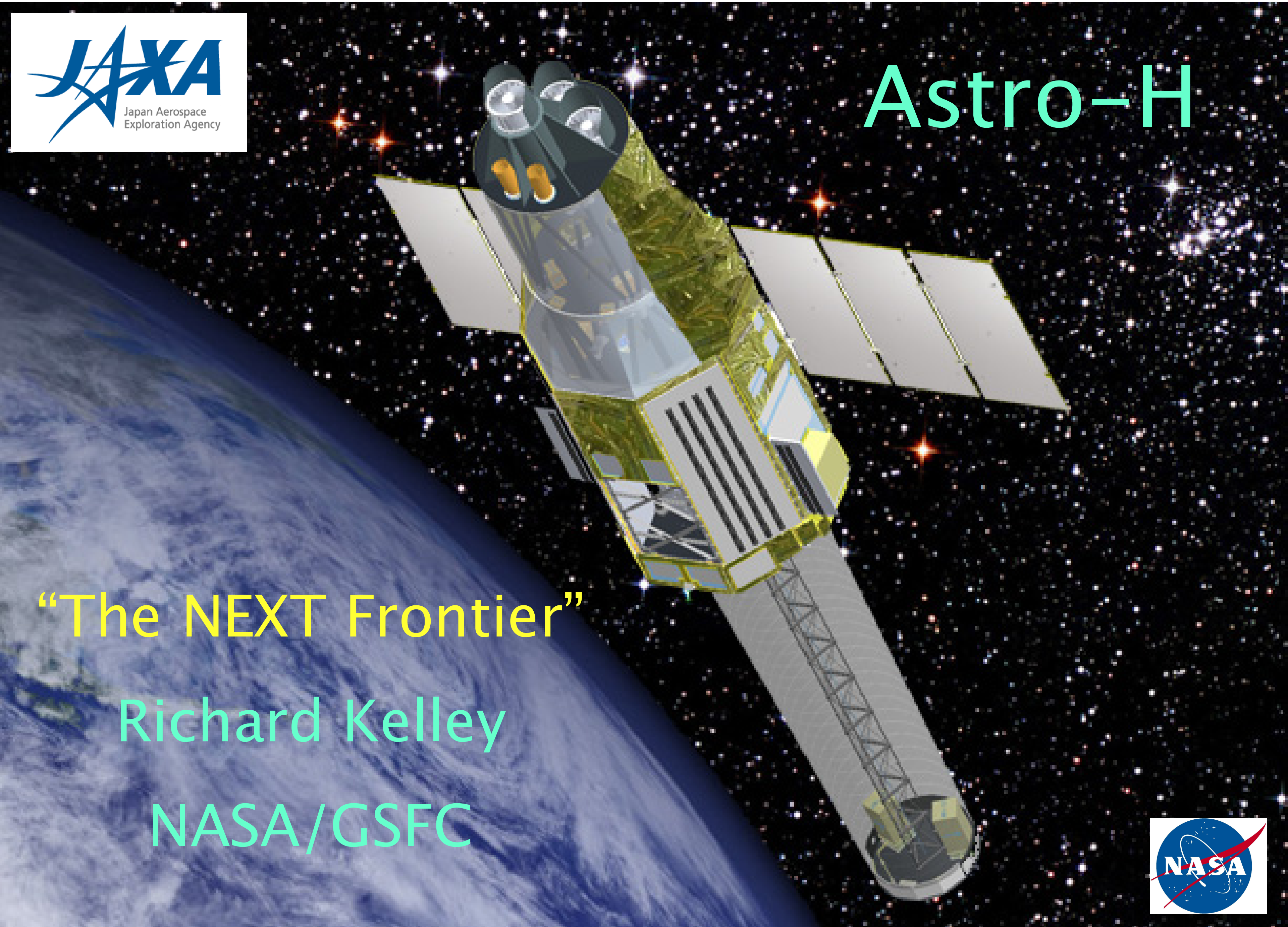
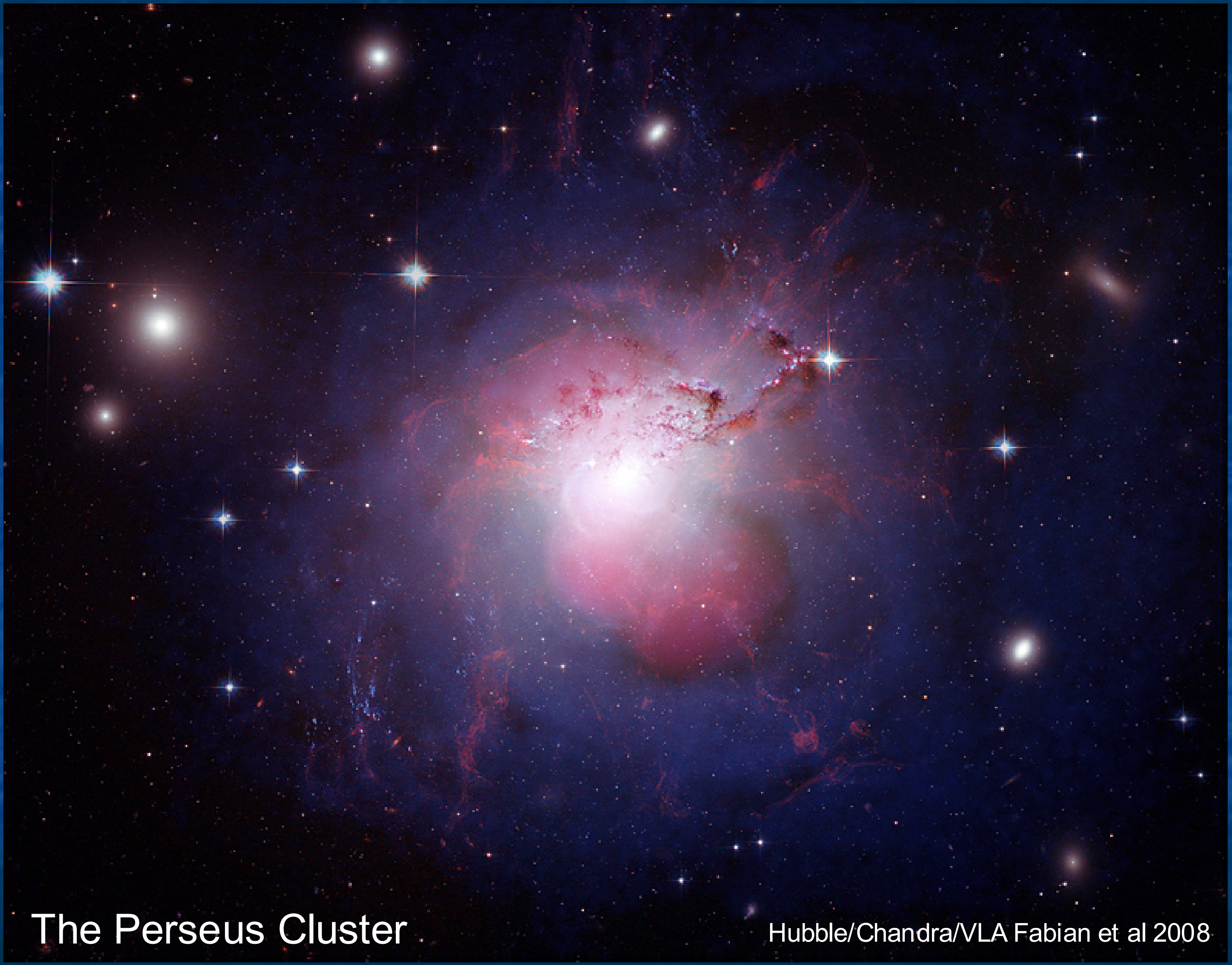


Astro-H

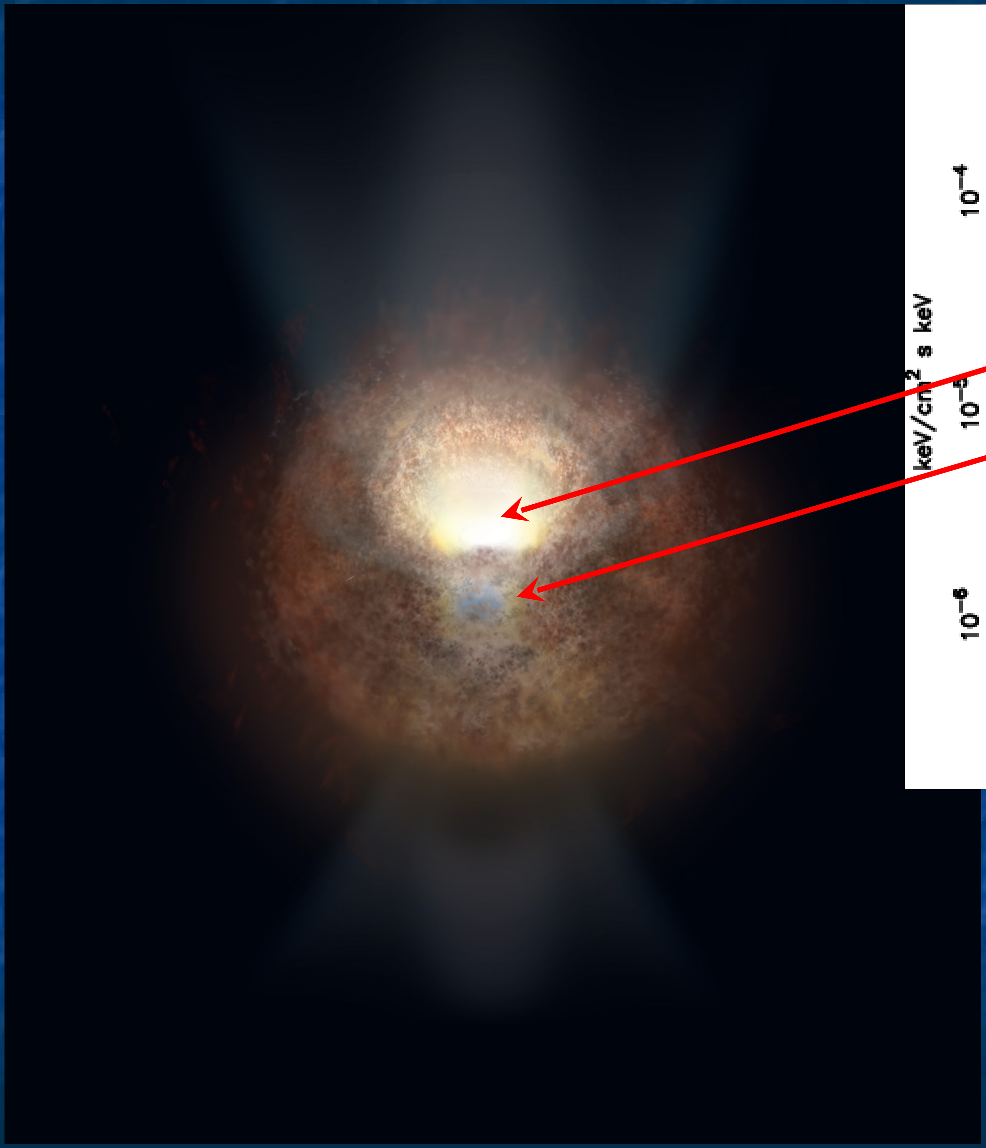
"The NEXT Frontier"

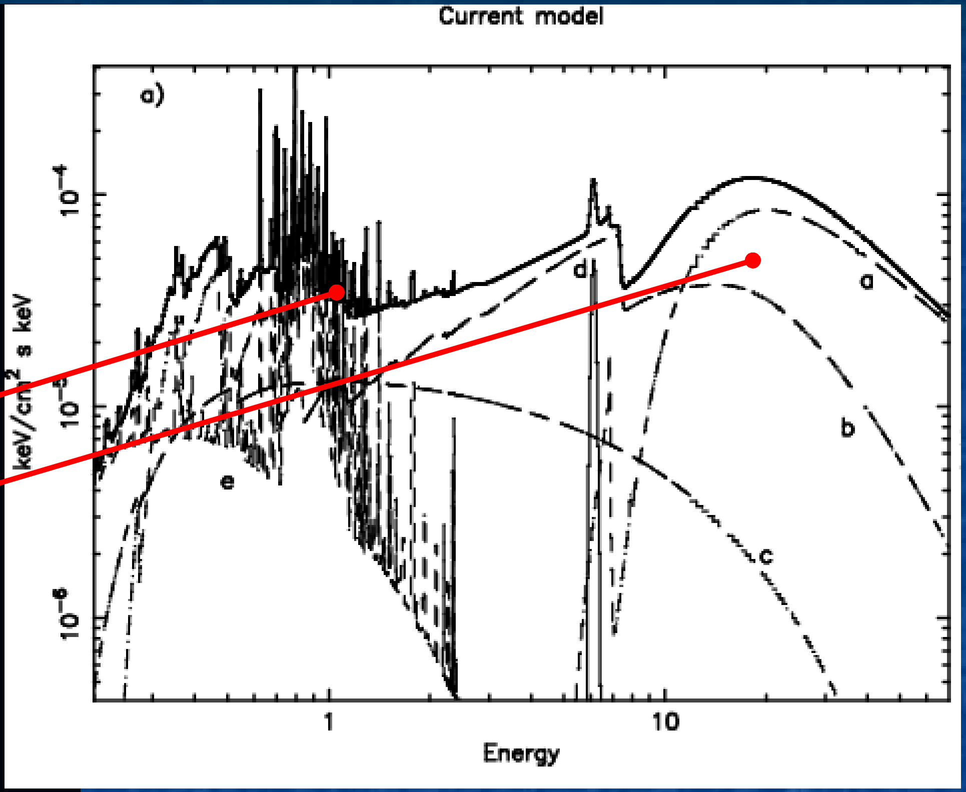
Richard Kelley
NASA/GSFC

X-Ray Emission Traces Large-Scale Structure



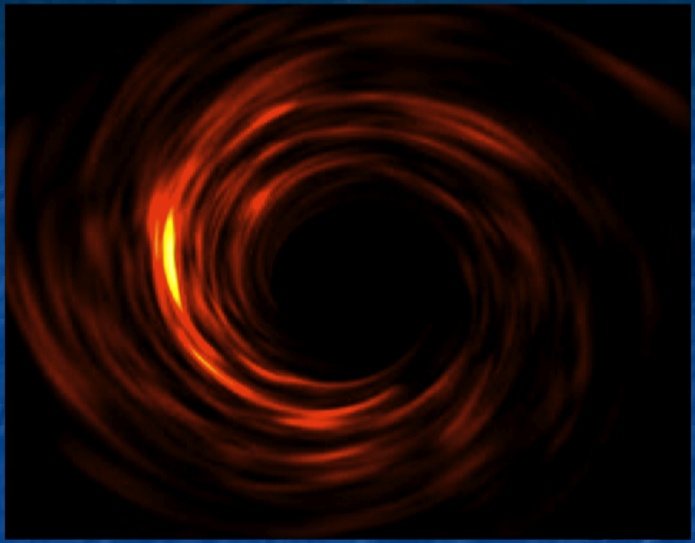
High-Energy X-Rays Reveal the Obscure Universe

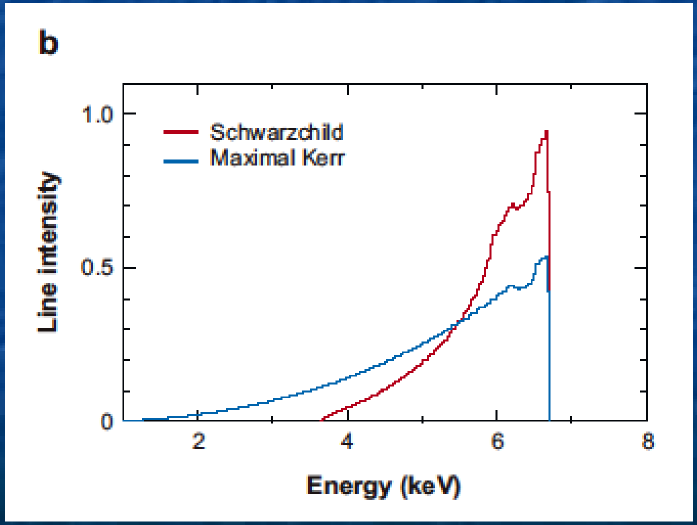




V. Braito et al 2004

X-Ray Emission Traces Matter Very Close to Black Holes



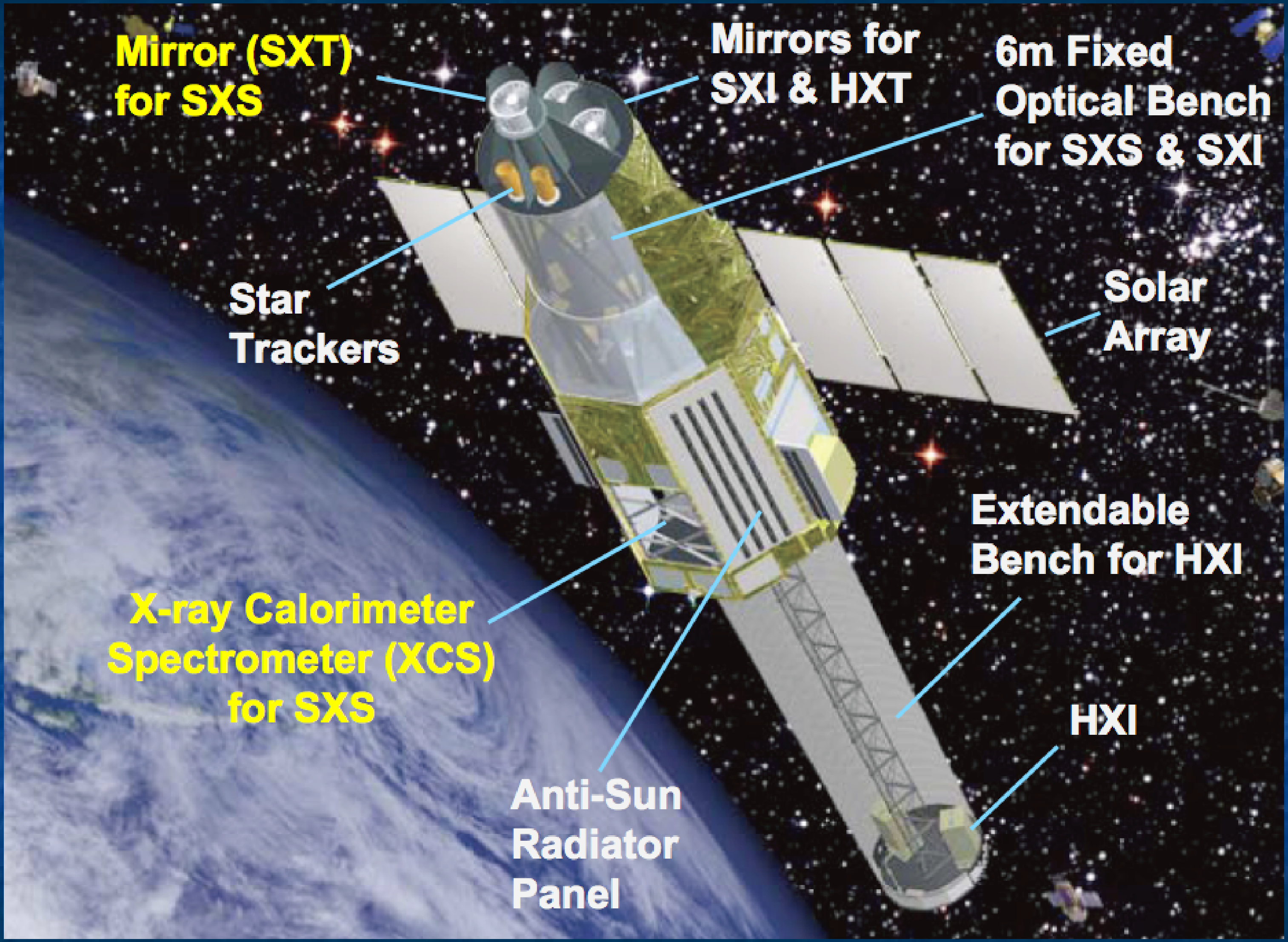


Strong Gravity close to event horizon of black hole distorts line profiles.

Measurement of line shapes provides valuable information on environment and nature of black hole metric.

- High spectral resolution enables capability to follow matter is it orbits from mater as it approaches black hole.
- Broadband spectra required to actually infer broad Fe-line profile.

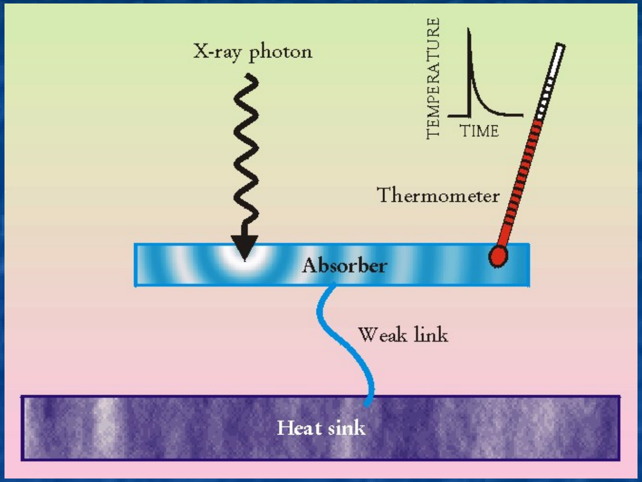
The ISAS/JAXA *Astro-H Mission*



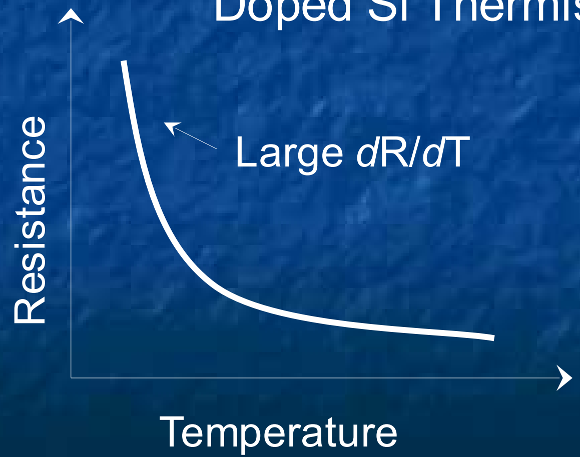
Takahashi et al 2008 SPIE

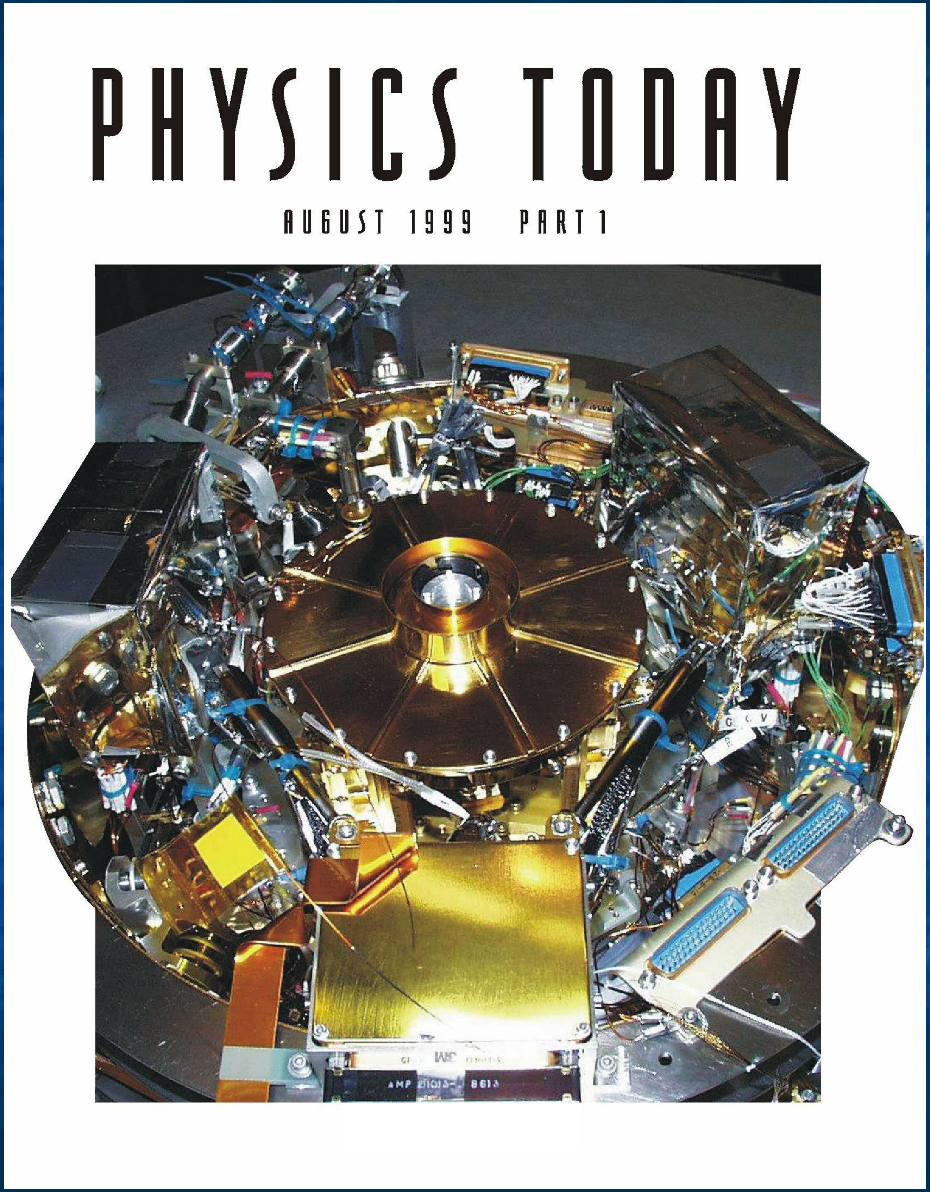
The X-Ray Calorimeter Spectrometer

Non-dispersive spectrometer



Doped Si Thermistor





Why use an X-ray calorimeter?

1. Resolution in the eV range is theoretically achievable.

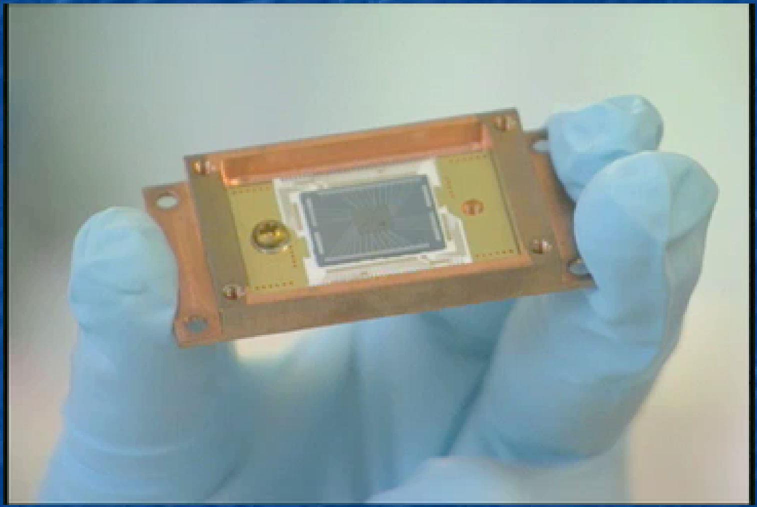
Energy resolution limited by thermodynamics, not the statistics of charge generation.

Noise terms: Power fluctuations, Johnson noise

$$\Delta E_{FWHM} = 2.35\zeta\sqrt{kT^2C}$$

Real devices have various non-ideal effects:

- Themistor decoupling from lattice
- Power fluctuations between absorber and thermometer
- Intrinsic noise (e.g., 1/f noise)



2. High intrinsic quantum efficiency

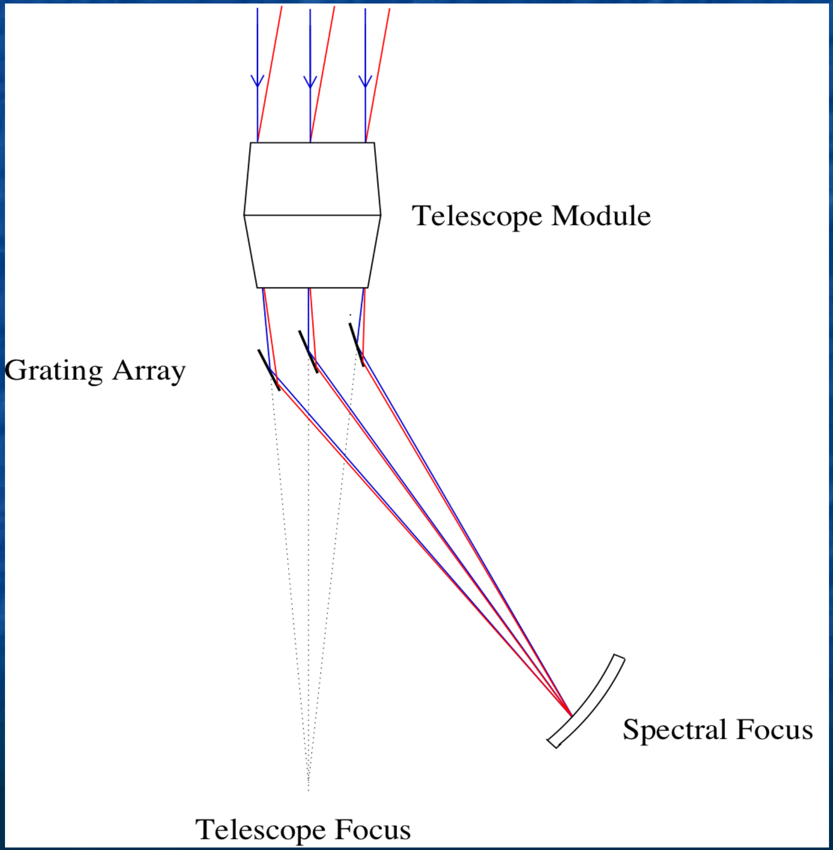
Efficiency determined by x-ray opacity of absorber.

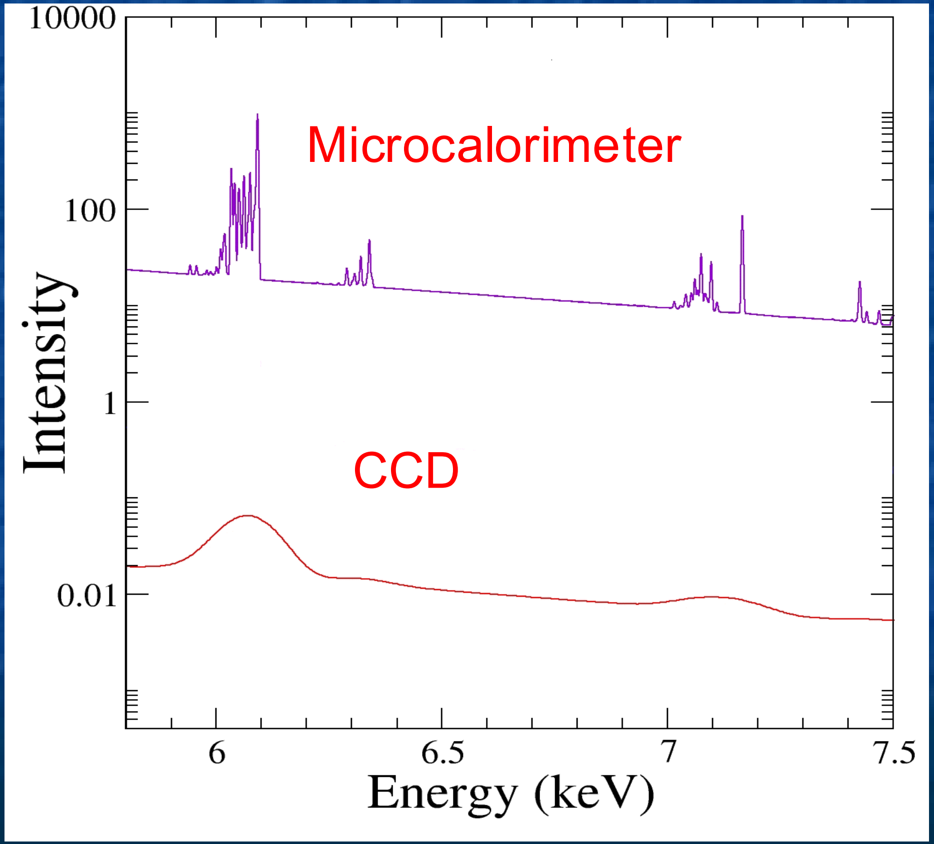
3. Arrays of calorimeters can be fabricated to provide imaging, non-dispersive x-ray spectroscopy.

Spectroscopy niche filled by x-ray calorimeter

Dispersive spectrometers (e.g., gratings) have very high resolution at low energies, but degrade with increasing energy. They are not well-suited for extended sources.

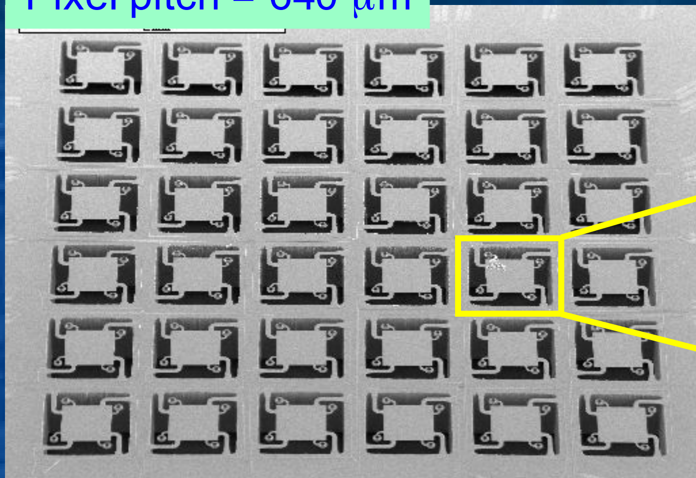
X-ray CCDs are excellent for imaging over large fields of view, but have comparatively low spectral resolution

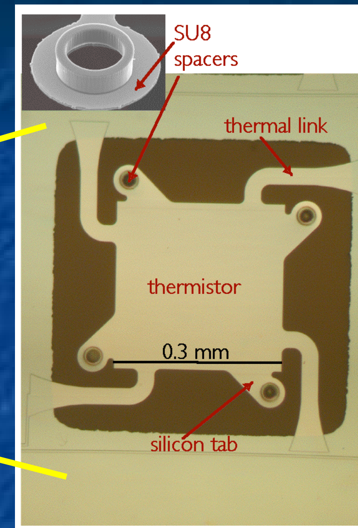




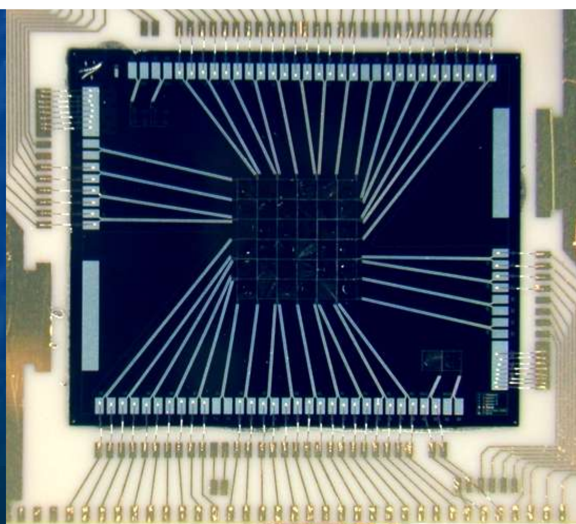
Suzaku/XRS Array

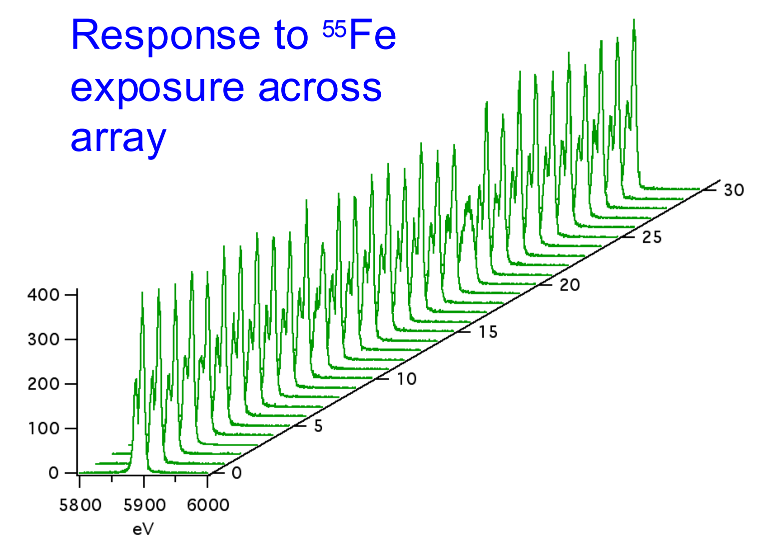
Pixel pitch = 640 μm



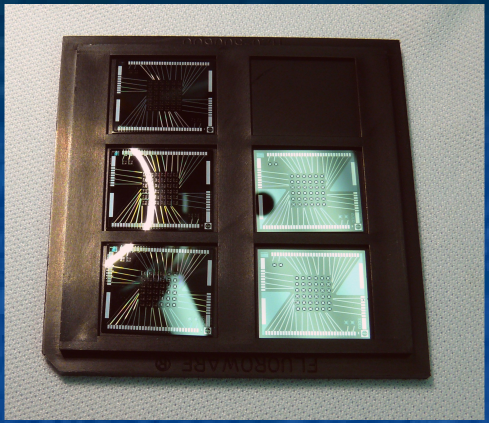


with HgTe absorbers attached



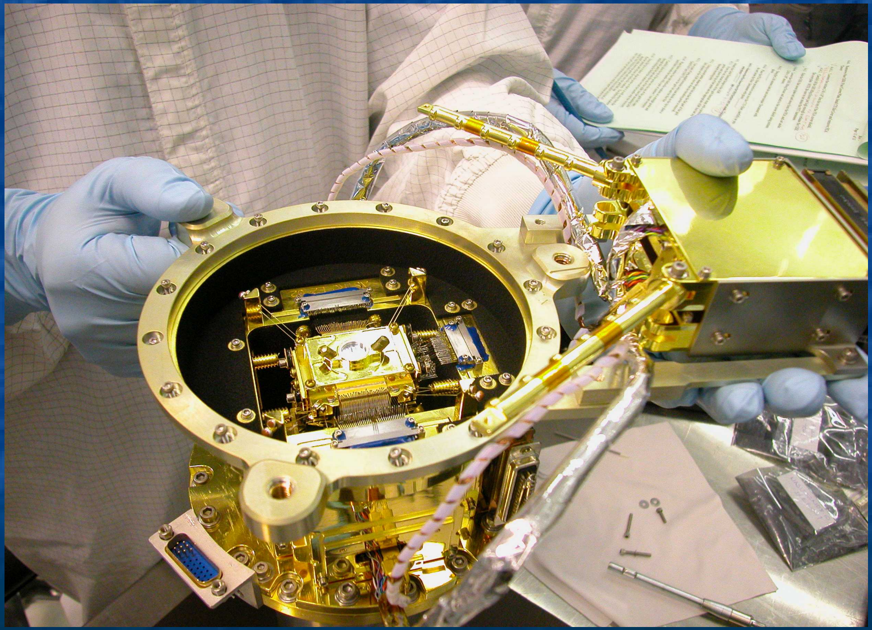


Calorimeter Detector & ADR Assembly



Use spare arrays from XRS program:

- 6x6 or new 8x8 array
- larger pixels (830 μm pitch)
- new HgTe absorbers



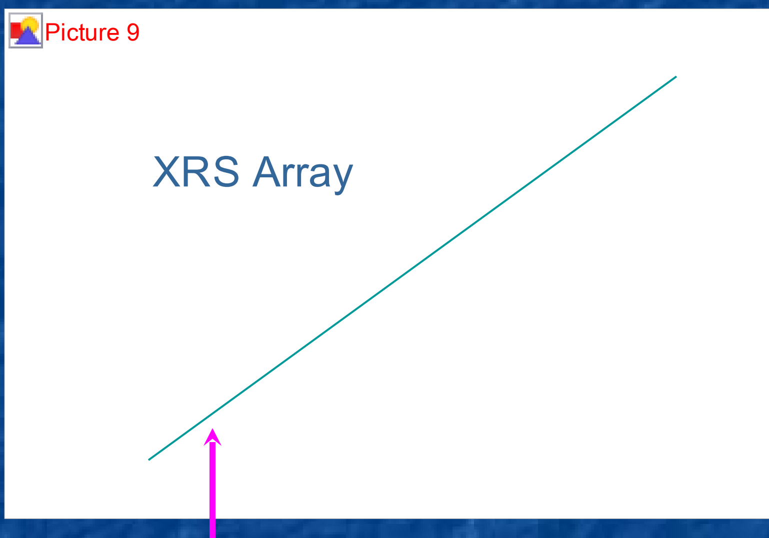
detector assembly - heritage XRS

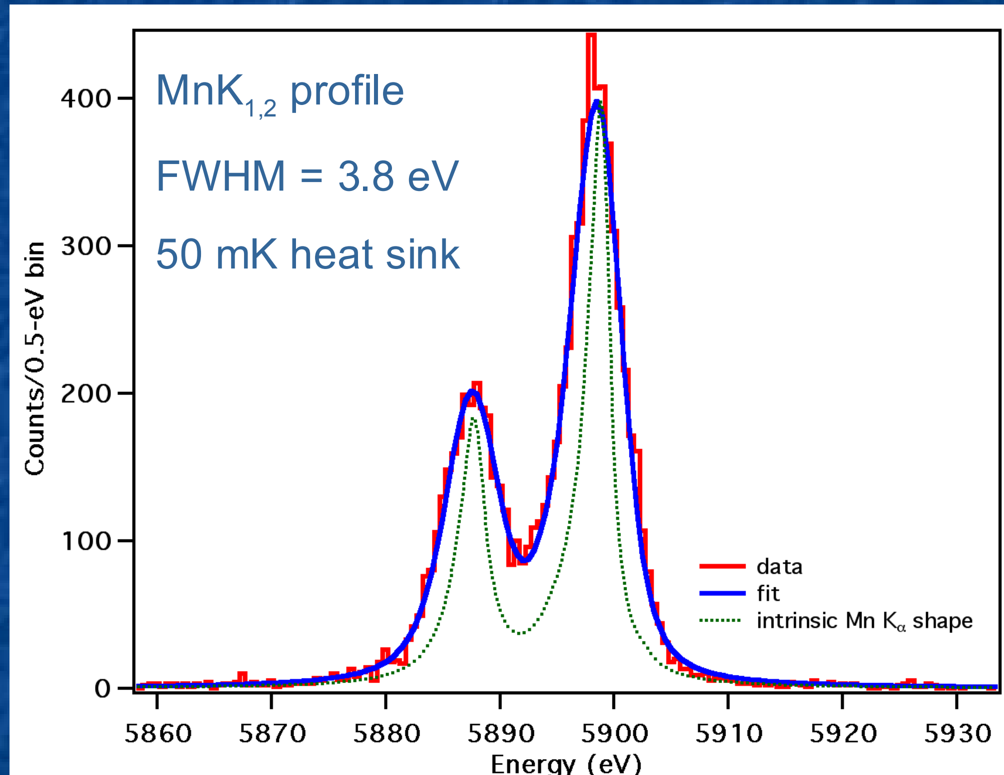
2-Stage ADR - heritage XRS

50 mK with ~ half the mass of the XRS ADR and high efficiency, even with higher heat sink temperature.

New X-ray Results - Better Resolution!

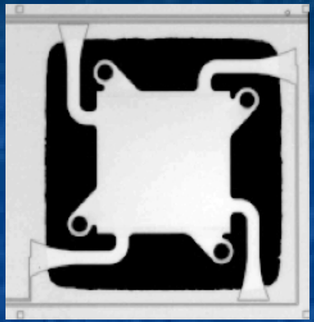
Improved energy resolution from lower heat capacity absorber material (HgCdTe)

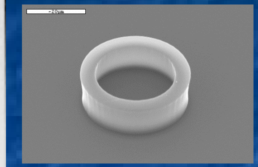


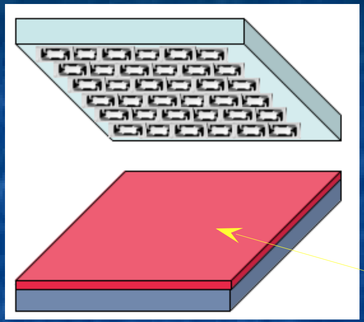


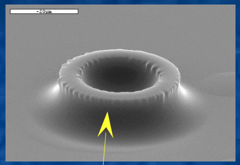
What we can obtain today - *4x lower!*

Implementing a Larger Array

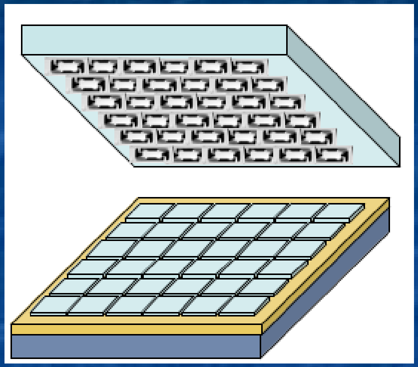




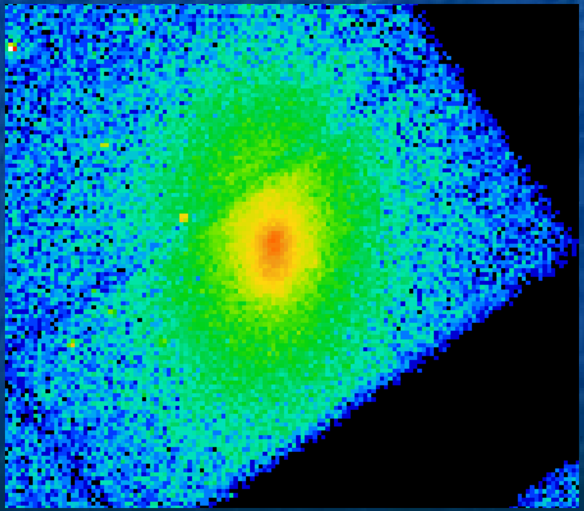




Epoxy



A1413



Chandra

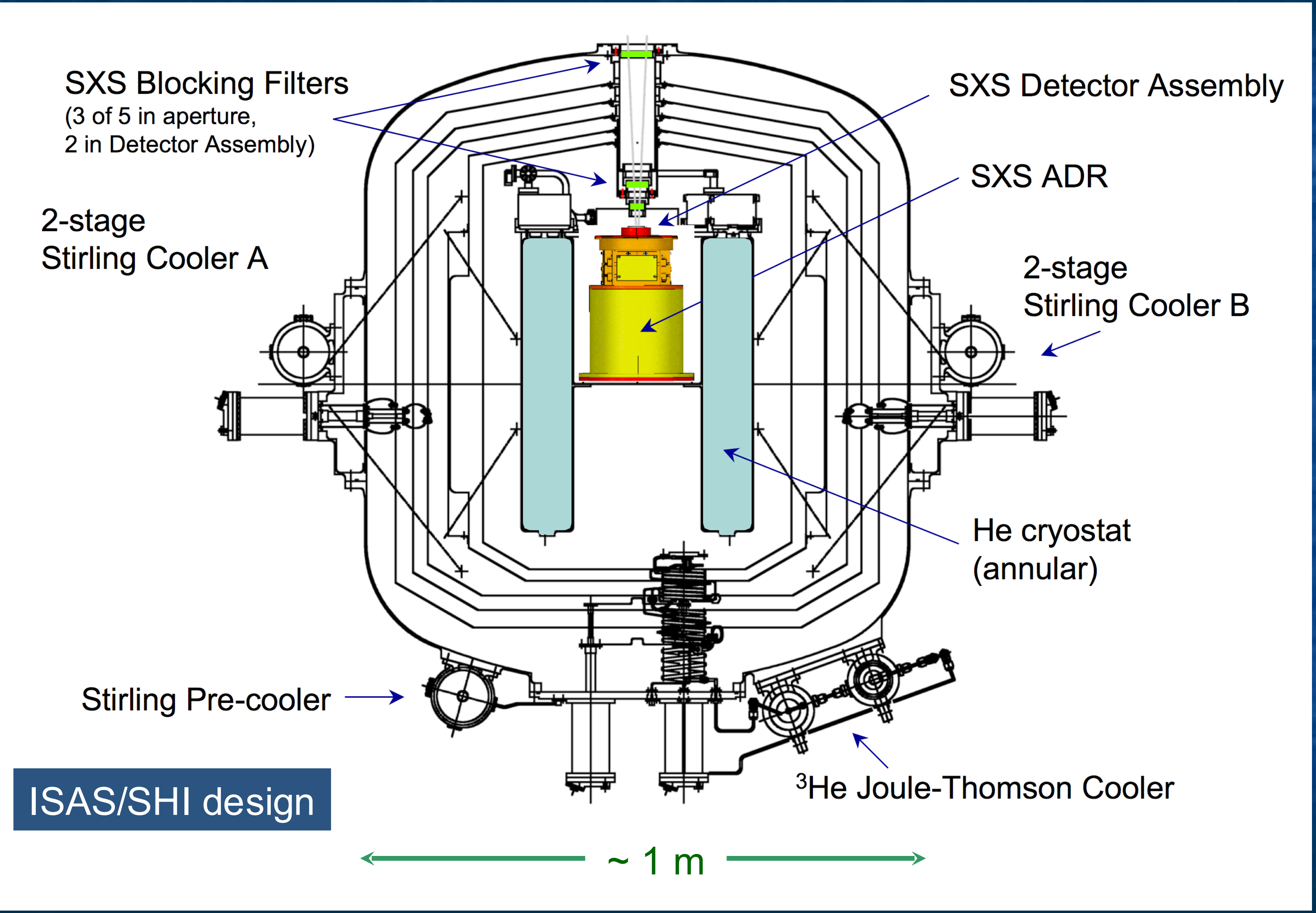
Suzaku/XRS

6x6

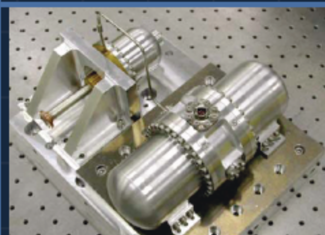
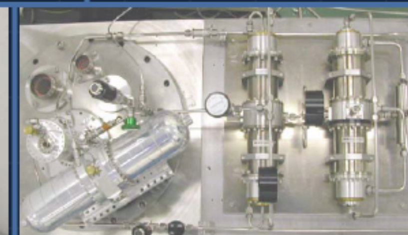
Astro-H/SXS

8x8

Long life, redundant dewar design



Strong Cryo-cooler Heritage at ISAS

Cooler	1ST (100K)	2ST (20K)	2ST+^{4}He JT (4K)	2ST+^{3}He JT (2K)
				
Specification	2W@80K 50W, 4.2kg	200mW@20K 80W, 9.5kg	20mW @4.5K 120W, 23kg	10mW@1.7K 180W, 25kg
Ground test status	Life time test > 5 years (still running)	Life time test > 4 years (still running)	1 year test was done. A new life time test will start April next year	Life time test will start April next year
Mission status	Suzaku, in orbit >1 year	Akari, in orbit > 0.5 years	FM for SMILES assembled	BBM for SPICA & NeXT assembled

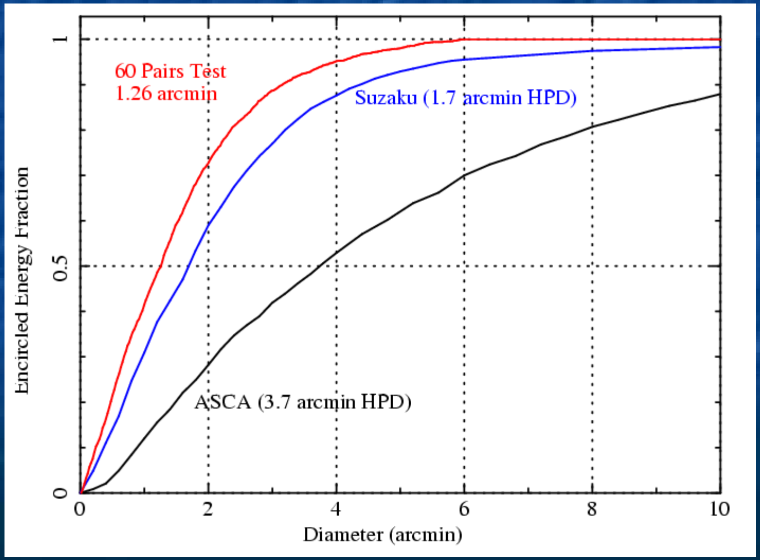
Narasaki (2006)

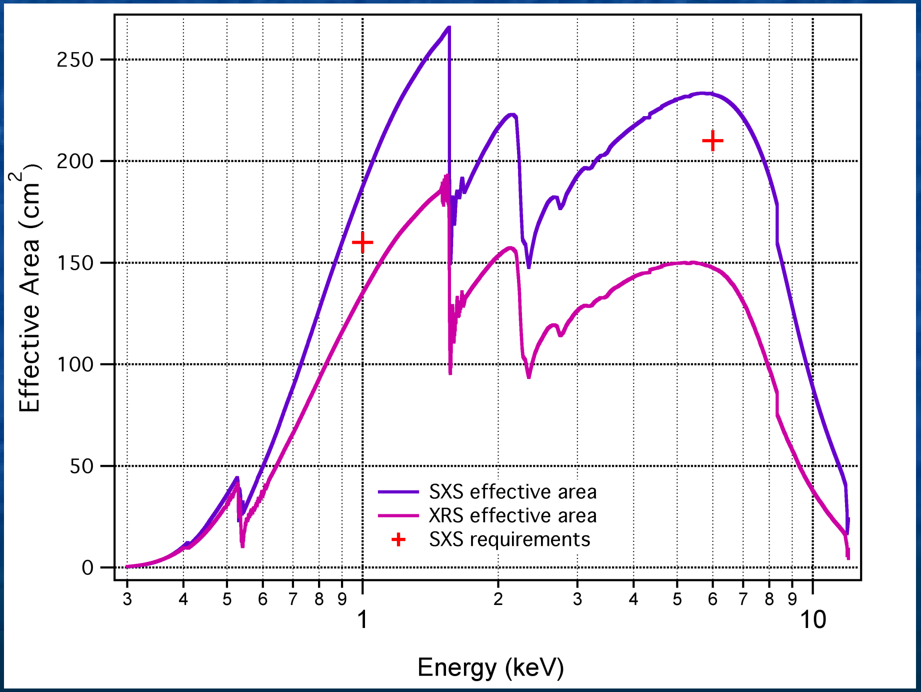
Improved low weight, high throughput X-Ray mirror

6 m focal length

Increase diameter from 40 to 45 cm

Decrease HPD from ~ 1.8 arcmin to ~ 1.3 arcmin





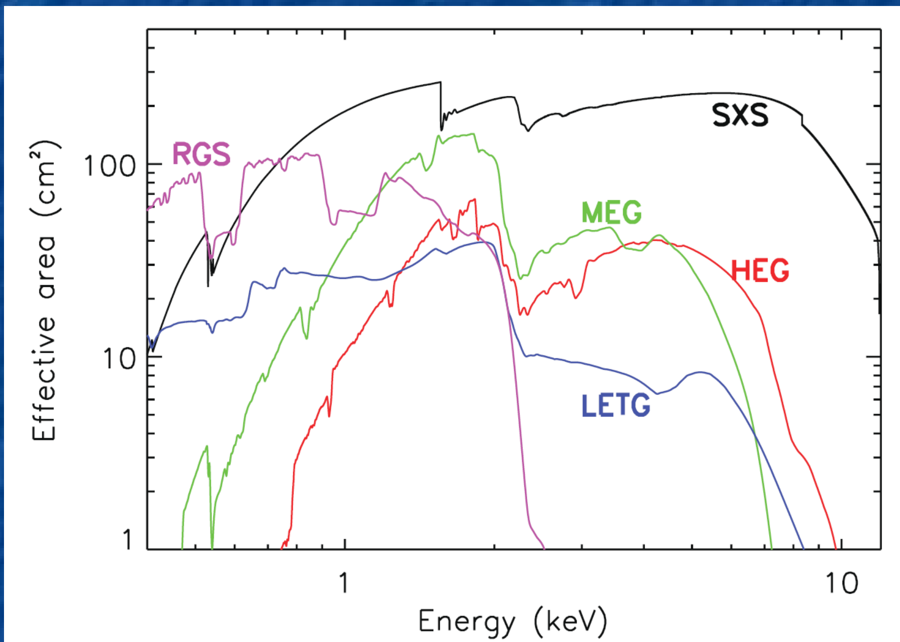
SXS Characteristics

SXT-S (Soft X-ray Telescope)/SXS (Soft X-ray Spectrometer)	
Focal Length	6 m
Effective Area	210 cm^2 (at 6 keV)
Energy Range	0.3–10 keV
Angular Resolution	$<$ 1.7 arcmin (HPD)
Effective FOV	$\sim 3 \times 3$ arcmin
Energy Resolution	$<$7 eV (FWHM, at 7 keV)
Timing Resolution	several 10 μs
Detector Background	$<5 \times 10^{-3}$ cts s^{-1} cm^{-2} keV^{-1}
Operating Temperature	50 mK

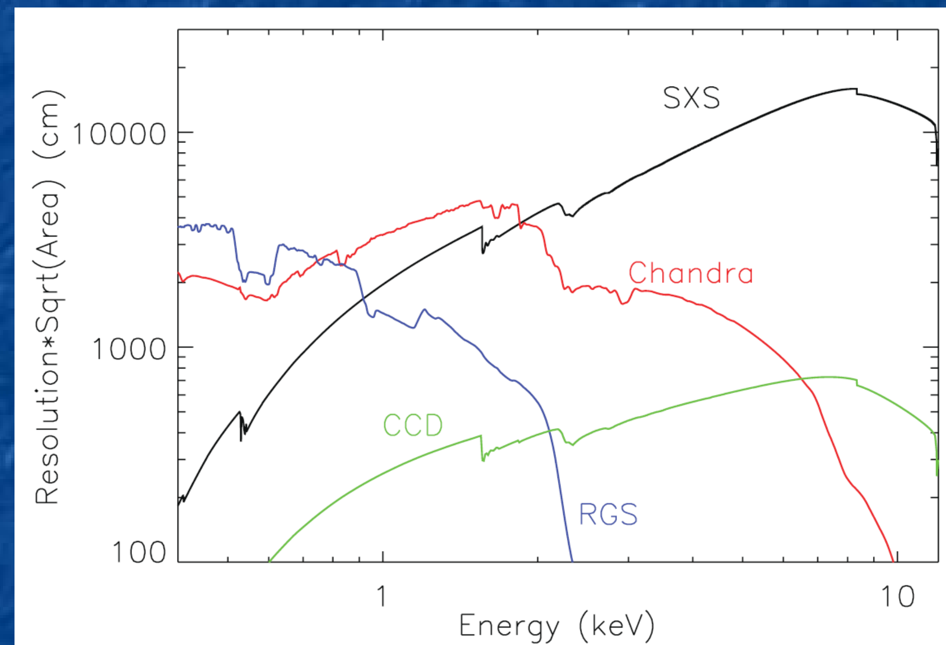
Spectrally-resolved images from SXS will address a broad range of questions with an order of magnitude increase in spectral line resolving power over existing X-ray satellites *for diffuse sources*, and a similar increase for all sources in the important Fe K line region.

Effective Area and Sensitivity

Effective Area for hi-rez spectroscopy

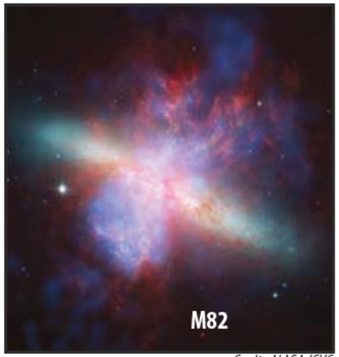


Energy Determination

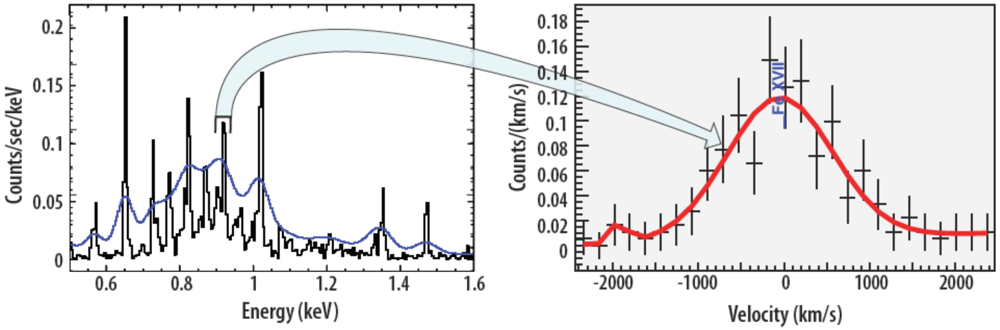


With 7 eV resolution, SXS can resolve the resonance, intercombination, and forbidden lines of He-like ions from Ne through Ni. Emission lines from this isosequence, in combination with lines from the hydrogenic ions, will be used to determine the temperature, excitation mechanism (collisional equilibrium, shock-heated, photoionized), and density of a plasma. Down to 2 eV equivalent width.

Science Possibilities

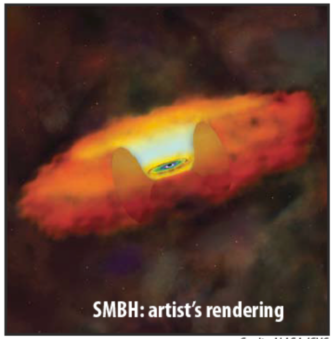


Credit: NASA/CXC

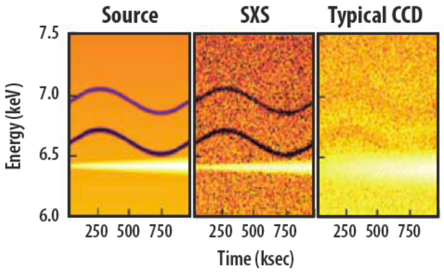


Simulated spectra of the cap region of M82 for the SXS (black) and a typical CCD (blue). SXS can determine both centroids and widths of the strong emission lines to an accuracy of +/- 100 km/s.

The SXS will detect the enrichment of the IGM due to supernovae and strong stellar winds, measuring how metals travel from their birthplace in stars into the hot diffuse medium of galaxies, groups, and clusters.



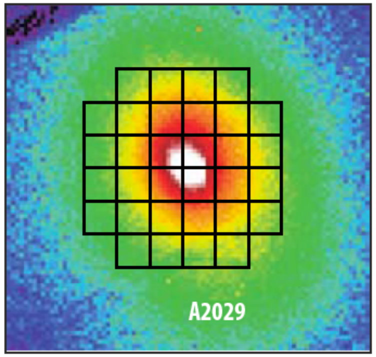
Credit: NASA/CXC

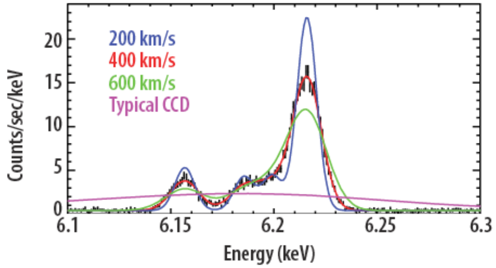


The simulated source shown here contains two slowly sinusoidally varying Fe absorption features and an Fe K line that becomes increasingly strong and broad as a function of time.

Supermassive black holes (SMBH) have had a major influence on the formation of all structure in the Universe, via winds and/or relativistic jets. Observations show that X-rays from SMBH frequently change their absorption and emission features in the 5-10 keV band which may represent gas moving at very high velocities with both red and blue shifts.

The SXS will measure velocity structure of 100 km/s on the 10 ksec orbital timescale of a $3 \times 10^7 M_\odot$ SMBH, which cannot be seen with CCDs.





A portion of a simulated spectrum (black) from the cluster A2029, assuming 400 km/s turbulence, and models assuming 200, 400, and 600 km/s, clearly showing the capability of SXS to measure cluster dynamics.

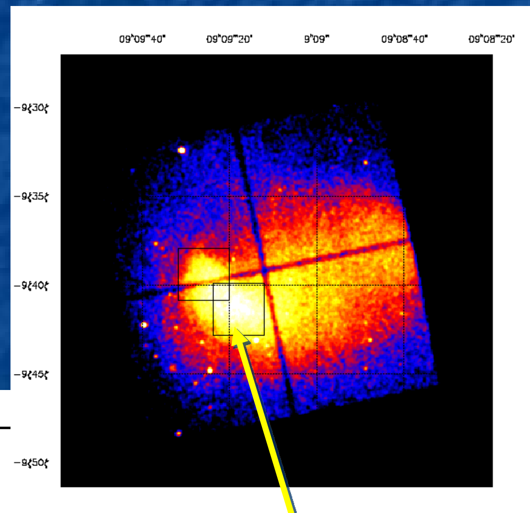
The SXS will survey 30 selected clusters to determine the relationship between observational parameters and total mass, the most significant unknown quantity limiting our ability to use clusters as probes of the structure of the Universe. The SXS will precisely measure the temperature, pressure, abundances, and internal dynamics of these clusters, including line of sight velocities accurate to ±100 km/s and line widths at the ±300 km/s level on scales of 100 kpc out to a redshift of 0.05.

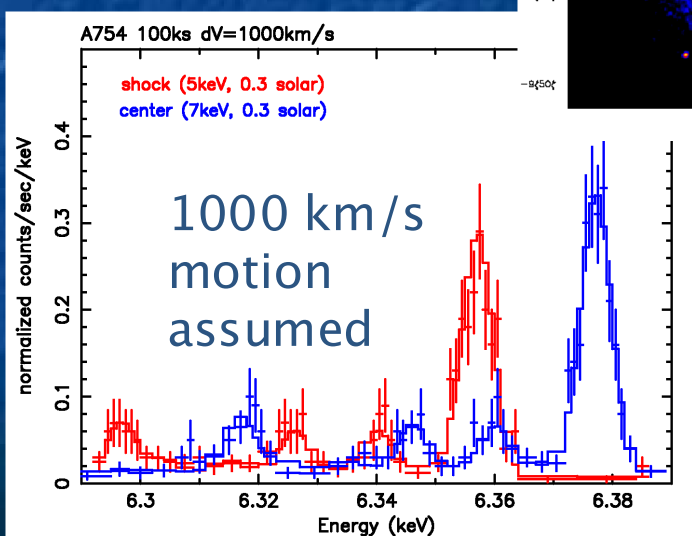
Cluster dynamics

The SXS will precisely measure the temperature, pressure, abundances, and internal dynamics of ~ 30 clusters, including line-of-sight velocities accurate to 100 km/sec and line widths at the level of 300 km/sec on scales 100 kps out to a redshift of 0.05

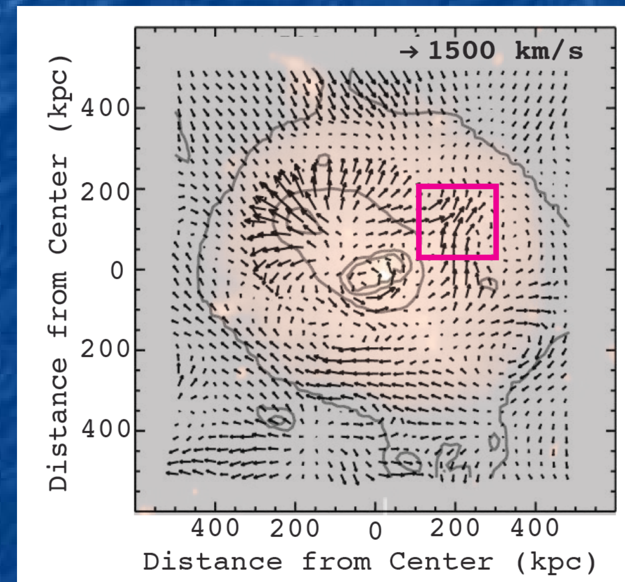
A754

(z = 0.054)





SXS



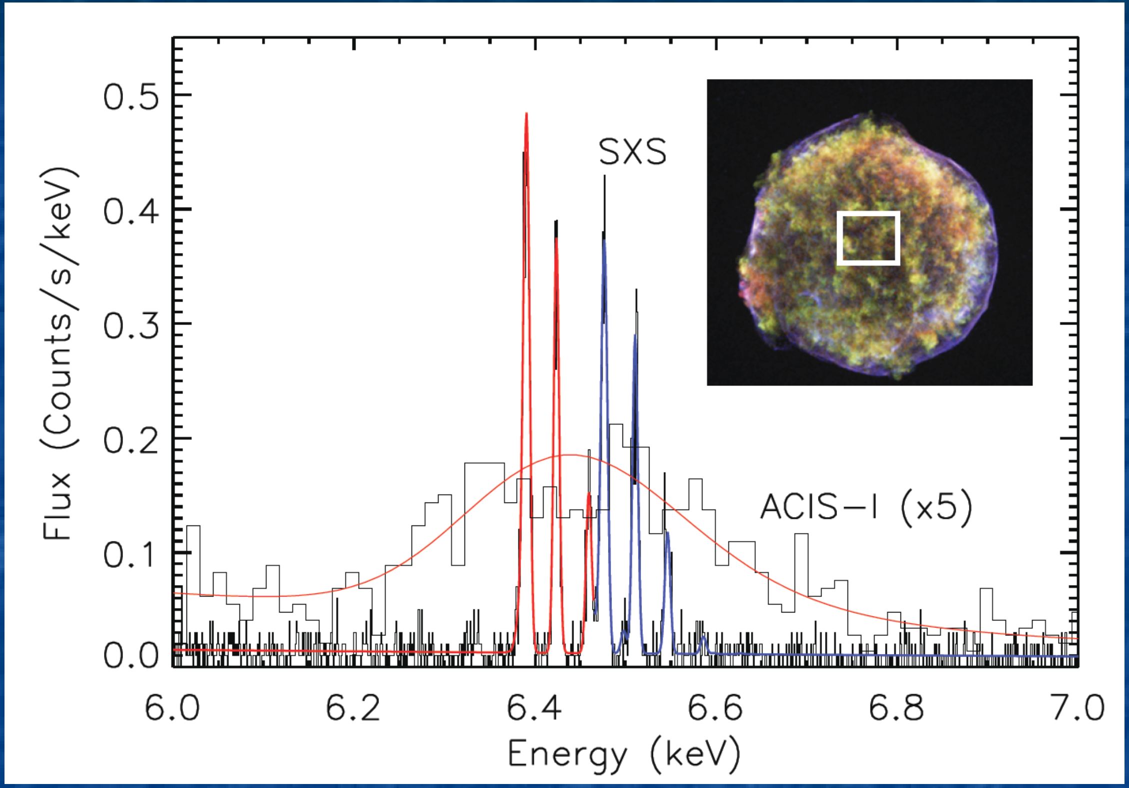
The figure shows the velocity field of a simulated cluster of galaxies overlaid on an X-ray image (Motl et al. 2004). The image corresponds to half the virial radius at redshift 0.05.

SXS resolves distinct velocity components in SNRs.

The spectrum is a 100 ks simulated SXS observation of Tycho using a dynamical model comprising two velocity components, separated by ± 2000km/s (blue and red).

The histogram is the spectrum from the Chandra CCD multiplied by 5.

The insert shows the SXS FOV (and ACIS extraction region) on the Chandra image of Tycho.

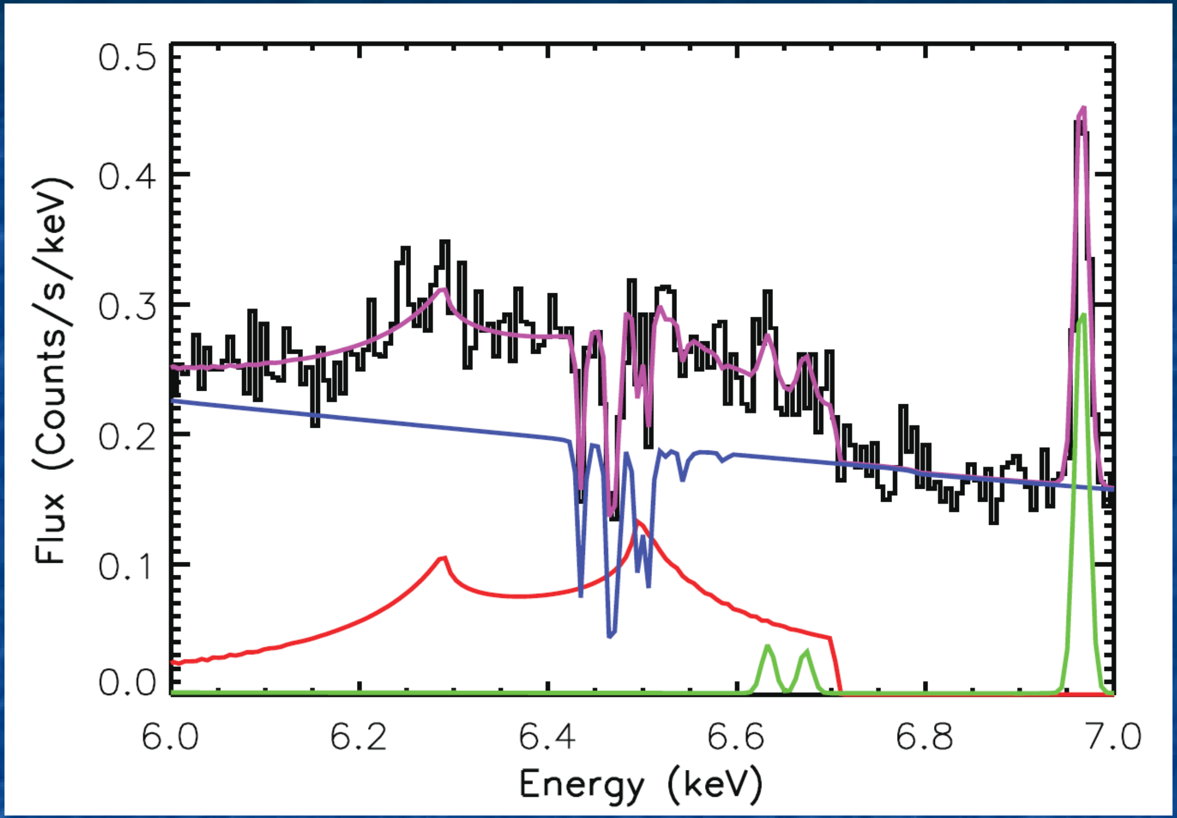


SXS will enable one to infer the properties of the precursors (including mass) of local Type Ia supernovae, providing important data for comparing models of explosion mechanism(s) and thereby improving confidence in their use for cosmological studies.

Absorption features in AGN and Black Holes

SXS can resolve the 2000 km/s FeK emission line in NGC 3783 and measure the ionization parameter, redshift, and optical depth of the Fe K absorption lines.

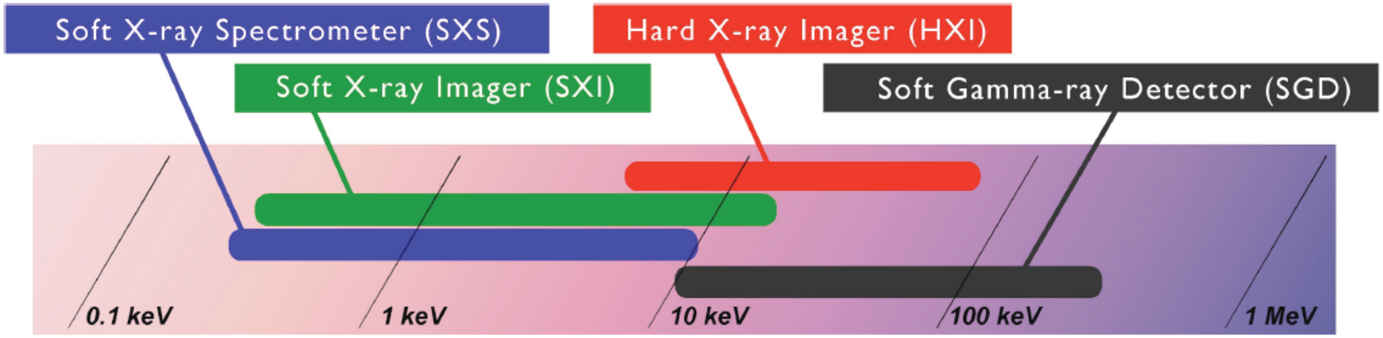
The spectrum shown (black) is a 100 ks simulation using parameters from Reeves et al. (2007). The models are the Fe K emission (green), absorption (blue) and photo-ionized emission from the warm absorber region (red).



SXS will measure both the velocity and width of the absorption features to better than 400 km/s.

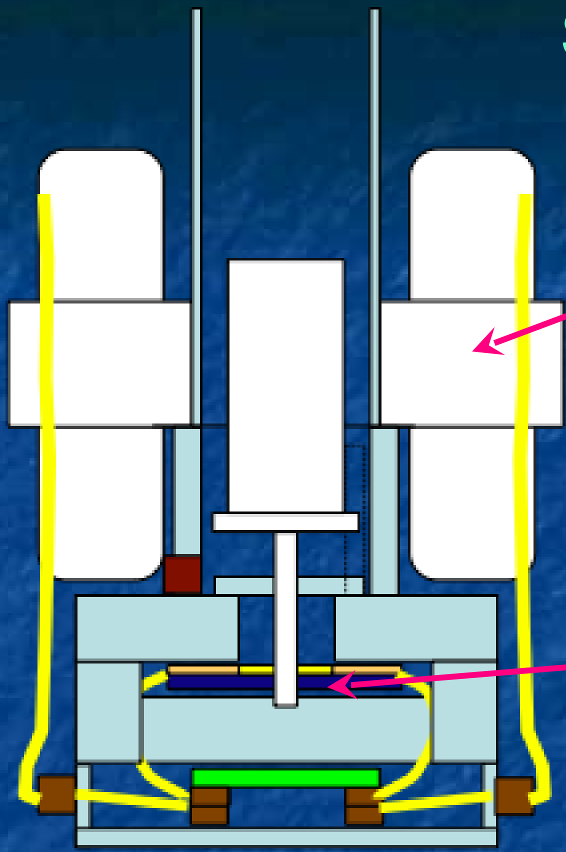
SXS observations provide high signal-to-noise measurements of the broad lines of hundreds of AGN up to z~2. These observations provide the first unbiased survey of broad Fe K line properties across all AGN.

Extreme Broadband!

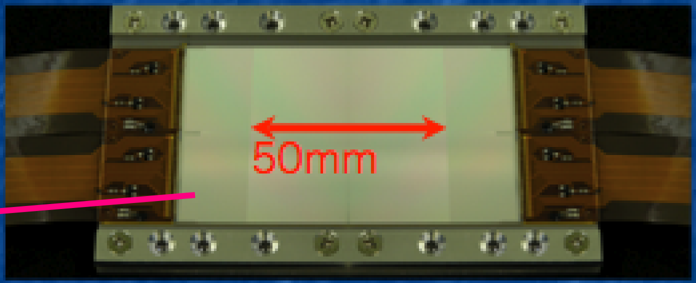


Hard X-ray Imaging System	HXT HXI	The first hard X-ray focus imaging
Soft X-ray Spectroscopy System	SXT-S SXS	X-ray micro-calorimeter + cooler
Soft X-ray Imaging System	SXT-I SXI	X-ray CCD camera
Soft Gamma-ray Detector	SGD	Semiconductor compton camera

Soft X-Ray Imager (SXI)



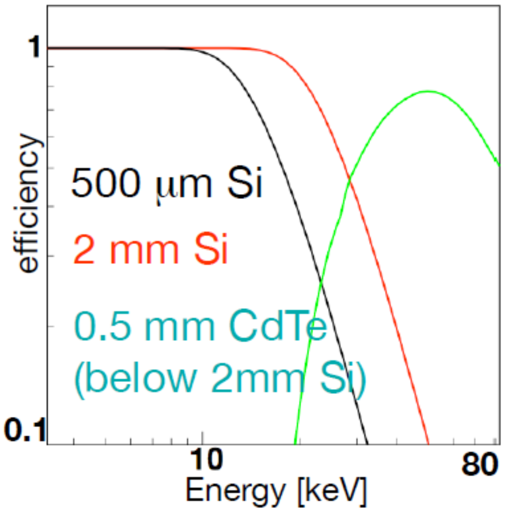
CCD



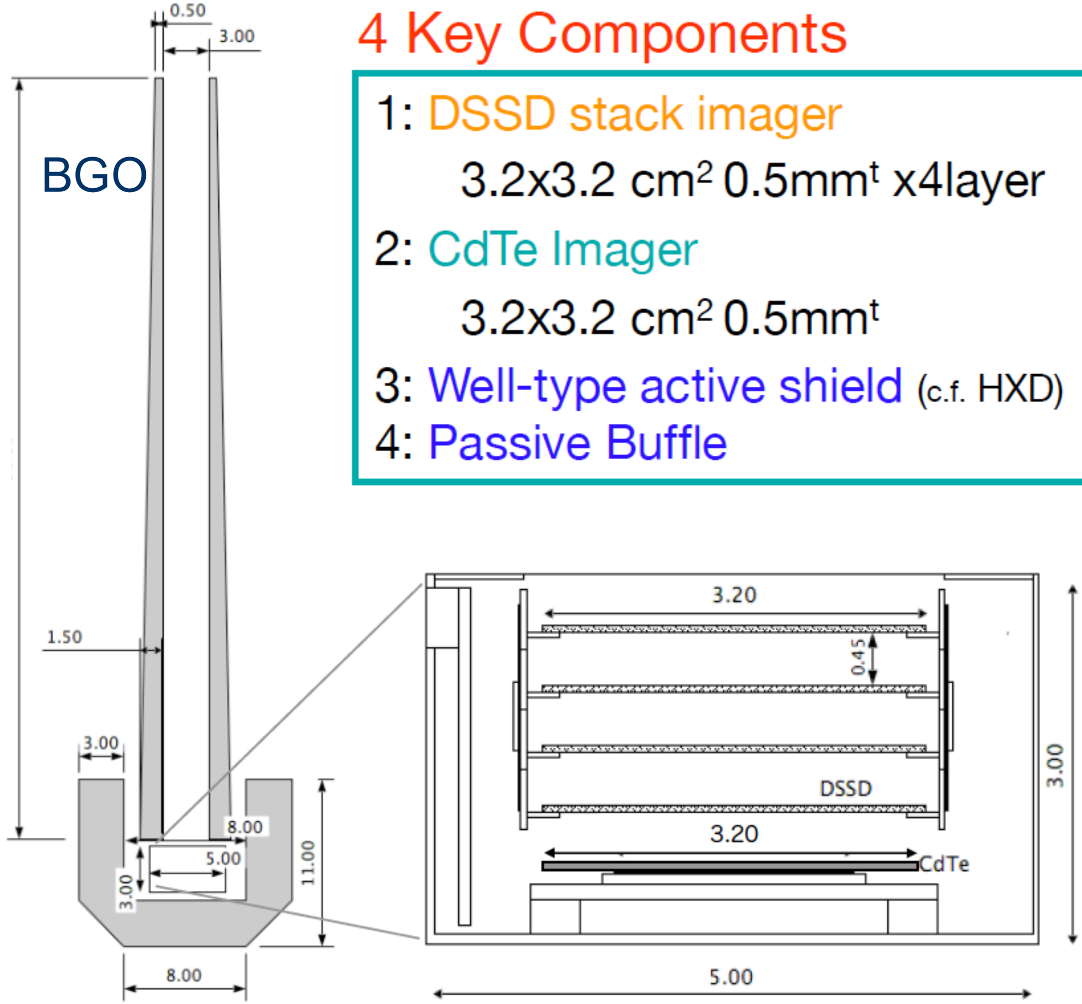
4x larger than Suzaku!

SXT-I (Soft X-ray Telescope)/SXI (Sard X-ray Imager)	
Focal Length	6 m
Effective Area	360 cm^2 (at 6 keV)
Energy Range	0.3–12 keV
Angular Resolution	< 1.7 arcmin (HPD)
Effective FOV	$\sim 35 \times 35$ arcmin
Energy Resolution	< 150 eV (FWHM, at 6 keV)
Timing Resolution	4 sec
Detector Background	< a few $\times 10^{-3}$ cts s^{-1} cm^{-2} keV^{-1}
Operating Temperature	−120 °C

Hard X-Ray Imager (HXI)



Energy coverage
DSSD stack 1st:
4-15 keV
DSSD stack all:
15-40 keV
CdTe Imager :
20-80 keV

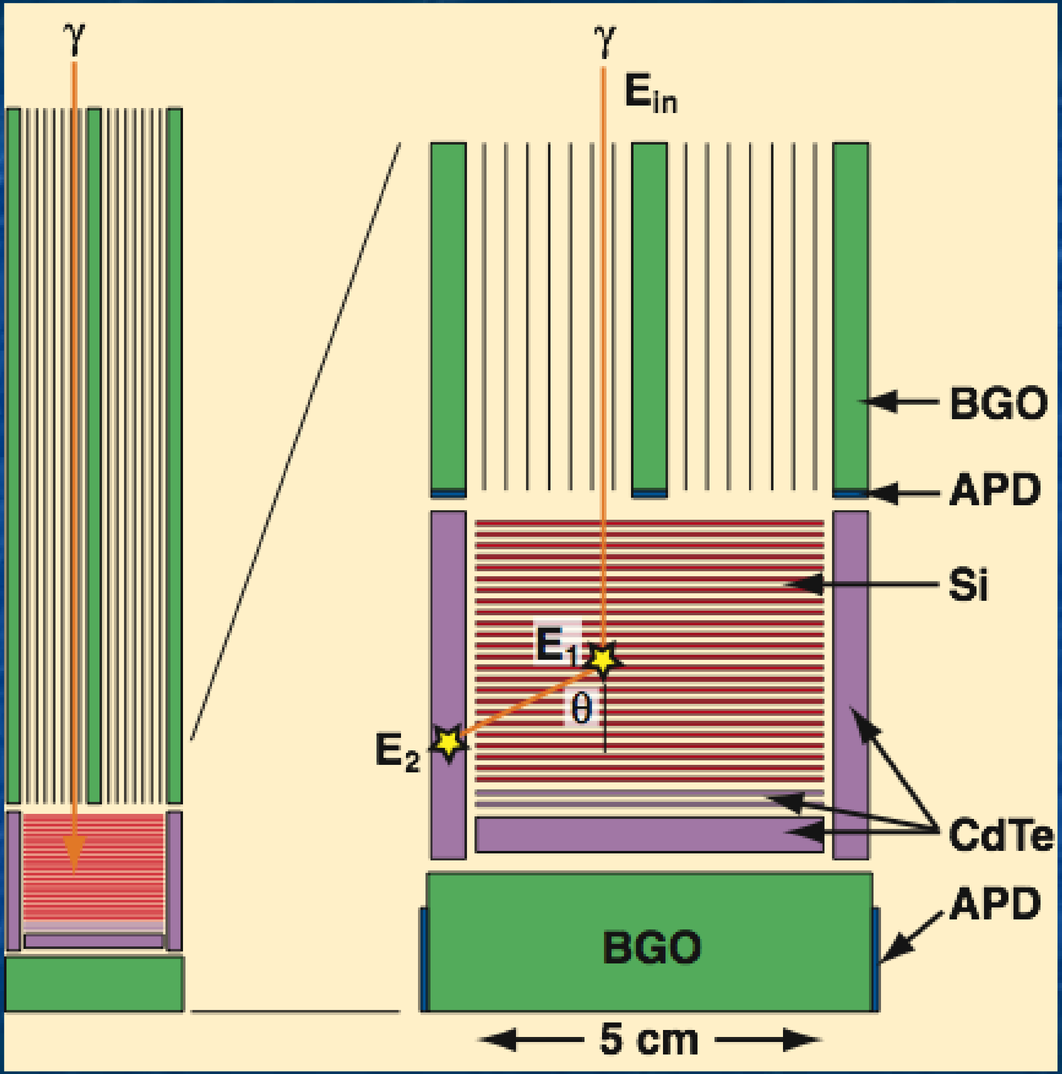


4 Key Components

1: DSSD stack imager
3.2x3.2 cm^2 0.5mm^t x4layer
2: CdTe Imager
3.2x3.2 cm^2 0.5mm^t
3: Well-type active shield (c.f. HXD)
4: Passive Buffle

FOV: 5.1 x 5.1 arcmin. Energy resolution: < 1.5 keV at 60 keV

Soft Gamma Detector



DSSD - 24 layers + CdTe and BSO active shielding

Compton scattering in DSSD + absorption in CdTe

FOV: 0.55 x 0.55 deg < 150 keV

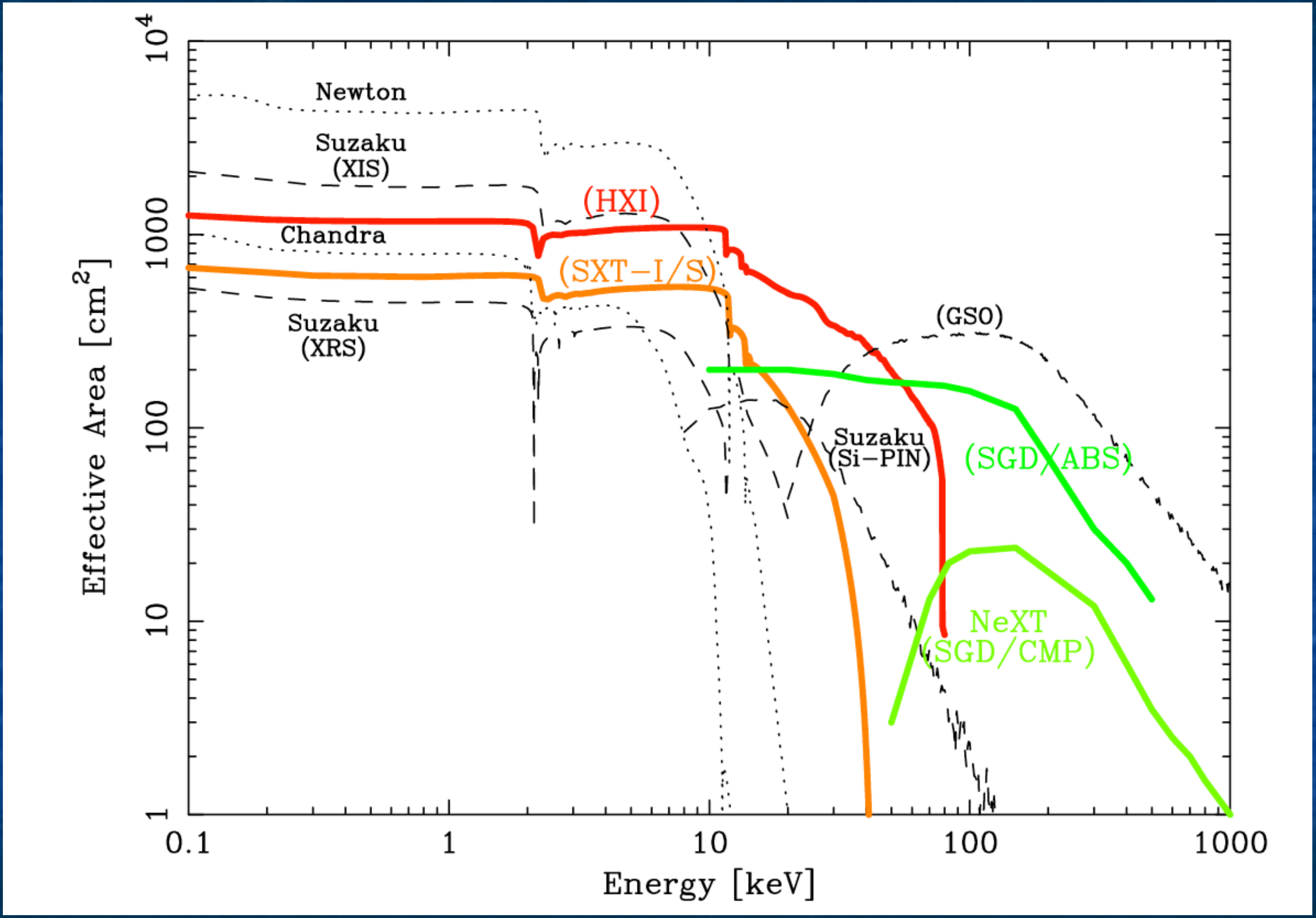
Two units on opposite sides of spacecraft

HXI and SXD Characteristics

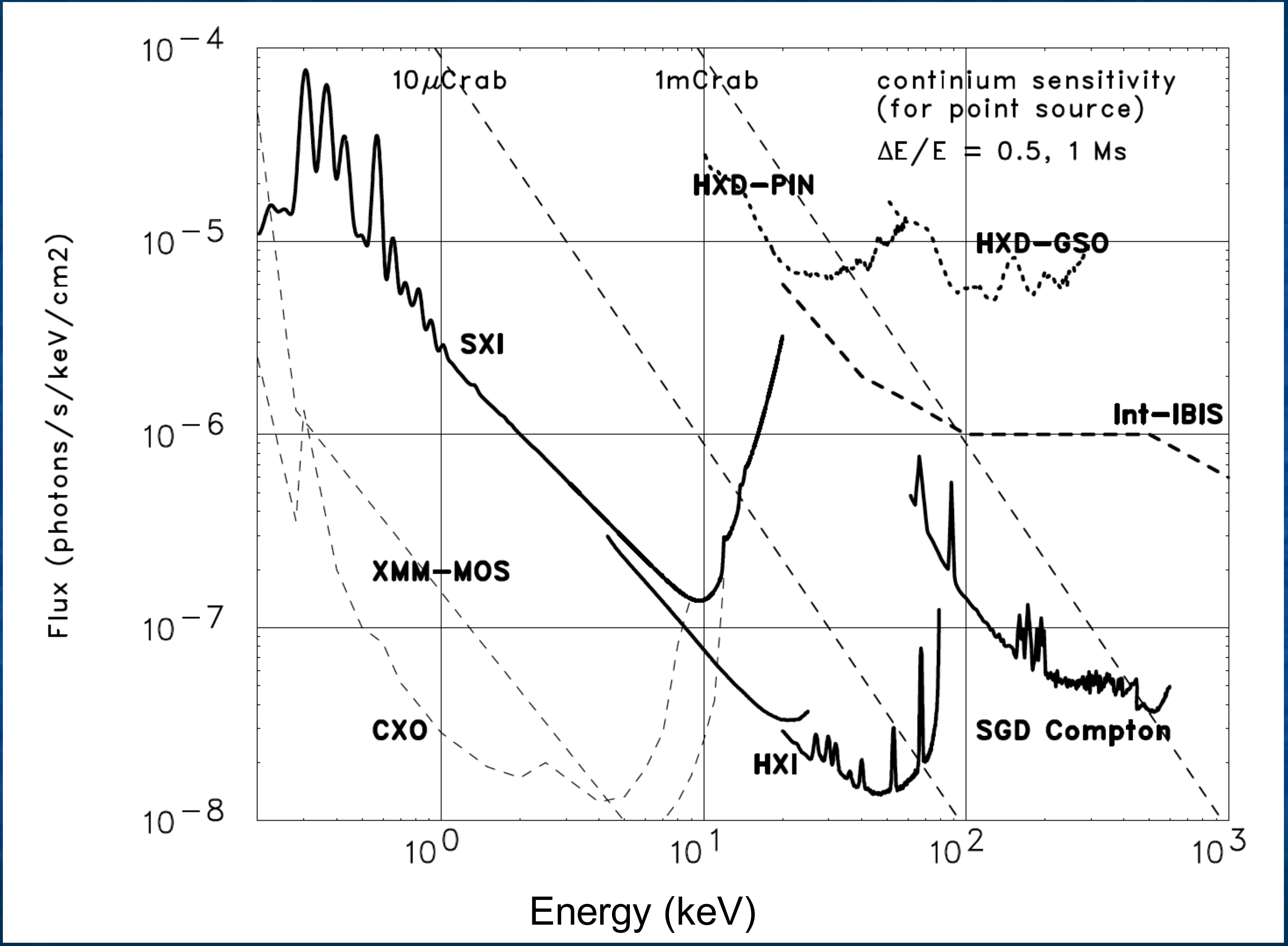
HXT (Hard X-ray Telescope)/HXI (Hard X-ray Imager)	
Focal Length	12 m
Effective Area	300 cm^2 (at 30 keV)
Energy Range	5–80 keV
Angular Resolution	<1.7 arcmin (HPD)
Effective FOV	~9 × 9 arcmin (12 m Focal Length)
Energy Resolution	< 1.5 keV (FWHM, at 60 keV)
Timing Resolution	several 10 μs
Detector Background	< 1–3×10^{-4} cts s^{-1} cm^{-2} keV^{-1}
Operating Temperature	< −20 °C

SGD (Soft Gamma-ray Detector)	
Energy Range	10 keV − 600 keV
Energy Resolution	2 keV (FWHM, at 40 keV)
Effective Area	>200 cm^2 Photo absorption mode (at 30 keV)
	>30 cm^2 (Compton mode, at 100 keV)
FOV	0.55×0.55 deg^2 (< 150 keV)
	$<10 \times 10$ deg^2 (> 150 keV)
Timing Resolution	several 10 μs
Detector Background	< a few $\times 10^{-6}$ cts s^{-1} cm^{-2} keV^{-1}
	(100 − 200 keV)
Operating Temperature	−20 °C

Effective Areas



NEXT Sensitivity



Other Science

Charge exchange emission from comets

Spectroscopic studies of the composition of the hot ISM

Young stars ⇒ dynamics of star formation

Stellar atmospheres - non-thermal components

Planetary nebulae - nucleosynthetic abundances in the extended emission

Pulsar wind nebulae - weak lines ⇒ information on progenitor star

Synchrotron-dominated SNRs - weak lines ⇒ age and evolution

Chemical abundances in AGN host galaxies ⇒ clues to source of accretion

…

GO Program:

We opted for the "Science Enhancement Option" to propose for a well-funded GO program.

The ISAS/JAXA *New Exploration X-Ray Telescope*

Launch date: 2013

Orbit:

circular, 550 km, < 30 deg

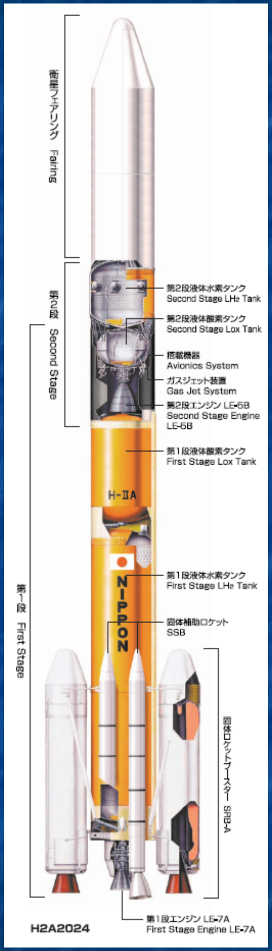
Launch Vehicle:

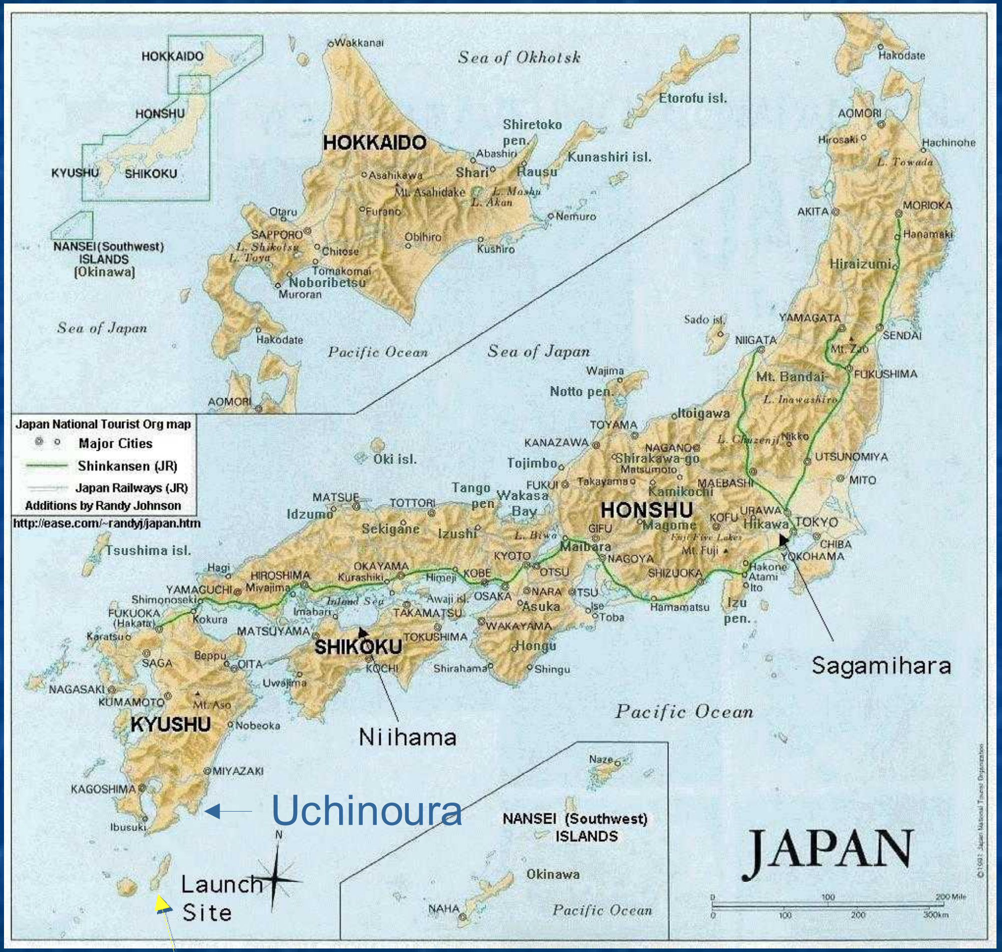
JAXA H-IIA

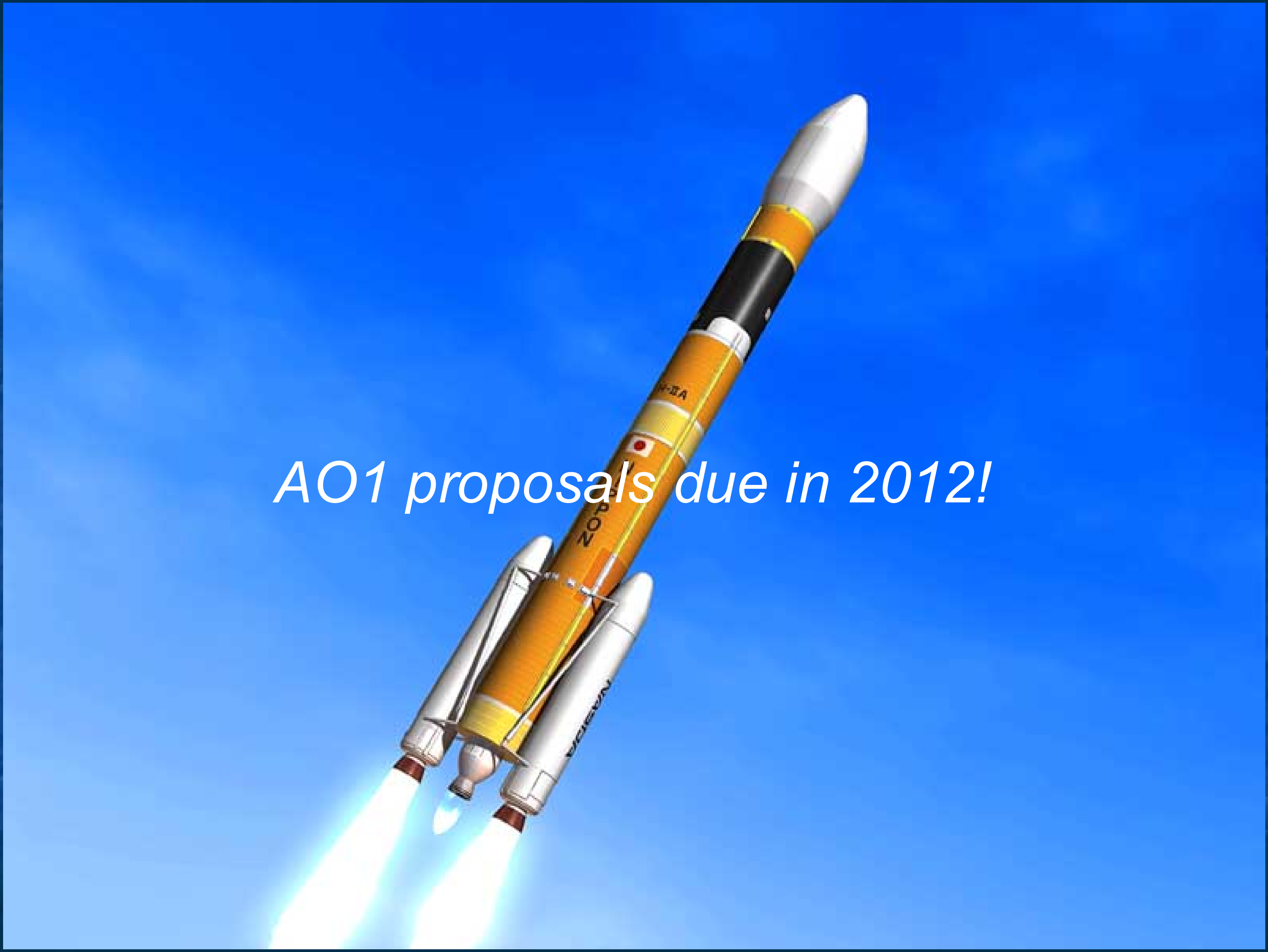
Launch site:
Tanegashima, Japan

Observatory mass:

2000 kg







AO1 proposals due in 2012!

Science Team

NASA/Goddard
- L. Angelini
- K. Arnaud
- Z. Arzoumanian
- K.-W. Chan
- J. Cottam
- K. Gendreau
- K. Hamaguchi
- I. Harrus
- A. Hornschemeier
- U. Hwang
- T. Kallman
- R. Kelley
- C. Kilbourne
- J. Lochner
- M. Loewenstein
- K. Mukai
- R. Mushotzky
- T. Okajima
- R. Petre
- F.S. Porter
- R. Sambruna
- P. Serlemitsos
- R. Smith
- Y. Soong

Lawrence Livermore National Lab.
- G. Brown

University of Miami
- M. Galeazzi

University of Wisconsin
- D. McCammon

Ames Research Center
- R. Pisarski

Yale University
- A. Szymkowiak

Stanford University/KIPAC
- T. Kamae
- G. Madejski
- H. Tajima

Inst. of Space & Astronautical Sci.
- K. Mitsuda
- N.Y. Yamasaki
- K. Shinozaki

Tokyo Metropolitan University
- T. Ohashi
- Y. Ishisaki
- Y. Ezoe

Kanazawa University
- R. Fujimoto

RIKEN
- M. Kawaharada