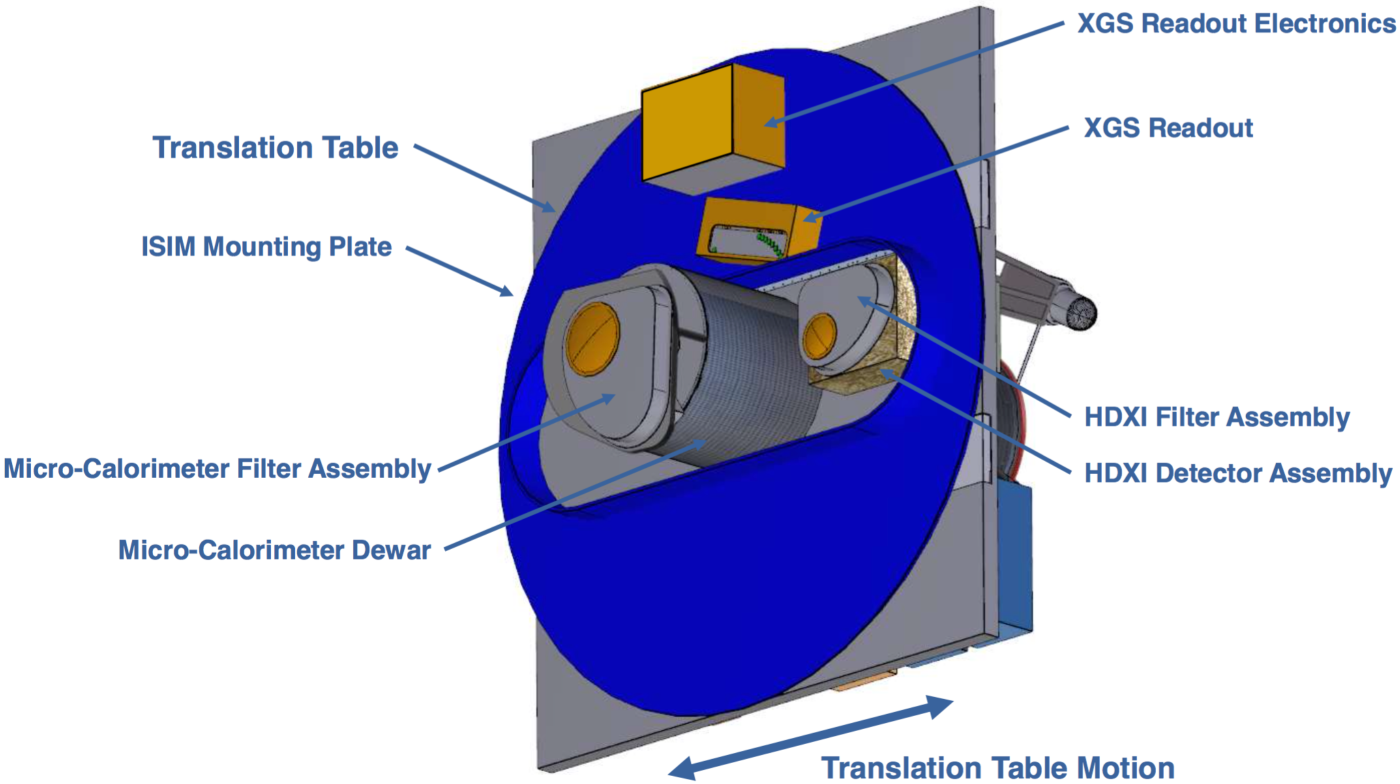
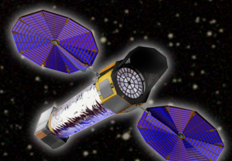
Lynx Science Instruments



Mark Bautz on behalf of
the Lynx Instrument Working Group

March 20, 2018

Figure credit: MSFC ACO



Thanks to:

Lynx IWG Leadership:

Randy McEntaffer (PSU)
Ralf Heilmann (MIT)
X-ray Grating Spectrometer

Ralph Kraft (SAO)
Abe Falcone (PSU)
High-Definition X-ray Imager

Simon Bandler (GSFC)
Tali Figueroa (Northwestern)
Lynx X-ray Micro-calorimeter

MSFC Advanced Concepts Office:

Jessica Gaskin, Doug Swartz, Karen Gelmis, Jack Mulqueen, Alexandra Dominguez & ACO team

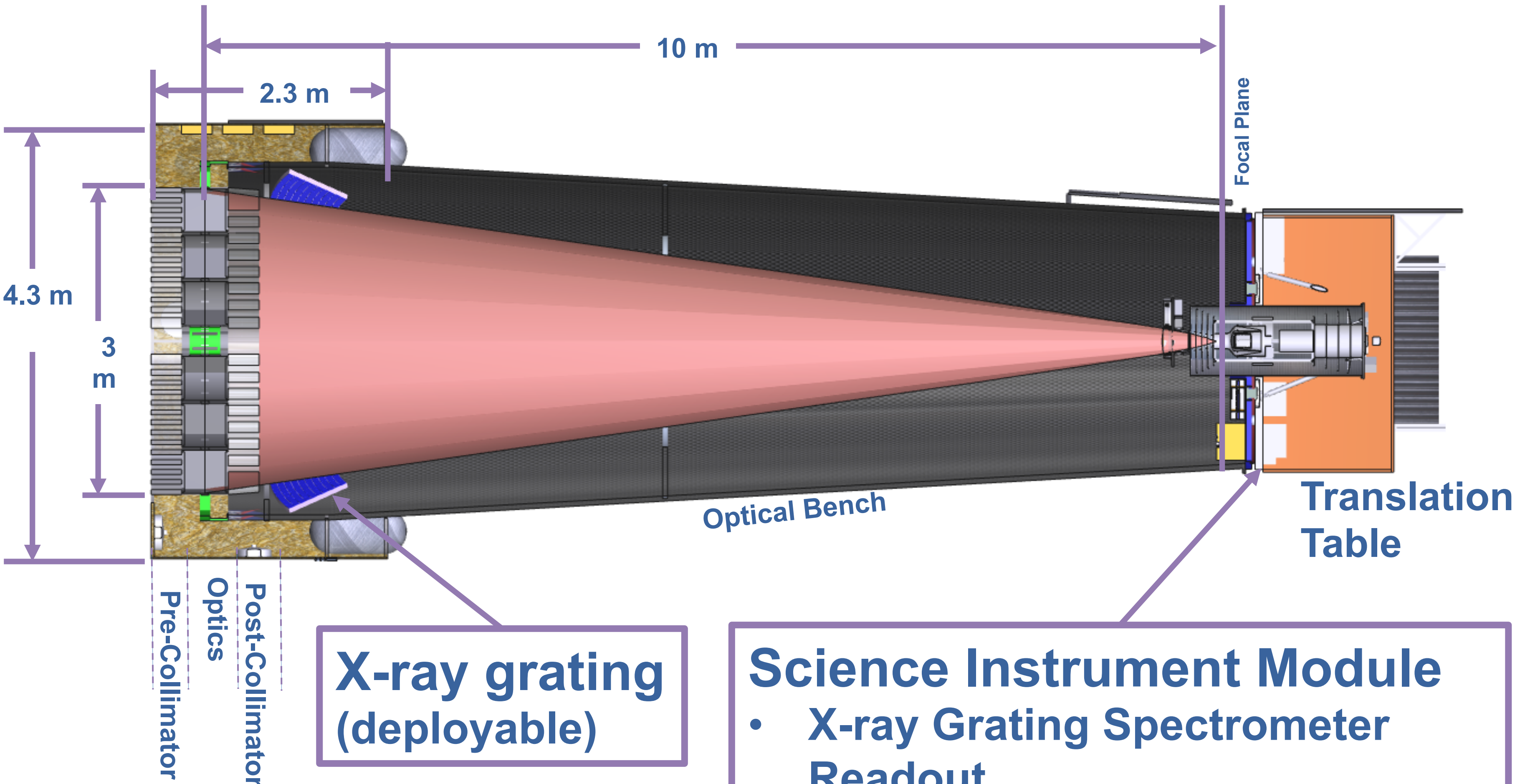
GSFC Instrument Design Laboratory:

Rob Petre, Tammy Brown & the IDL team

Overview

- The Lynx Instrument Complement
- Instrument requirements & specifications
- Instrument Technology Development

Lynx Configuration



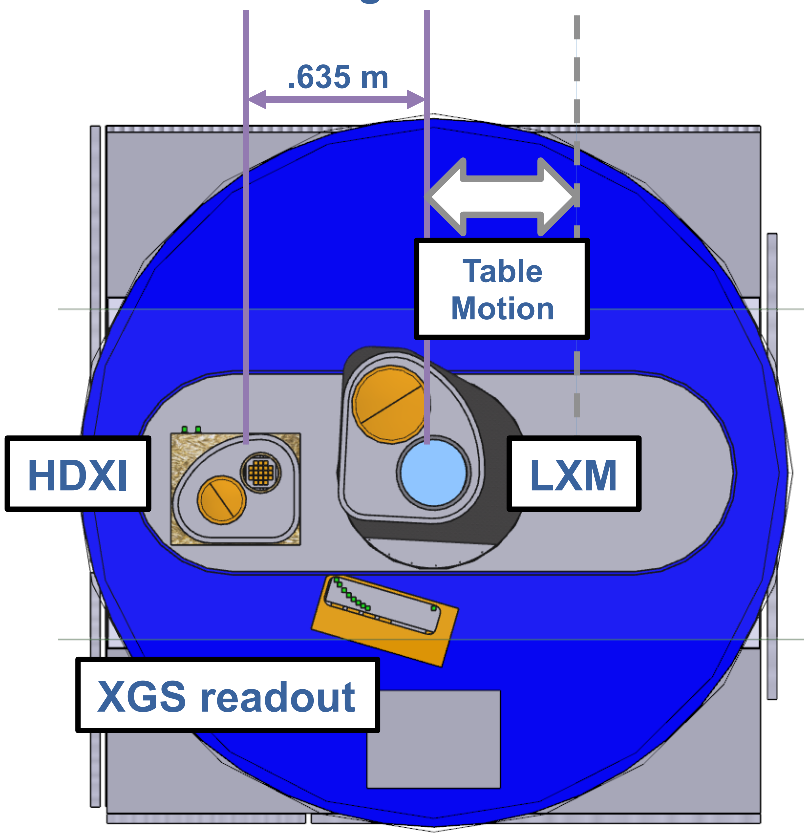
X-ray grating (deployable)

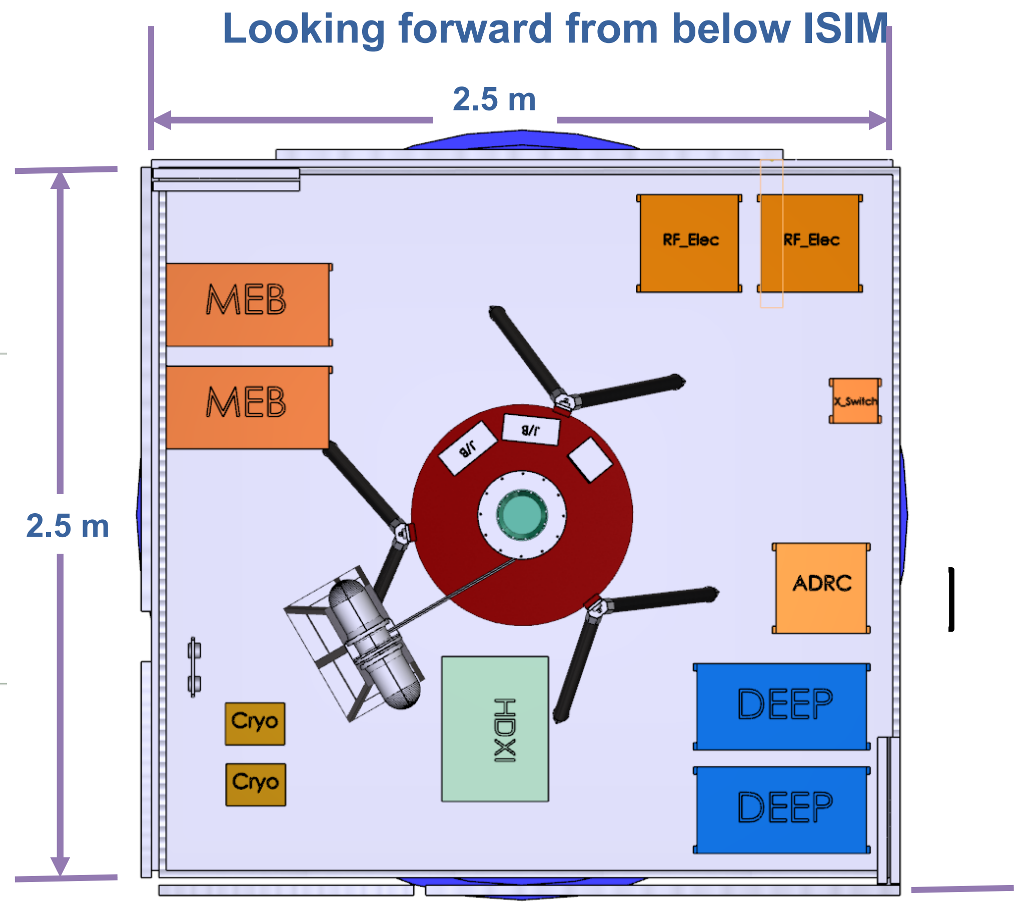
Science Instrument Module

- X-ray Grating Spectrometer Readout
- High-Definition X-ray Imager
- Lynx X-ray Micro-calorimeter

Credit: MSFC ACO

Science Instrument Accommodation





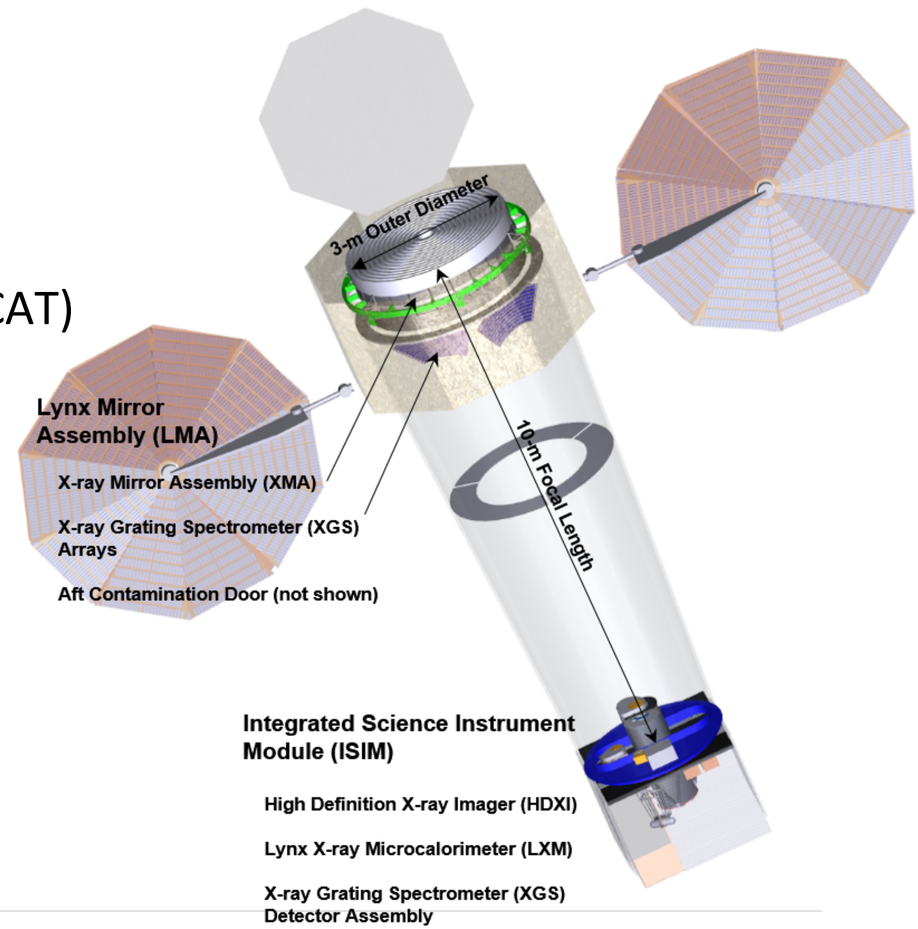
Credit: MSFC ACO

- Translation table (gray) positions either LXM or HDXI at focus
- XGS readout mounted on stationary bench (blue)
- 4 observing configurations: (HDXI or LXM) x (w/ or w/o grating in beam)

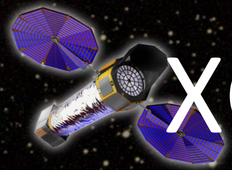
Lynx X-ray Grating Spectrometer (XGS)

- Grating Array mounted just aft of the X-ray Mirror Assembly
  - Actuated in/out of optical path
  - Two viable grating technologies :
    Off-plane reflection gratings (OPG)
    Critical-angle transmission gratings (CAT)

- Key science
  - Absorption spectroscopy of AGN
    - Distribution of hot baryons
      - WHIM
      - Galactic halos
    - Galactic feedback
  - Stellar spectroscopy



Credit: MSFC ACO

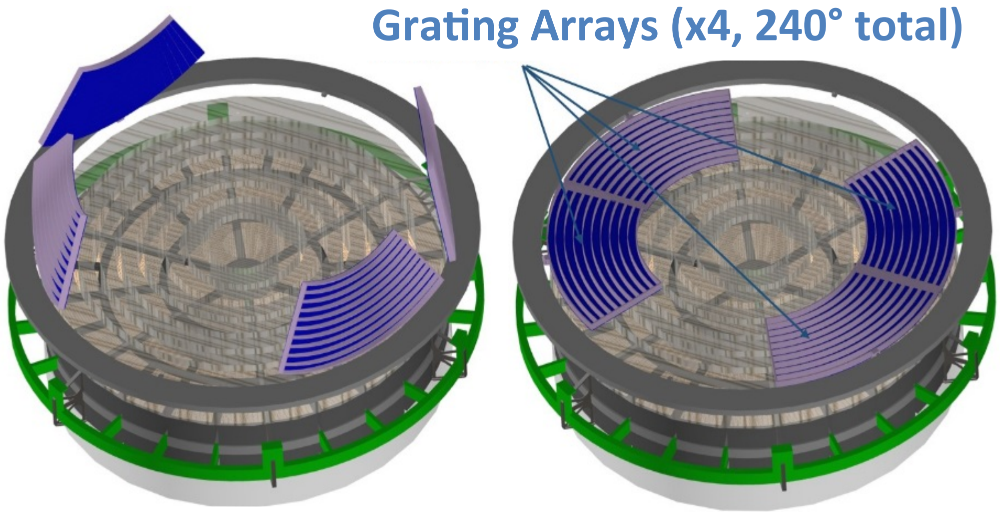


XGS performance requirements

XGS System	Requirement	Science Drivers
Energy range	0.2 – 2.0 keV	Cover K-shell transitions of key elements from C to Si, plus Fe L-shell
Effective area	4000 cm^2 @ 600 eV	Absorption line spectroscopy of OVII/ OVIII lines
Spectral resolving power	5000 @ 600 eV	Resolve thermal width in nearby galaxy halos; Stellar spectroscopy
Line spread function width	1 arcsec	Spectral resolving power
XGS Readout		
Pixel size	16 µm x 16 µm	Spectral resolving power
Noise	$< 4\ e^-$	Low-energy QE
Energy resolution	80 eV @ 277 eV	Order separation

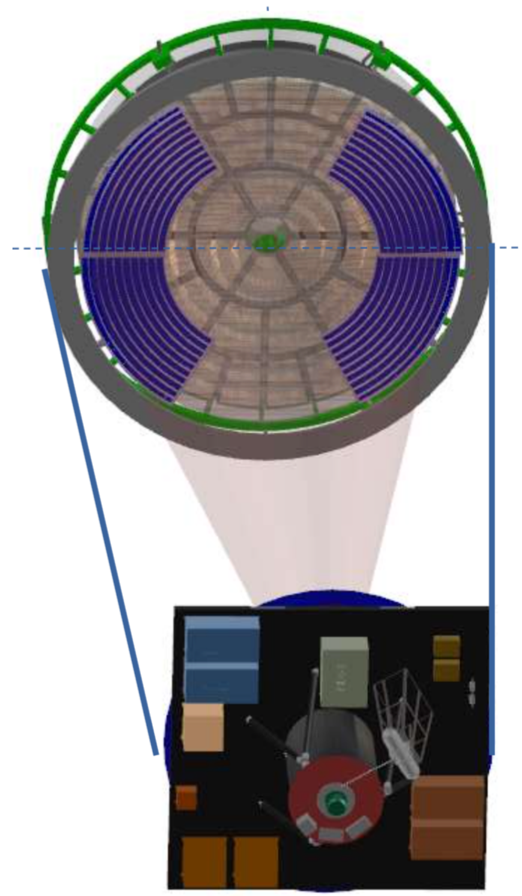
XGS Configuration

Credit: MSFC ACO



Gratings Retracted

Gratings Inserted



View from aft, gratings inserted

Resources w/ margin	XGS-OPG	XGS-CAT
XGS Power (W)	**117**	**165**
XGS Mass (kg)	**181**	**120**
Grating Arrays	115	49
Readout	66	71

XGS Technology Development

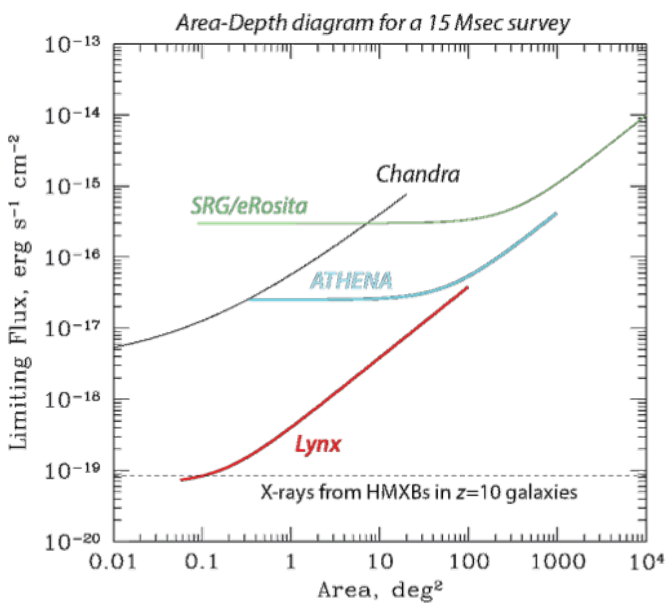
- Critical technology is high-efficiency, high-resolution X-ray grating array
- Two viable technologies (OPG and CAT) both judged TRL 4 by NASA/PCOS (2017 Program Annual Technology Report)
- Technology maturation path includes assembly and alignment of multiple individual grating facets into brassboard 'arrays' and demonstration of expected performance
- Required developments include
  - Improved grating facet fabrication to ensure period uniformity, adequate diffraction efficiency and resolution
  - Advanced alignment and metrology techniques
  - Assessments of resource requirements of each grating technology, including diffraction efficiency, alignment tolerances, thermal control requirements and readout system complexity

High-Definition X-ray Imager (HDXI)

See Kraft et al. poster

Lynx Science Pillars

- *The Dawn of Black Holes*
- *The Invisible Drivers of Galaxy Formation and Evolution*
- The Energetic Side of Stellar Evolution and Stellar Ecosystems

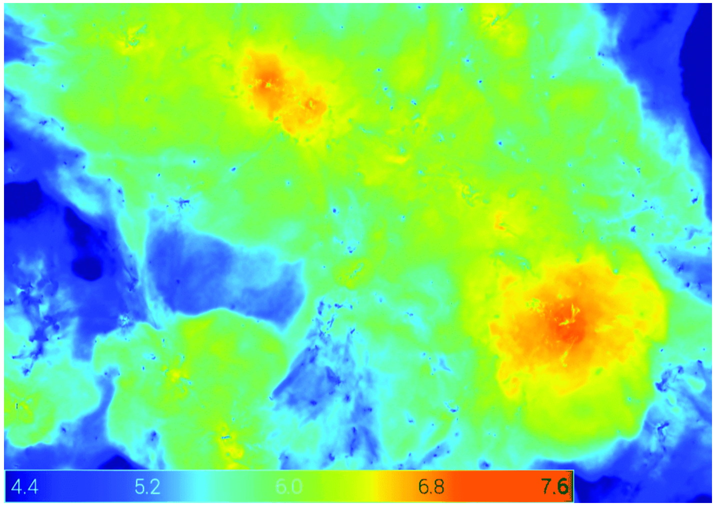


Sensitivity of deep Survey with Lynx HDXI

Lynx High-Definition X-ray Imager

Large area focal plane of advanced silicon sensors

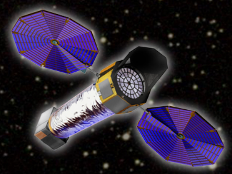
- 21 sensors with 22'x22' FOV
- 16 μm/0.3" pixels to oversample PSF
- Curved focal plane to match Rowland circle – better than 1" imaging over 300 arcmin^2
- High frame rate and low read noise to maximize low energy (<0.5 keV) QE



Gas Temperature of Merging Galaxies in IllustrisTNG simulation

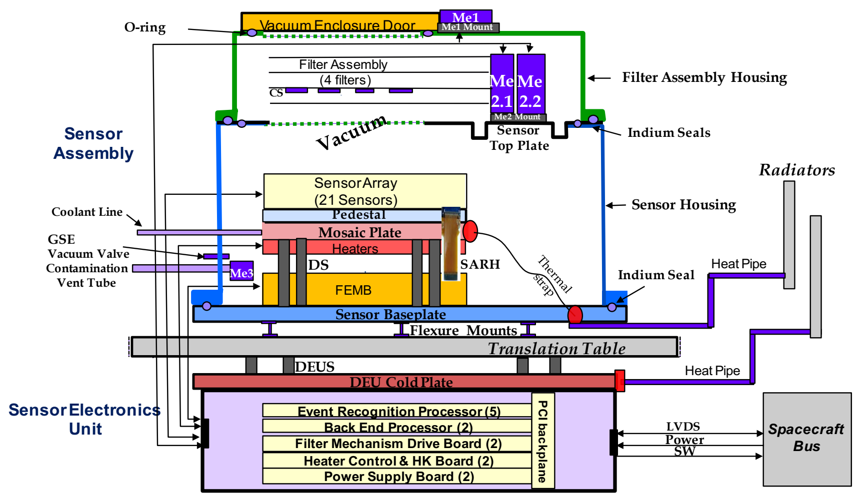
Key HDXI Requirements

HDXI Parameter	Requirement	Science Drivers	Notes
Energy Range	0.3 – 10 keV	Sensitivity to high-z sources	
Field of view	22 x 22 arcmin	Deep Survey efficiency R_{200} for nearby galaxies	
Pixel size	16 x 16 μm	Pt. source sensitivity Resolve AGN from group emission	
Read noise	$\leq 4\ e^-$	Low-energy detection efficiency	Derived
Energy Resolution (FWHM)	~70 eV @ 300 eV	Low-energy detection efficiency	
Full-field count-rate capability	8000 ct s^{-1}	No dead time for bright diffuse sources (e.g. Perseus or Cas A)	
Frame Rate Full-field Window mode (20"x20")	 > 100 frames s^{-1} > 10000 windows s^{-1}	Maximize low-energy throughput Minimize background	Derived



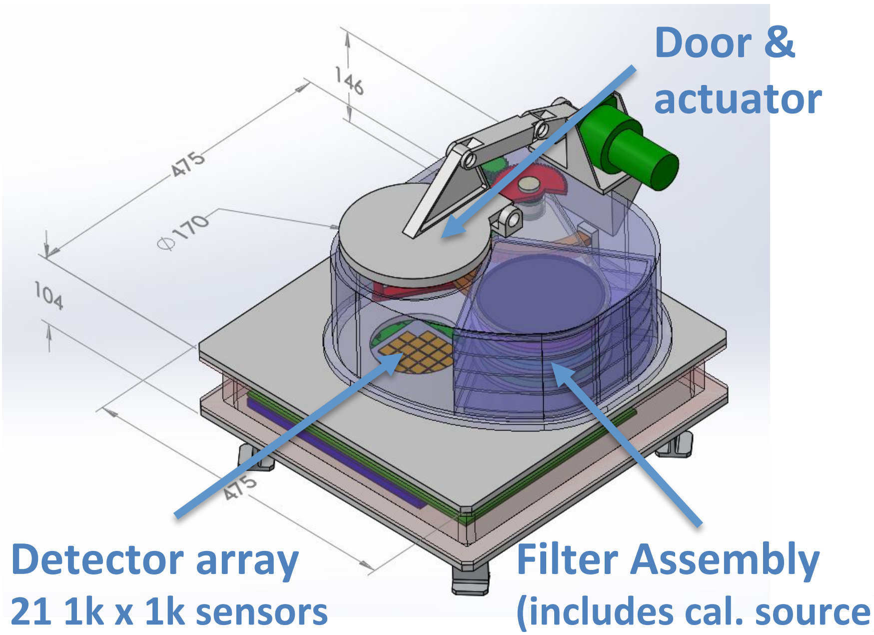
HDXI Configuration

Block Diagram



Resources	
Power (W)	**175**
Mass (kg)	**48**
Detector Assy	36
Electronics	12

Detector Housing Concept

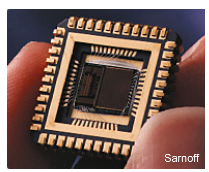


Credit: GSFC IDL

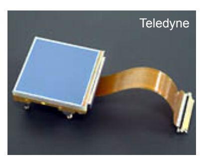
HDXI Technology Development

Primary technology development required for HDXI is sensor technology. Three technologies currently being developed – each meets some of the requirements but none presently meet all.

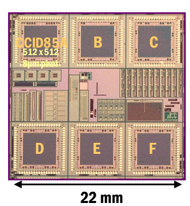
- Monolithic CMOS Active Pixel Sensor
  - Single Si wafer used for both photon detection and read out electronics
  - Sarnoff/SAO



- Hybrid CMOS Active Pixel Sensor
  - Multiple bonded layers, with detection layer optimized for photon detection and readout circuitry layer optimized independently
  - Teledyne/PSU



- Digital CCD with CMOS readout
  - CCD Si sensor with multiple parallel readout ports and digitization on-chip
  - LL/MIT

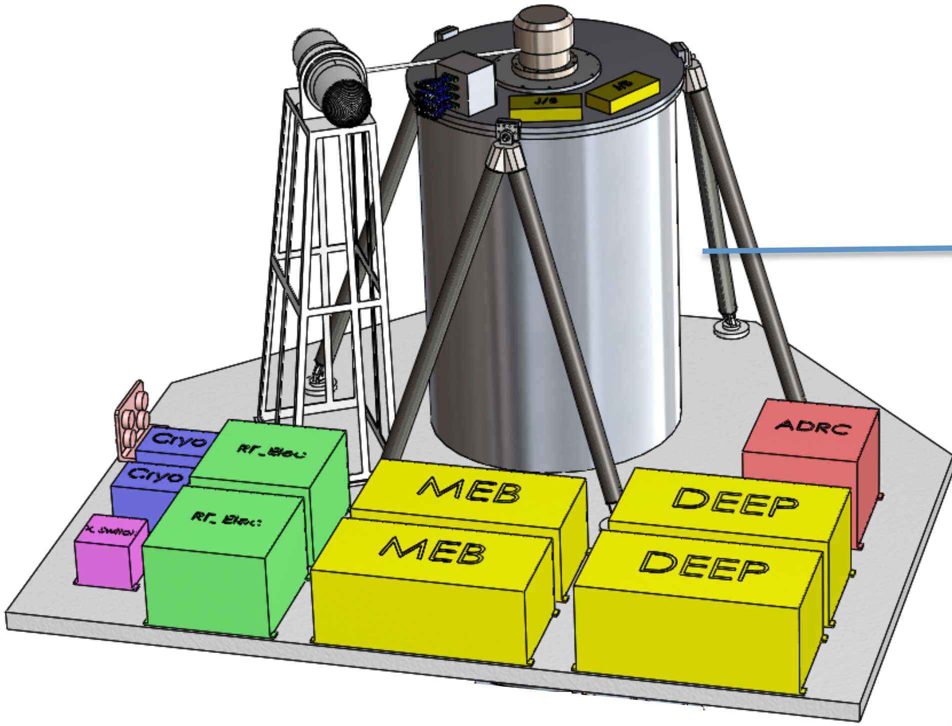


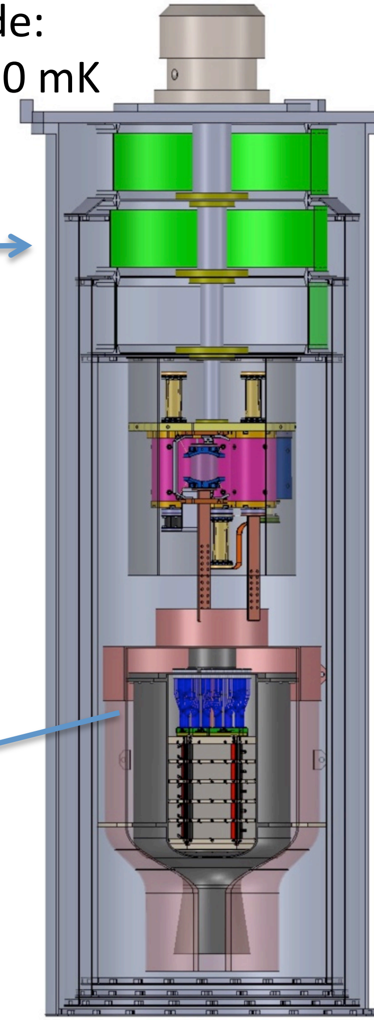
Additional technical and engineering development required in three areas:

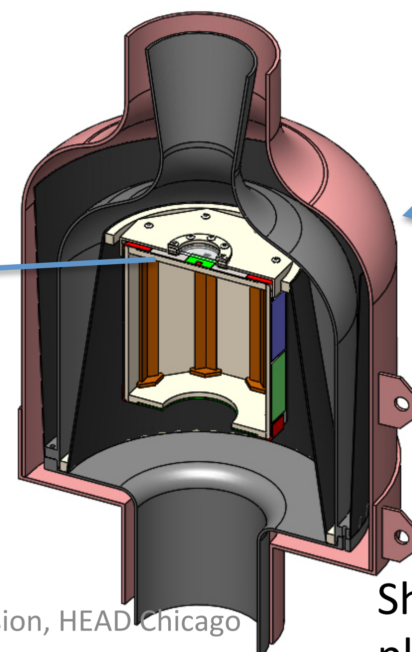
- Driver ASICs
  - Depending on sensor technology chosen for flight, a custom ASIC may need to be developed to clock sensors
- FPGA/Event Recognition processors
  - Event recognition will be done in radiation tolerant FPGAs with sufficient processing power to keep up with large (>2 Gpix s-1) data rate from sensors. Requires development of flight firmware and software
- Optical blocking filters
  - Large area, thin unsupported optical blocking filters (Al on polyimide) need to demonstrate sufficient mechanical and thermal stability

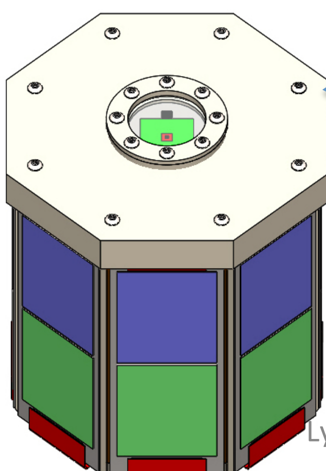
Lynx X-ray Microcalorimeter (LXM)

What's inside:
Cooling to 50 mK







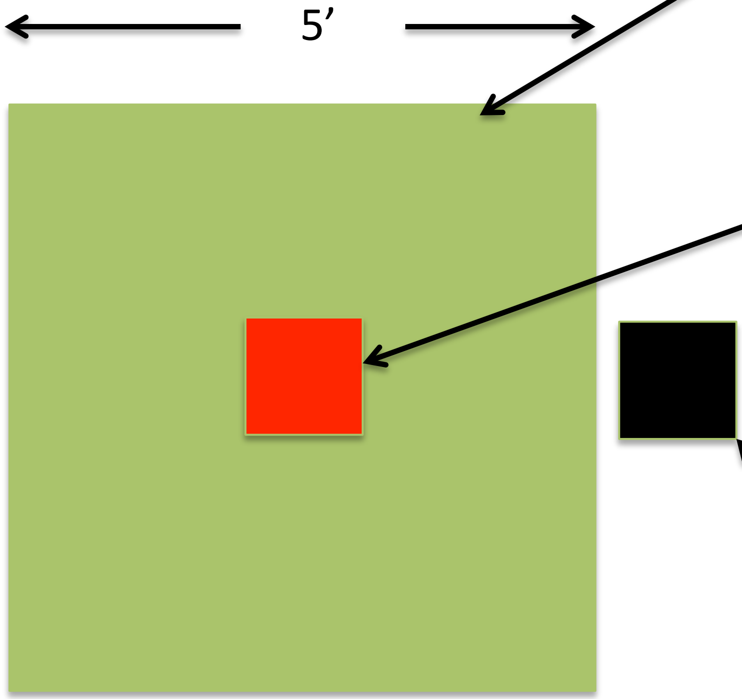


Microcalorimeter array, read out using multiplexed microwave SQUID resonators.

Shielded focal plane assembly

Credits: MSFC ACO GSFC/Bandler/IDL

LXM Array Layout



Main Array
- **1” pixels, 5’ FOV,** 50 µm pixels
- **ΔE = 3 eV**
- Up to 7 keV
- 86,400 pixels

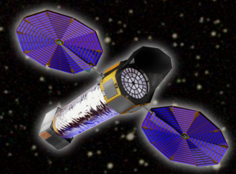
Will study metallicity in galaxy clusters to z=3 as a probe of galaxy formation processes near the peak of cosmic star formation

Enhanced Main Array:
- **0.5” pixels, 1’ FOV,** 25 µm pixels
- **ΔE = 1.5 eV**
- Up to 7 keV
- 12,800 pixels

Will study plasma physics effects related to dissipation of energy from active galactic nucleus (AGN) outflows.

Ultra-Hi-Res Array
- **1” pixels, 1’ FOV,** 50 µm pixels
- **ΔE = 0.3 eV**
- **Up to 0.8 keV**
- 3,600 pixels

Will spatially and spectrally resolve starburst-driven winds in low-redshift galaxies

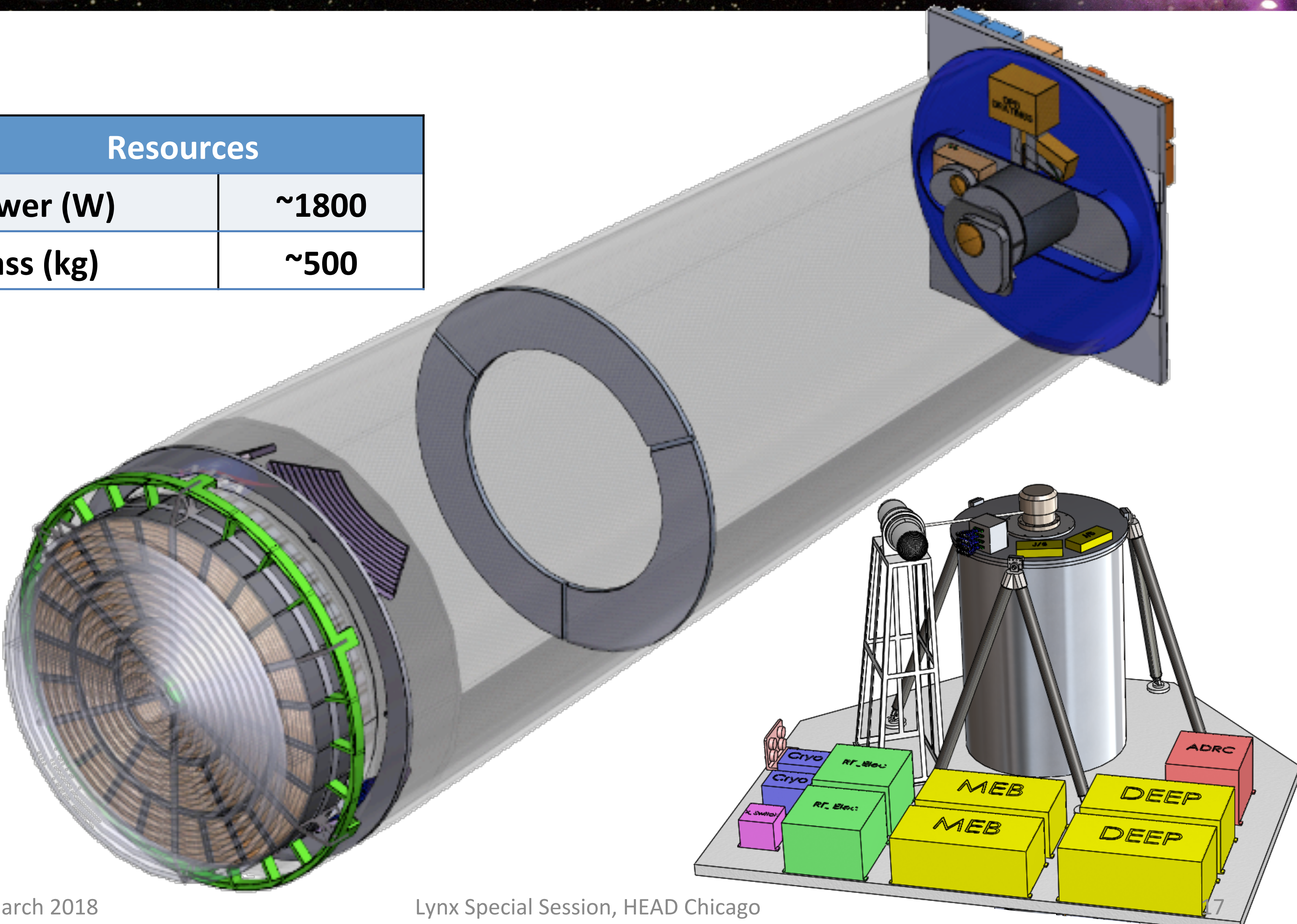


Key LXM Requirements

Main Array	Requirement	Science Drivers
Energy Range	0.2 - 7 keV for 3 eV	Low temperature thermal emission or low energy non-thermal sources
Field of view	5 arcmins x 5 arcmins	SNR, galaxies and clusters of galaxies for high-res imagining and spectroscopy
Pixel size	1 arcsec x 1 arcsec	Arcsec scale features in shocks and filaments, and point sources in crowded regions (XRBs and stars)
Energy Resolution	3 eV (FWHM) (high-res mode) 5 eV (FWHM) (mid-res mode) 10 eV (FWHM) (low-res mode)	Energetics and dynamics of plasmas
Enhanced Main Array		
Energy Range	0.2 - 7 keV for 3 eV	Low temperature thermal emission or low energy non-thermal sources
Field of View	1 arcmin x 1 arcmin	Jets, centers of galaxies, and cores of clusters of galaxies
Pixel Size	0.5 arcsec x 0.5 arcsec	Sub-arcsec features in shocks and filaments, and point sources in crowded regions (XRBs and stars); Study of distribution of AGN within and around groups/clusters; removing AGN; study of thermodynamic properties of cluster gas; feedback in groups and clusters
Energy Resolution	1.5-2.0 eV (FWHM) (high-res mode) 4 eV (FWHM) (mid-res mode) 10 eV (FWHM) (low-res mode)	Energetics and dynamics of plasmas, SMBH growth and AGN feedback at peak
Ultra High-Res. Array		
Energy Range	0.2 - 0.75 keV	Faint diffuse baryons in emission, such as in galactic halos.
Field of View	1 arcmin x 1 arcmin	Sample hot gas around galaxy halos
Pixel size	1 arcsec x 1 arcsec	Arc-second scale features in shocks and filaments, and point sources in crowded regions (XRBs and stars)
Energy Resolution	0.3-0.4 eV (FWHM) (high-res mode) 0.75 eV (FWHM) (mid-res mode) 2.0 eV (FWHM) (low-res mode)	Velocities/turbulent broadening down to ~50 km/s (outflows and thermal velocities)

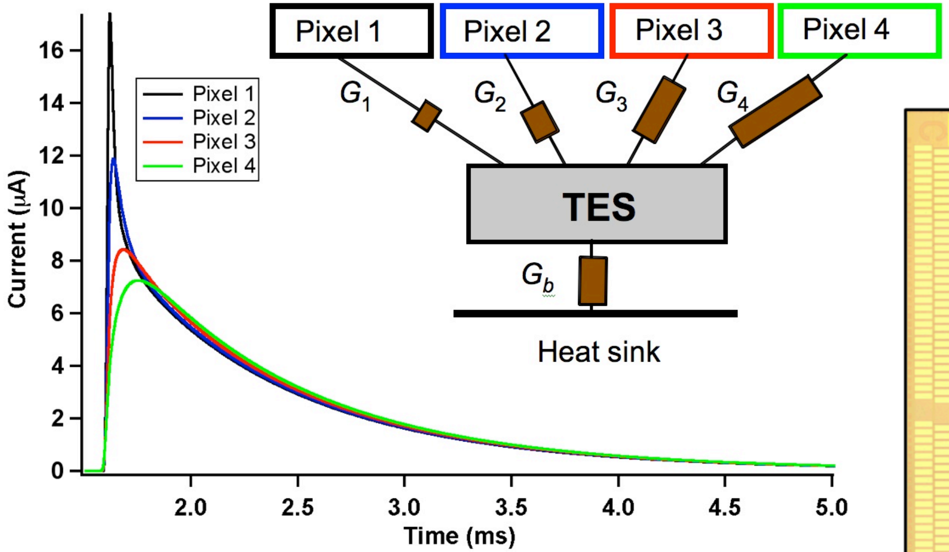
LXM Resource Requirements

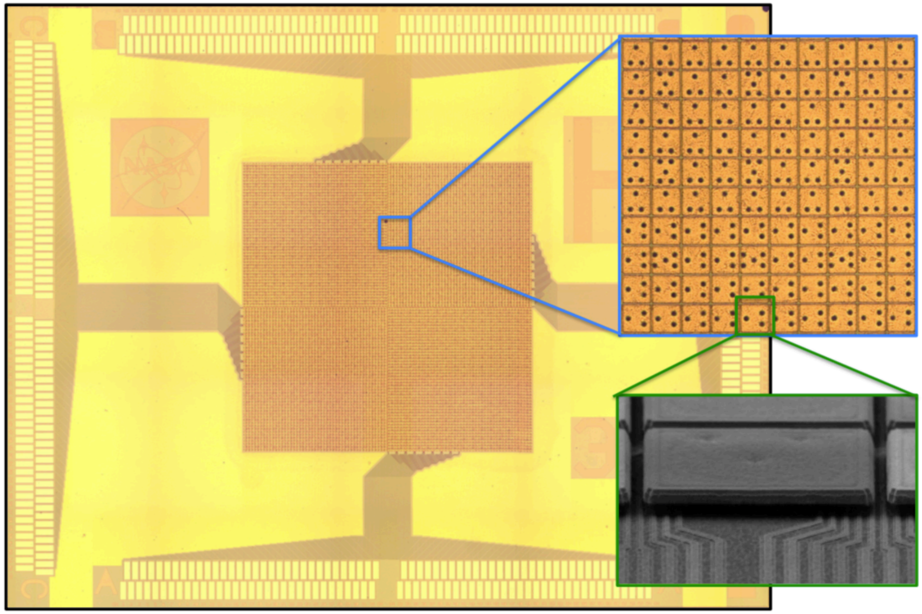
Resources	
Power (W)	~1800
Mass (kg)	~500



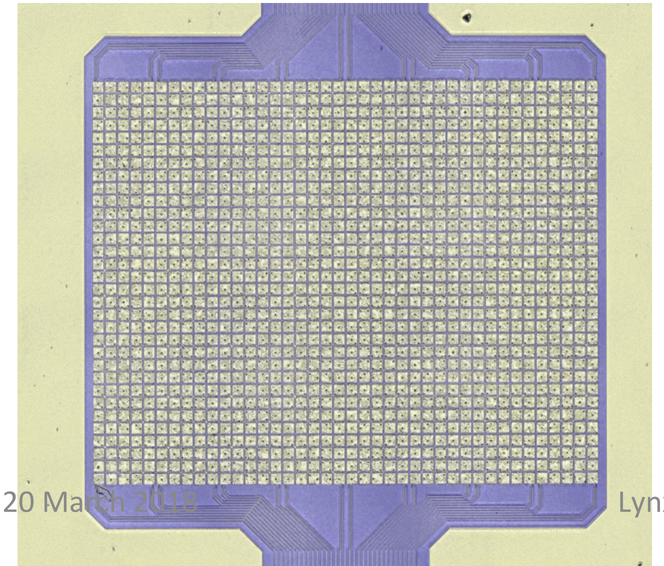
Credits: MSFC ACO GSFC/Bandler/IDL

Need to develop very large format arrays, e.g. using "Hydras"



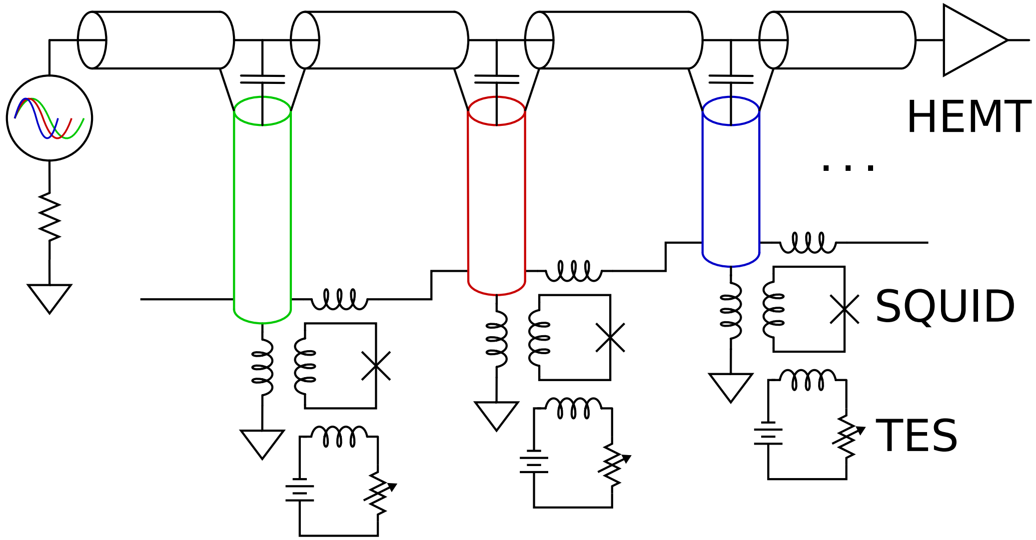


Example of a fully wired 10,000 pixel array



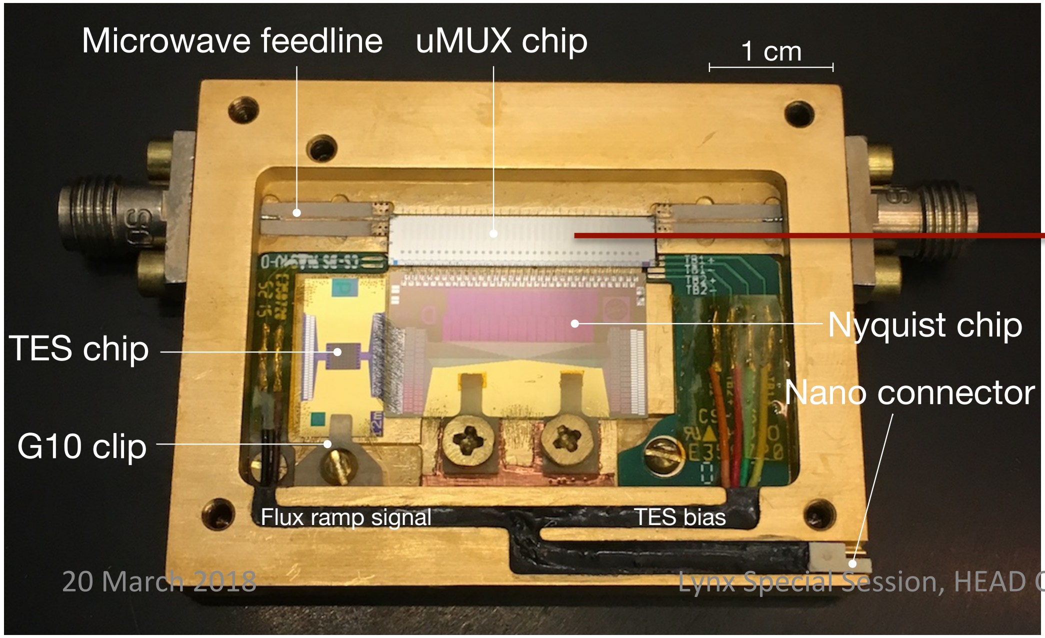
Photograph of 8x8 array of 5x4 "hydras" with pixels on 50 μm pitch (3.4 eV at 5.4 keV – Cr Kα)

LXM Technology Development

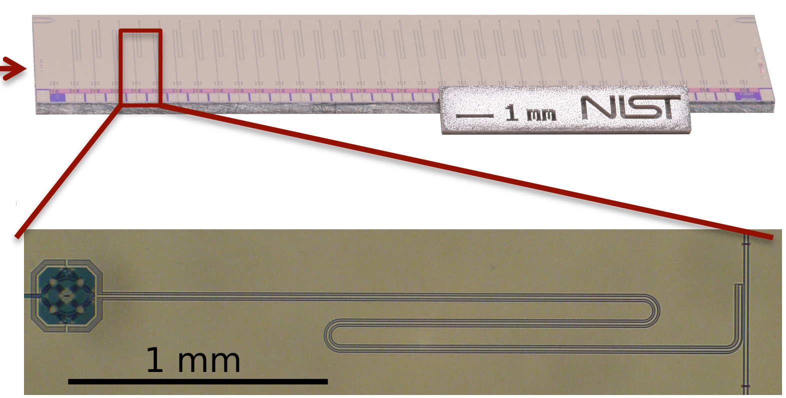


Need to develop multiplexed read-out technology

Circuit diagram for high-resolution X-ray microcalorimeter readout using microwave SQUID multiplexing



Microwave SQUID resonator chips:



Summary

Lynx Instruments will provide extraordinary capabilities:

Lynx X-ray Microcalorimeter:

- High spectral resolution imaging spectroscopy over a the full Lynx passband (R $\gtrsim$1000, 0.3 -1 0 keV)
- Micro-calorimeter resolution (3 eV) over a wide (5’) field

High-Definition X-ray Imager:

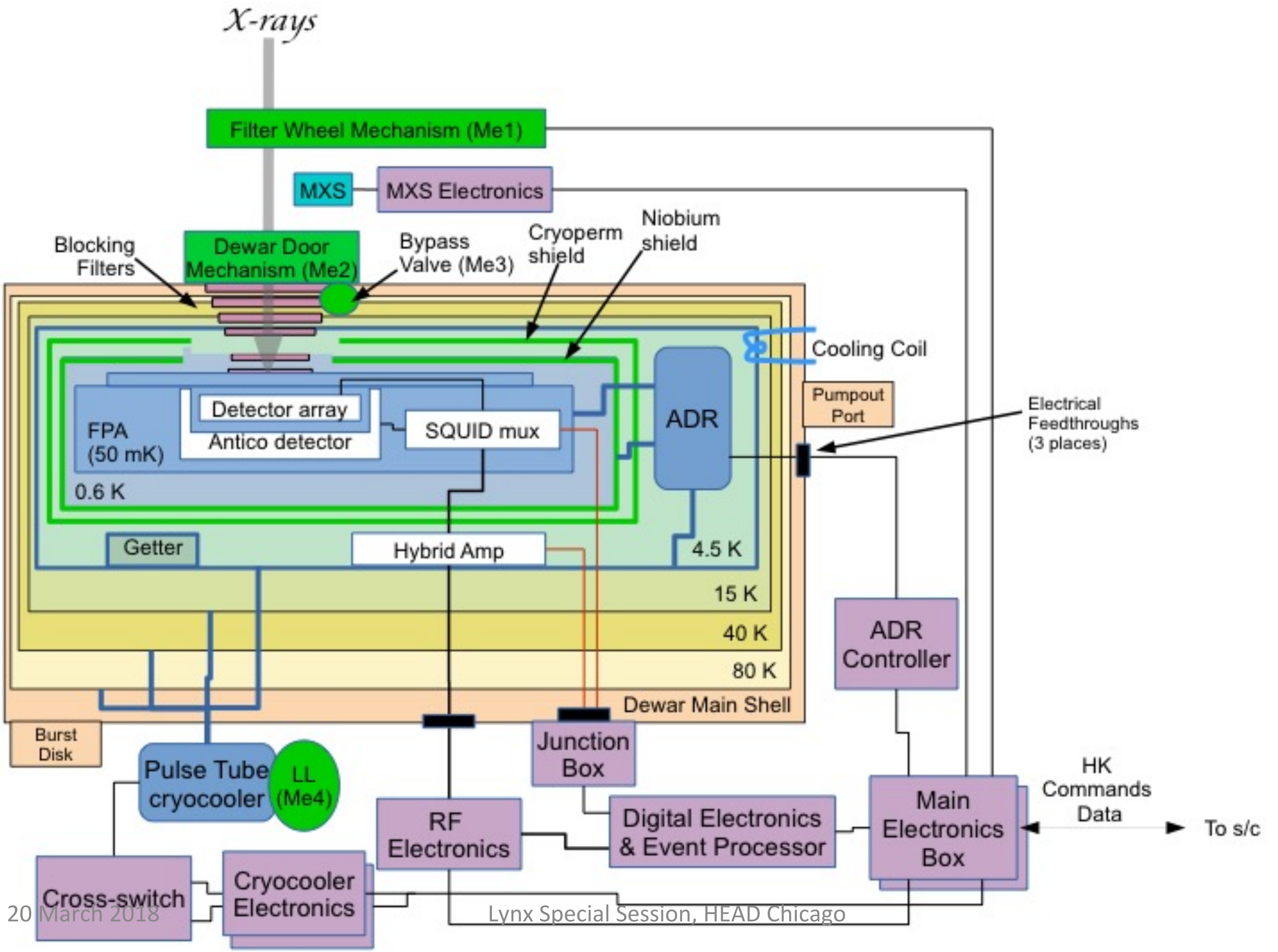
- Sub-arcsecond imaging spectroscopy over a very wide field (r > 10’) over the full Lynx passband
- Excellent soft (E< 1 keV) response and rapid readout

X-ray Grating Spectrometer:

- Very high-resolution (R ~ 4000) & throughput (4000 cm^2) spectroscopy, simultaneous with LXM or HDXI imaging

Backup

Back-up – if needed



Power Requirements

Source	Launch	Cruise	Science	Safe Hold	Survival
	(W)	(W)	(W)	(W)	(W)
Payloads					
Microcalorimeter	14	434	4193	434	14
HDXI	0	213	7	7	7
XGS	0	190	190	7	7
Mirror Heater	525	1356	1356	1356	593
Optical Bench Heaters	0	0	0	0	0
Totals (Payloads)	**539**	**2193**	**5746**	**1804**	**621**

5746 + 2359 = 8105W (Max Pwr)

621 + 535 = 1156W (Battery Pwr for 1 Hr)

Source	Launch	Cruise	Science	Safe Hold	Survival
	(W)	(W)	(W)	(W)	(W)
Spacecraft					
Avionics	0	1079.4	1079.4	1079.4	394.8
GN&C	0	420	420	420	0
Propulsion	0	509.6	509.6	509.6	0
Mechanisms	0	0	210	210	0
Thermal	140	140	140	140	140
Totals	**140**	**2149**	**2359**	**2359**	**534.8**