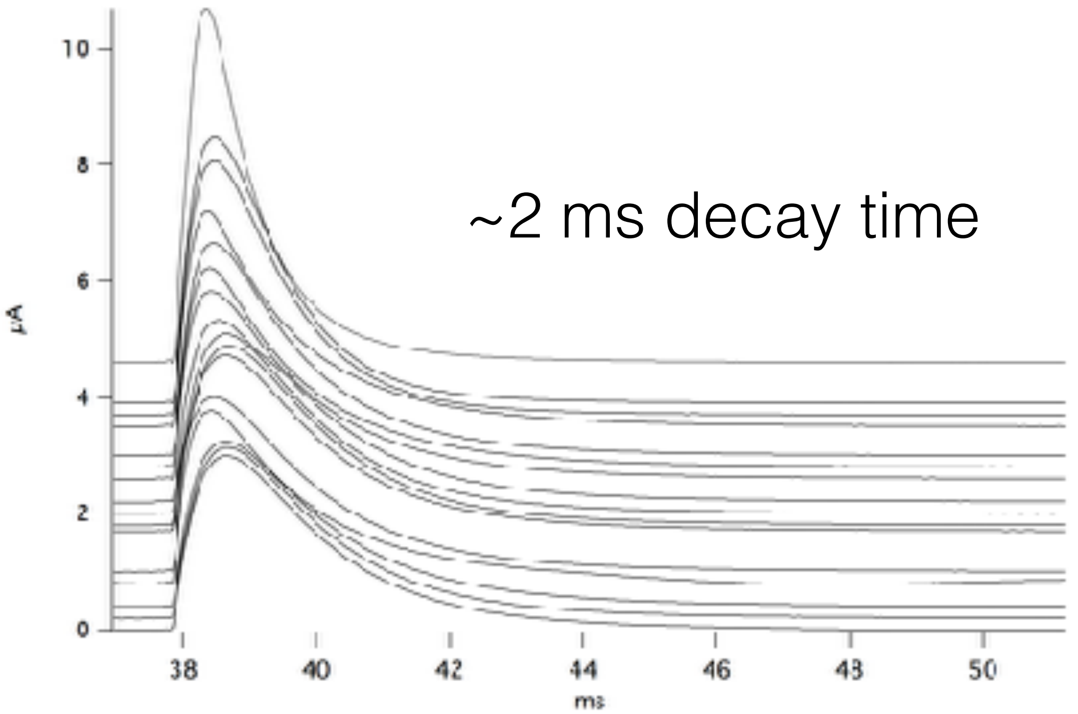


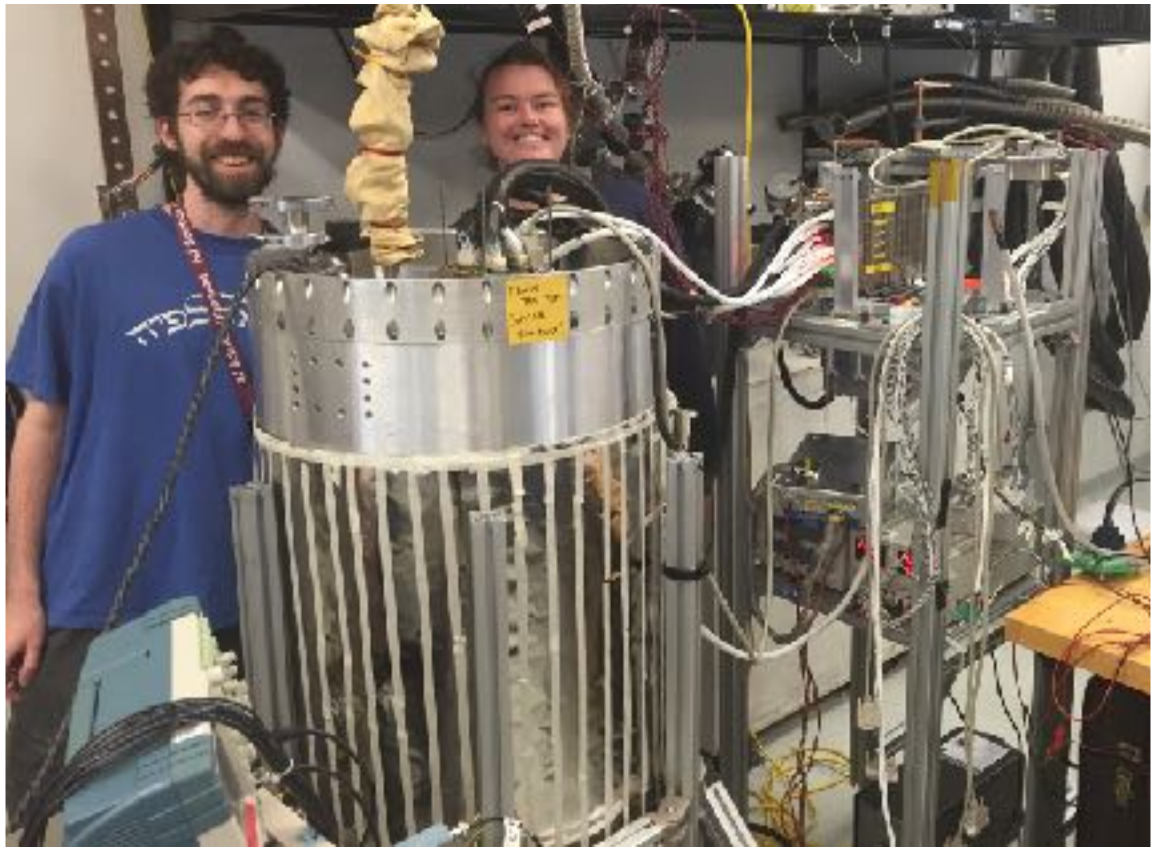




Micro-X Status

- Taking pulse data in flight configuration
  - Cryostat, calibration source, time-multiplexed SQUID readout, flight electronics, data readout
- Past 2 years: instrument has passed all functionality tests and improved mechanical, thermal, electrical performance
  - Vibration isolation: stay at 75 mK for 9 hours and can withstand 5 “launches”
  - Improved electronics noise
  - ADR flight controls (temperature, magnet)
- Current work: optimization (noise abatement) and integration
- **Launch expected February 2018**





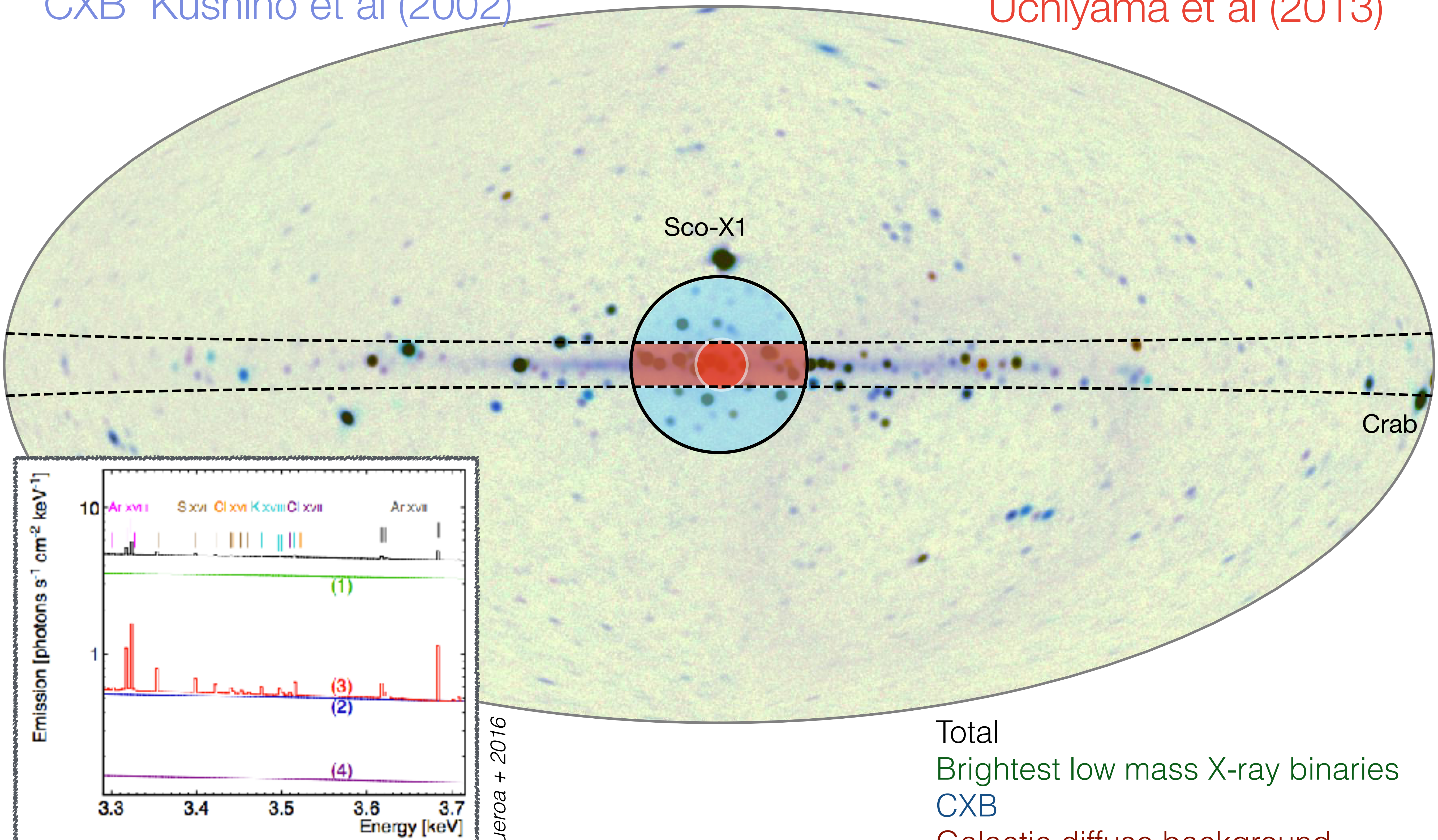
GC Backgrounds

LMXBs

CXB Kushino et al (2002)

Galactic Thermal Model

Uchiyama et al (2013)



Figueroa + 2016

Total

Brightest low mass X-ray binaries

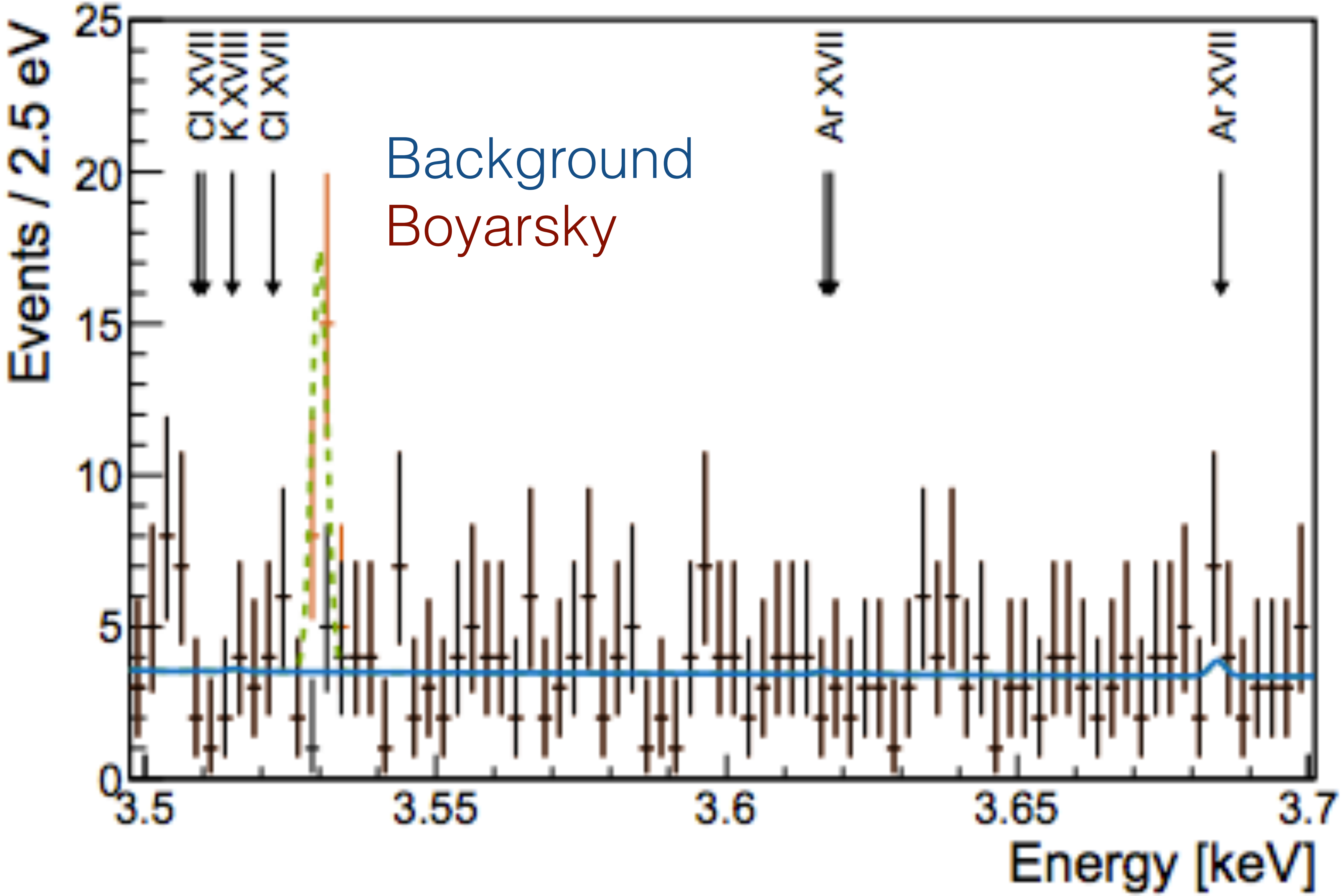
CXB

Galactic diffuse background

Ionized cold ISM neutral Fe

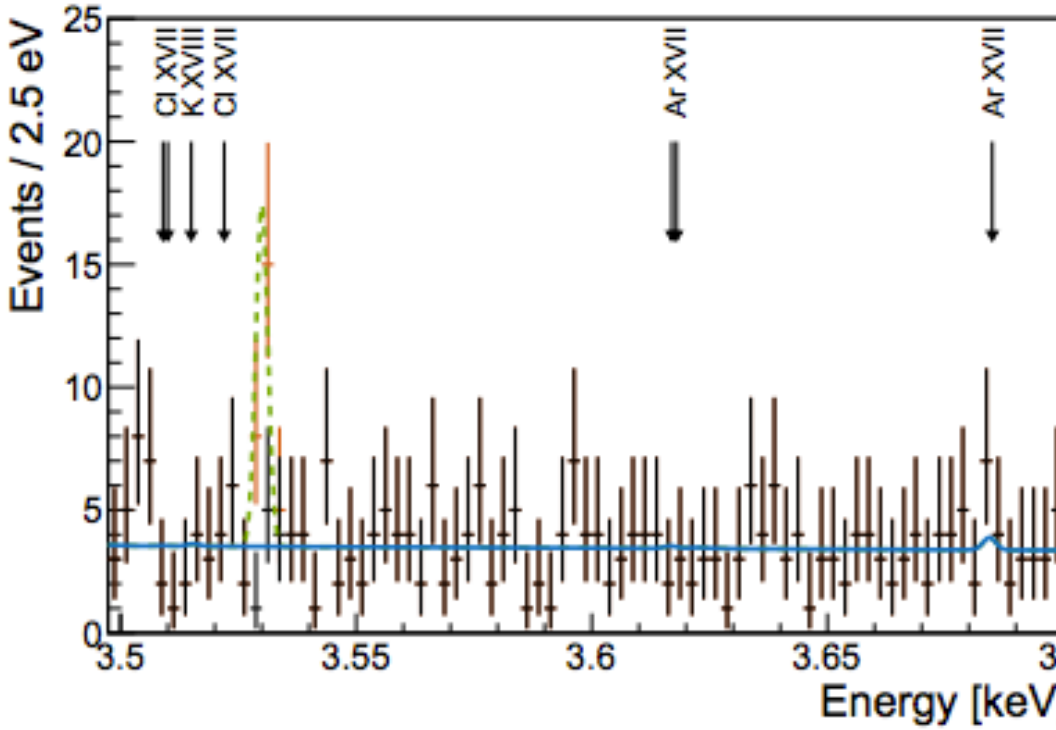
Micro-X Projected Spectrum

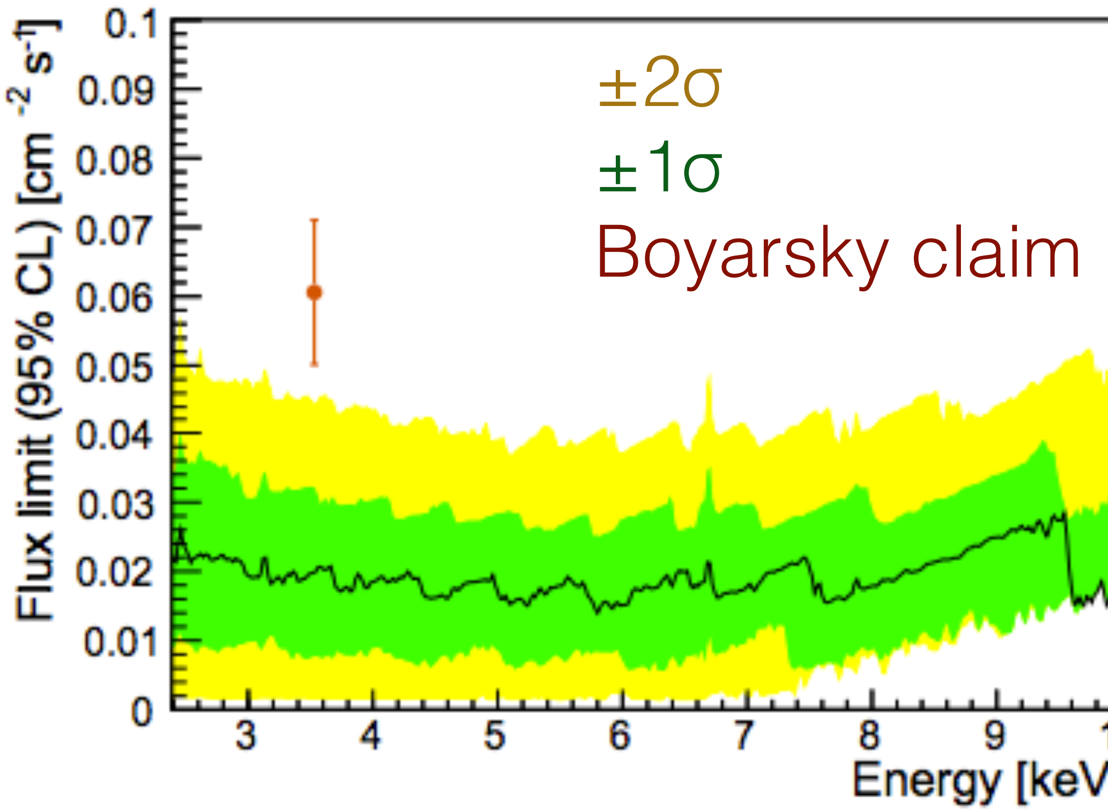
Figueroa+ 1506.05519



Sterile Analysis Modeling: Signal

- Projected 300s GC observation corresponds to 5.6σ significance
  - 18.2 total signal events
  - 3.4 background events in 2.5 eV (±1σE) bin
    - 4.5 cts/cm^2/s/keV at 3.5 keV
  - Boyarsky: 1.4 Ms with 7,500 signal and 500,000 background counts
- Strongest lines are from K XVIII and Cl XVII, with <1 event/ observation



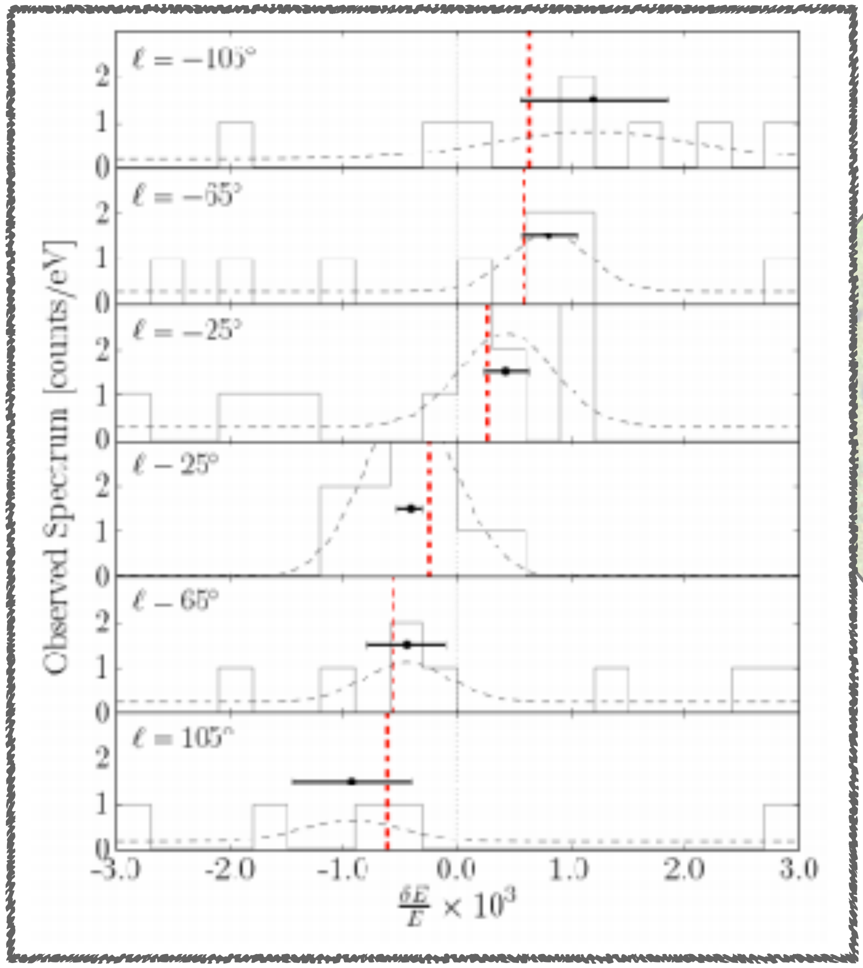


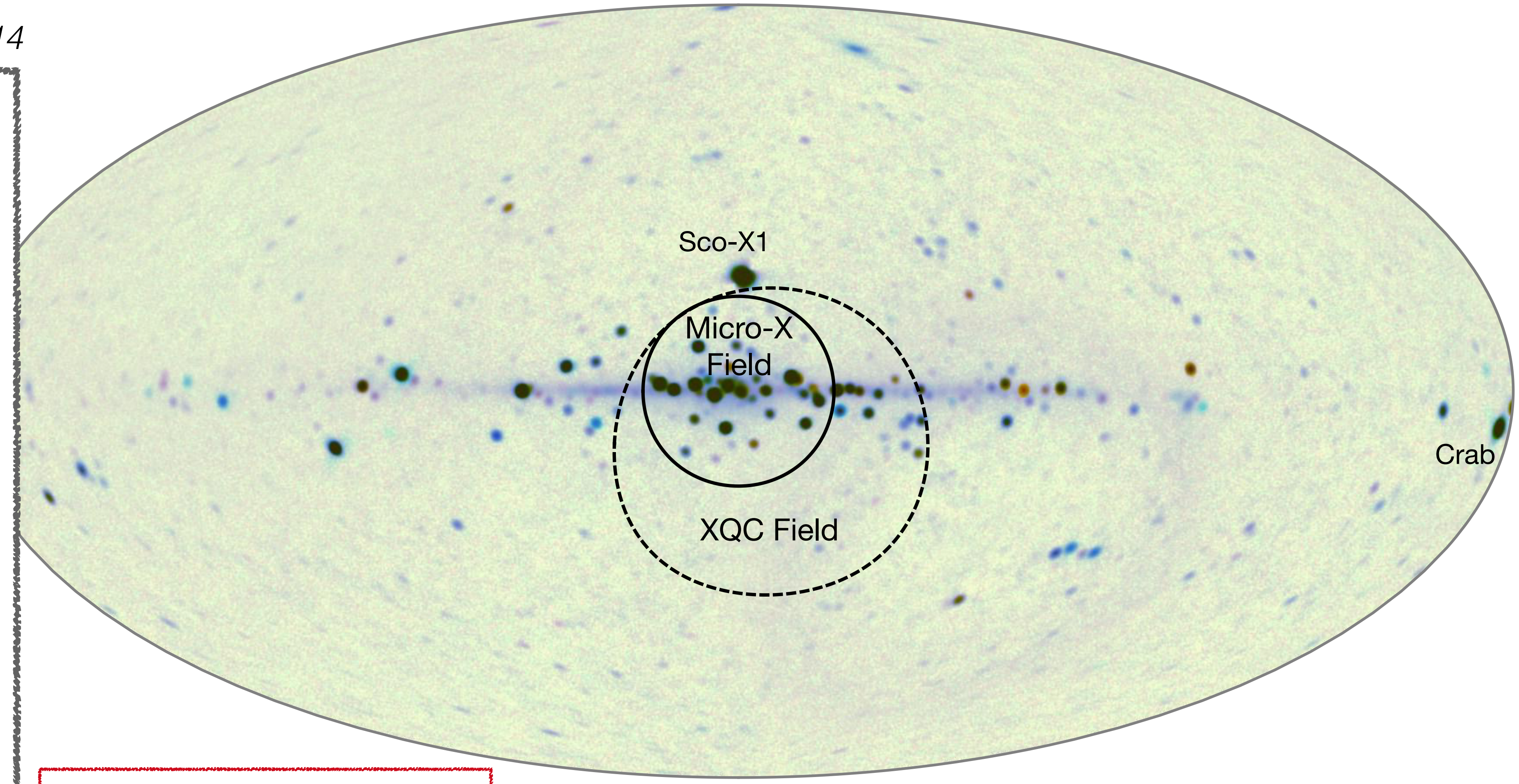
Figueroa+ 1506.05519

3.5 keV Morphology

- Back-to-back flights of XQC and Micro-X will allow profile measurements of a 3.5 keV observation
- The flux in the XQC's wider FOV compared to that in Micro-X observation will distinguish between a point-source or extended-source origin
- Multiple Micro-X flights will allow Doppler mapping of an observed line

Powell+ 1611.02714





Ranjan Laha's talk

Conclusions

- Large FOV sounding rocket micro-calorimeters have unique sensitivity to X-ray signatures from dark matter interactions
    - Open up new sensitivity beyond what we can do with current satellites!
- These flights are photon-starved, so more flights = higher sensitivity
- First flight (SNRs) in February 2018, and sterile neutrino flight from Australia in 2019

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