The Astro-H X-Ray Observatory

Richard Kelley, for the International Astro-H Team
NASA/Goddard Space Flight Center

Astrophysics Subcommitte
NASA HQ October 20, 2011

International Partnerships

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* Competitively selected via NASA call

Astro-H at a Glance

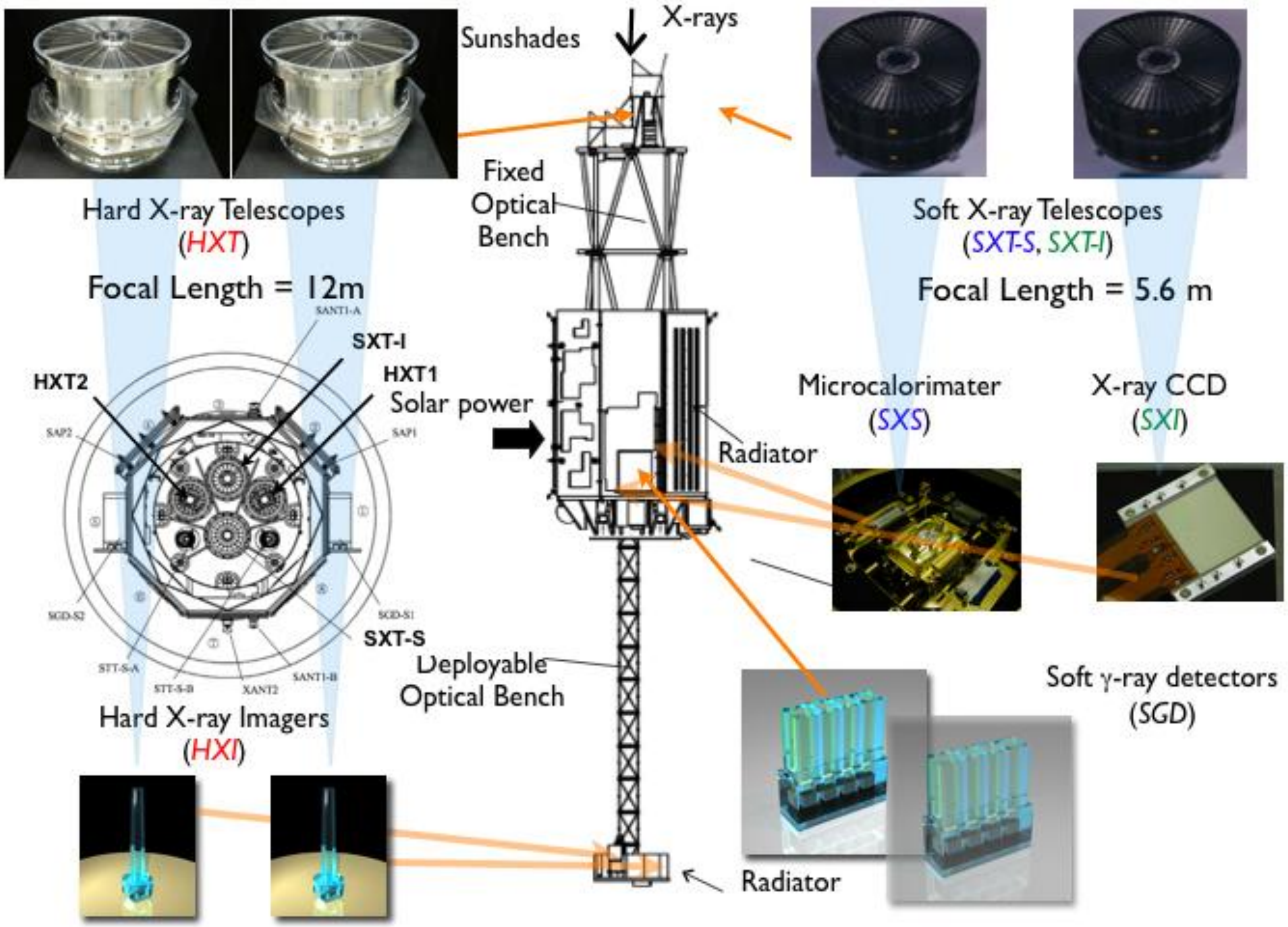
26th Science Satellite of Japan
6th X-Ray mission

Suzaku (6m, 1.7t)

- Launch in 2014
- Launch site:
  Tanegashima Space Center, Japan
- Launch vehicle: JAXA H-IIA rocket
- Orbit Altitude: 550 km
- Orbit Type: Approximate circular orbit
- Orbit Inclination: ~ 31 degrees
- Orbit Period: 96 minutes
- Total Length: 14m
- Mass: 2.7 metric ton
- Power: 3.5 kW
- Telemetry Rate: > 8 Mbps (X-band)
- Recording Capacity: > 12 Gbits
- Mission life: > 3 years

Institute of Space and Astronautical Science (ISAS/JAXA)

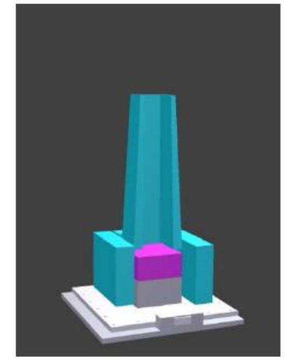
Astro-H Instruments and Configuration



Institute of Space and Astronautical Science (ISAS/JAXA)

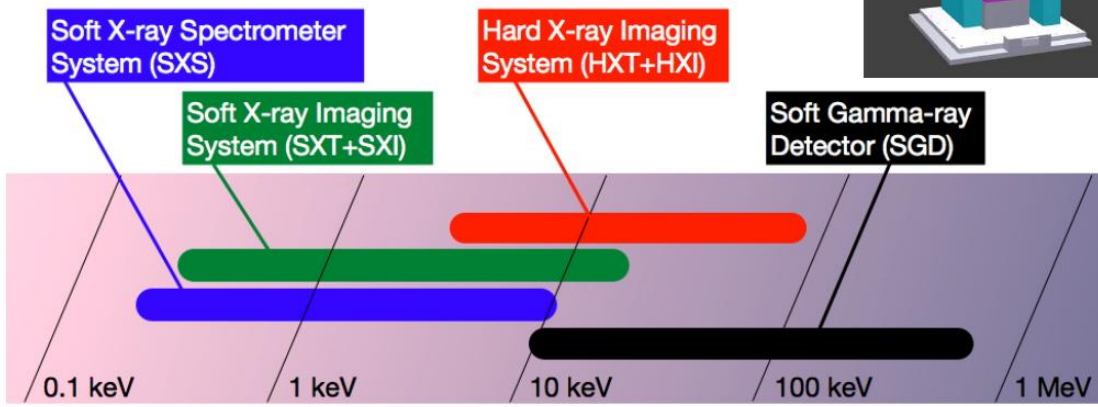
Broad-band Imaging Spectroscopy

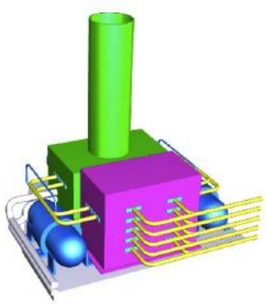
All instruments co-aligned and operate simultaneously

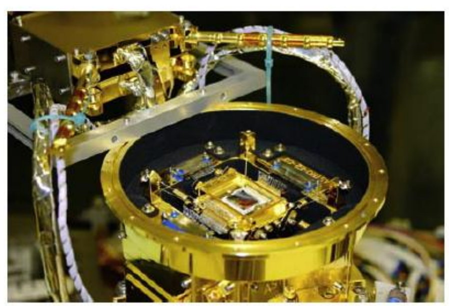


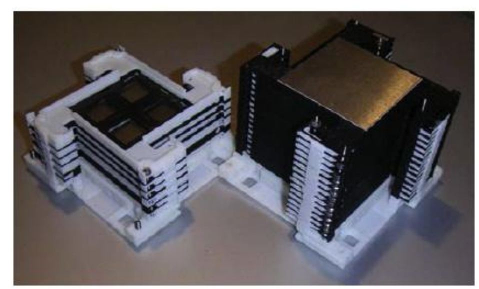
Spectroscopy + Imaging

0.3 keV - 600 keV







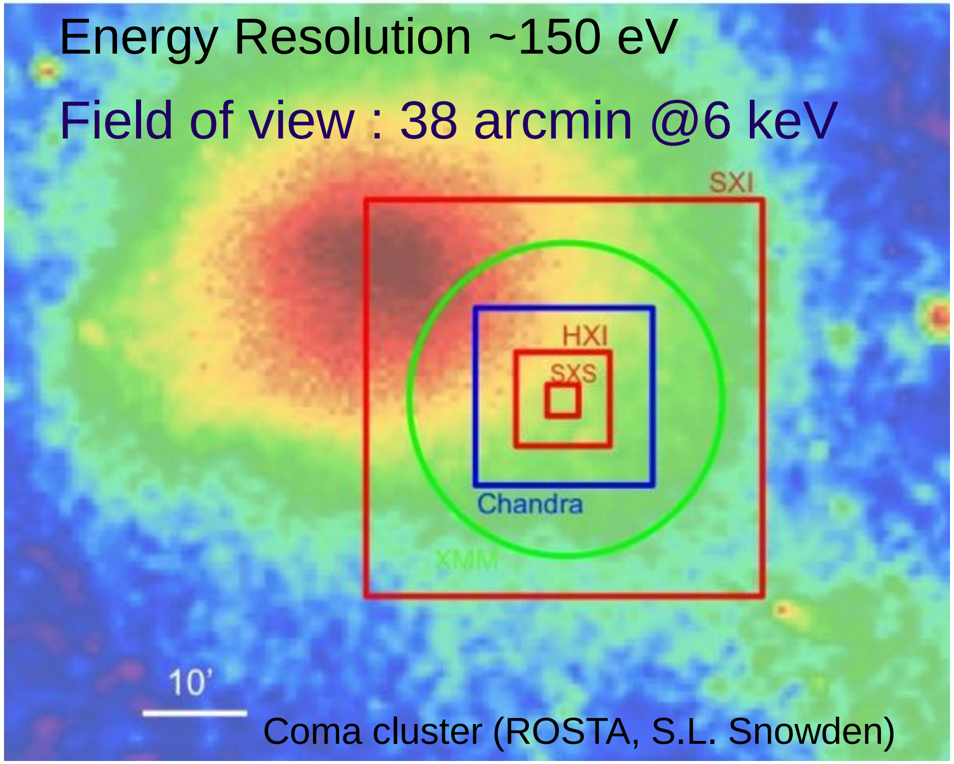


Soft X-ray Imager (SXI): X-ray CCD

Large FOV X-ray CCD (F.L. 5.6 m)

Energy Resolution ~150 eV

Field of view : 38 arcmin @6 keV



Coma cluster (ROSTA, S.L. Snowden)

4 CCD chips/62x62mm^2

Depletion Layer ~200 micron

Recent Progress

EM Model/

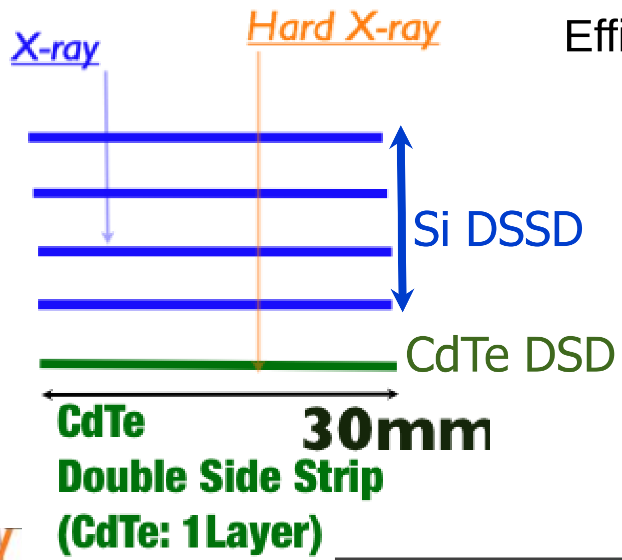
Thermal Balance Test

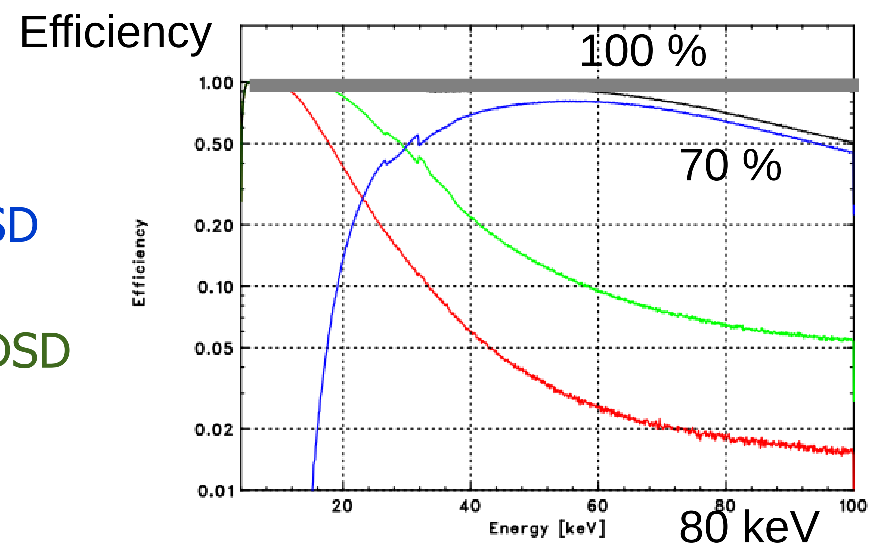
(2011/June)

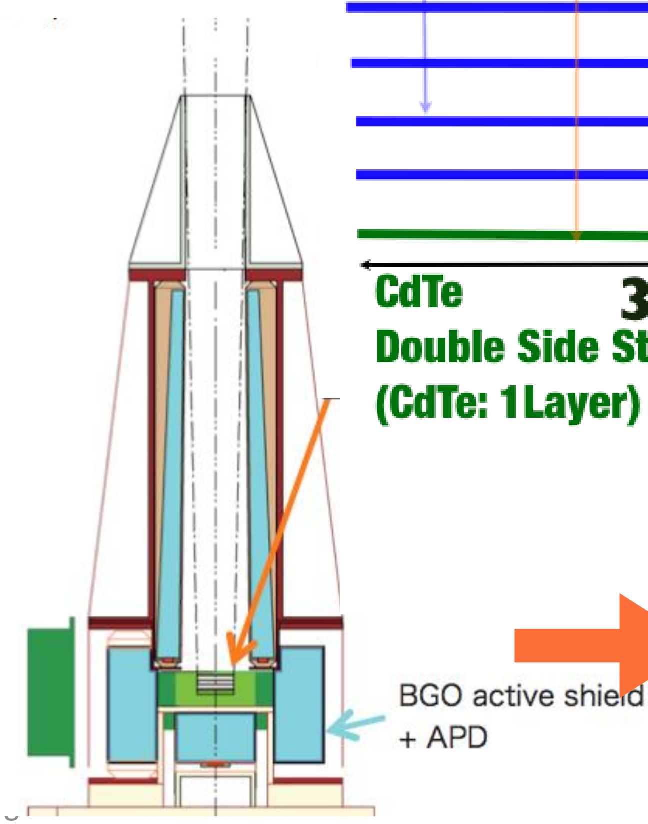
Hard X-ray Imager (HXI)

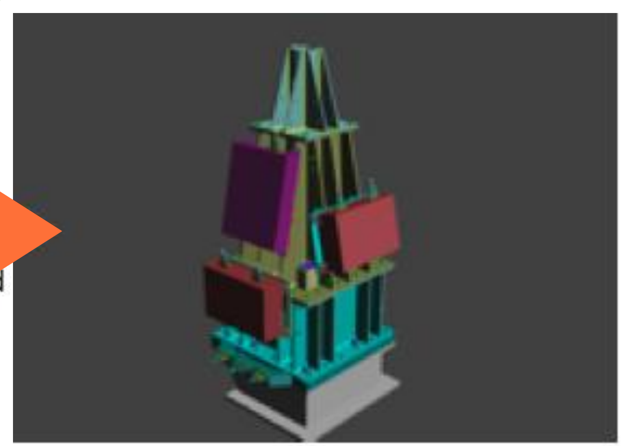
Si and CdTe Hybrid Imager (5 - 80 keV):

Soft X-ray photons below < 20 keV are absorbed in the Si part (DSSD), while hard X-ray photons go through the Si part and are detected by the newly developed CdTe double sided cross-strip detector





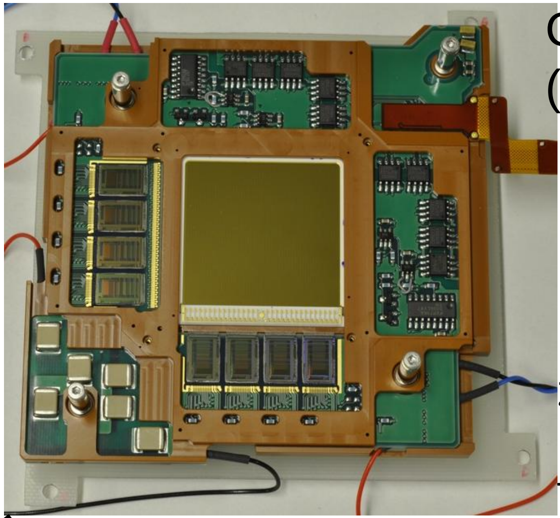




“Stacked Si/CdTe Detector” and “Well-type BGO shield” will reduce background

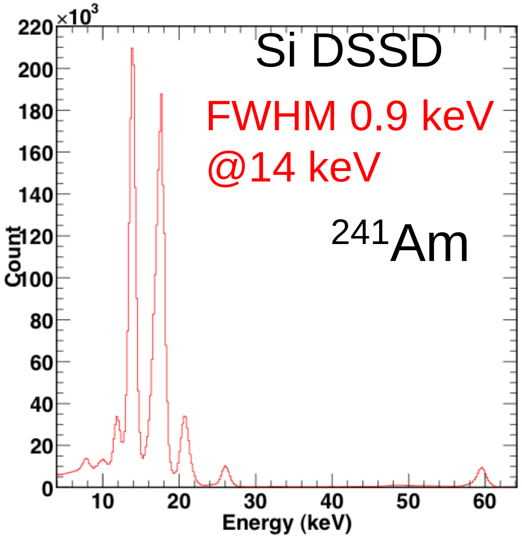
Hard X-ray Imager (HXI) :

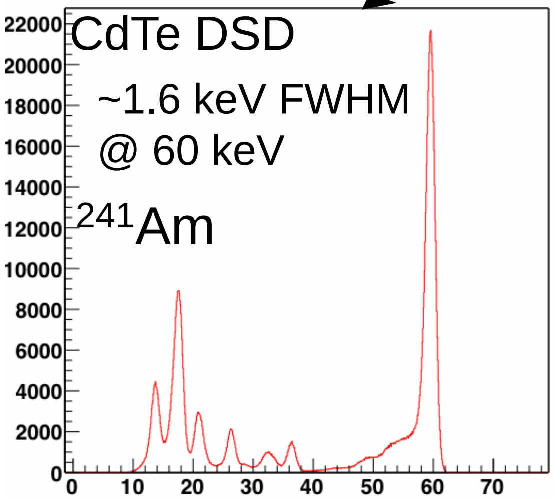
Engineering Model
4 layer of Si DSSD and 1 layer of CdTe DSD

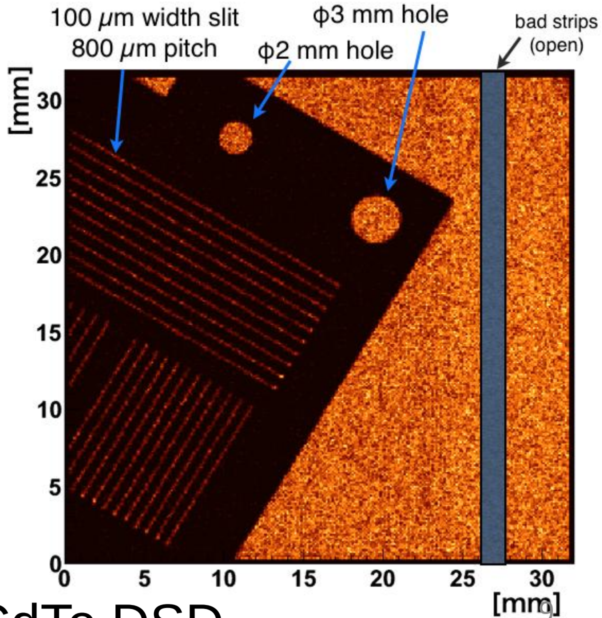


CdTe DSD
(ISAS)

250 micron
pitch strips
for both side



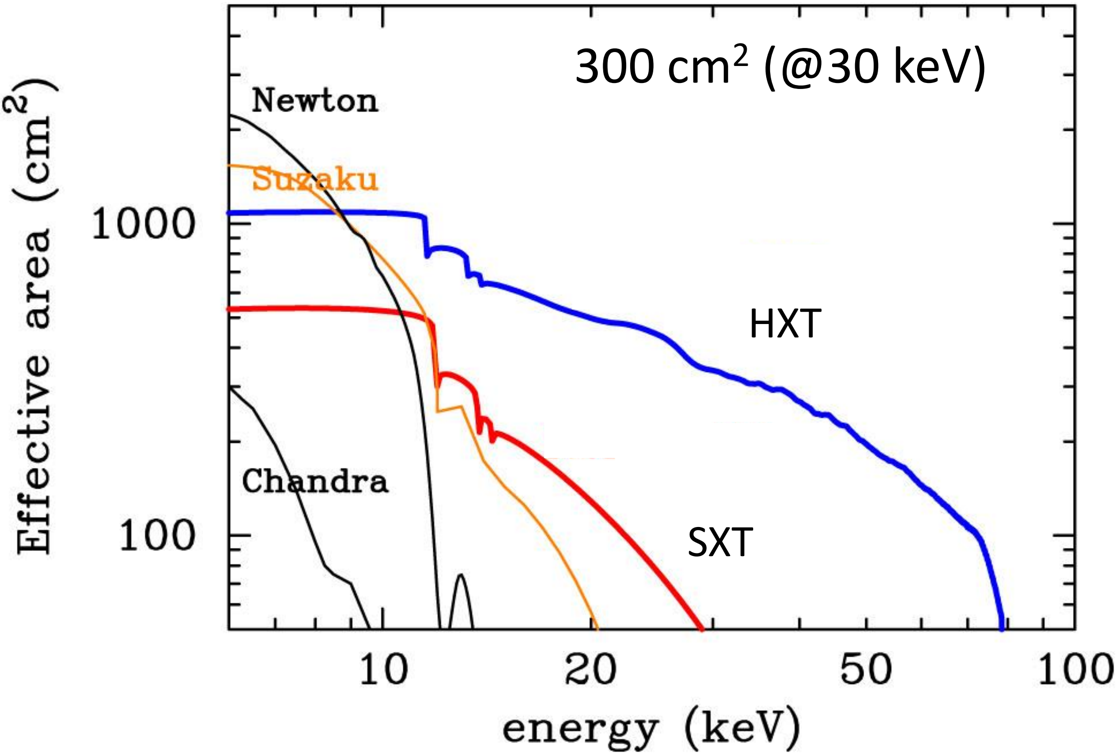


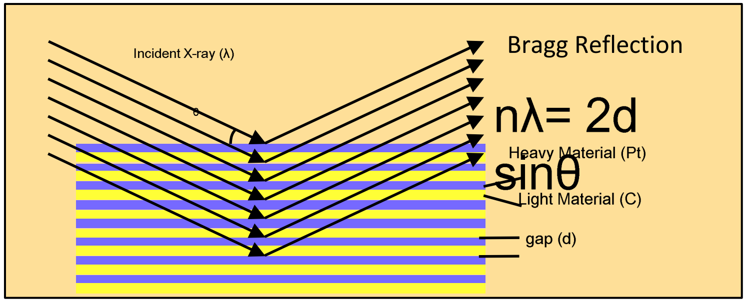


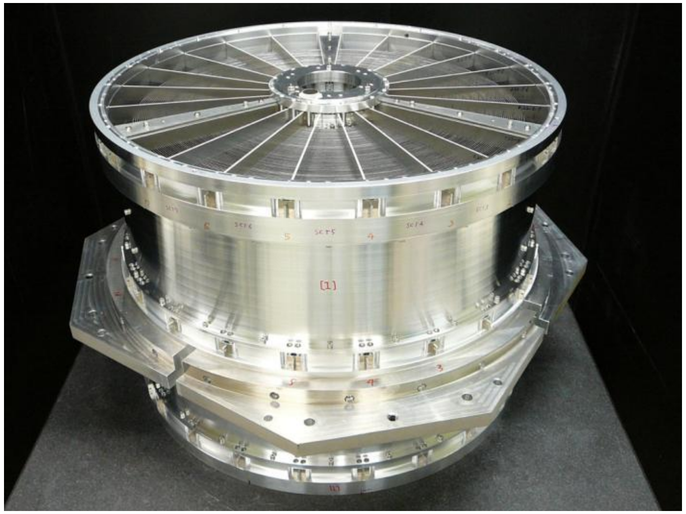
CdTe DSD

Hard X-ray Telescope (HXT)

- Pt/C depth-graded multilayer X-ray telescope
- Large photon collecting area: out to ~ 80 keV.
- Calibration using SPring-8 Hard X-ray Beam line is going on



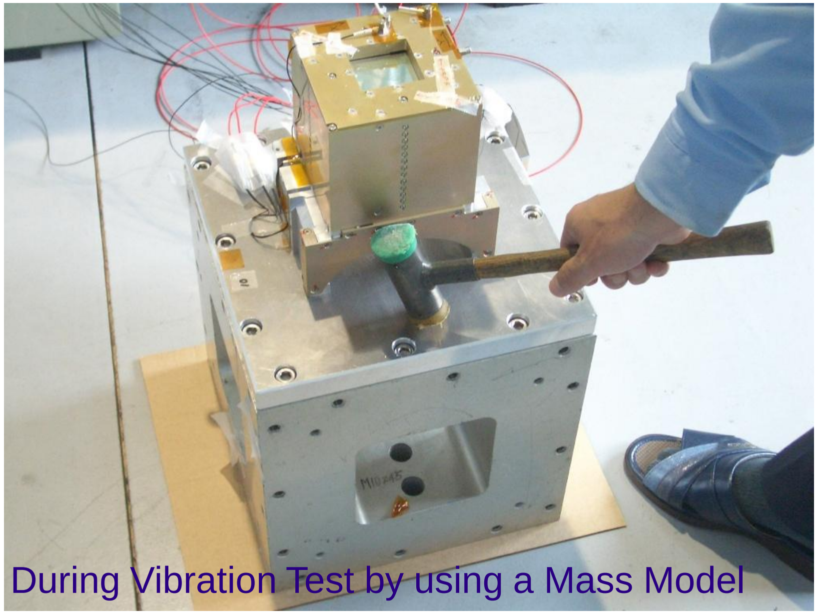




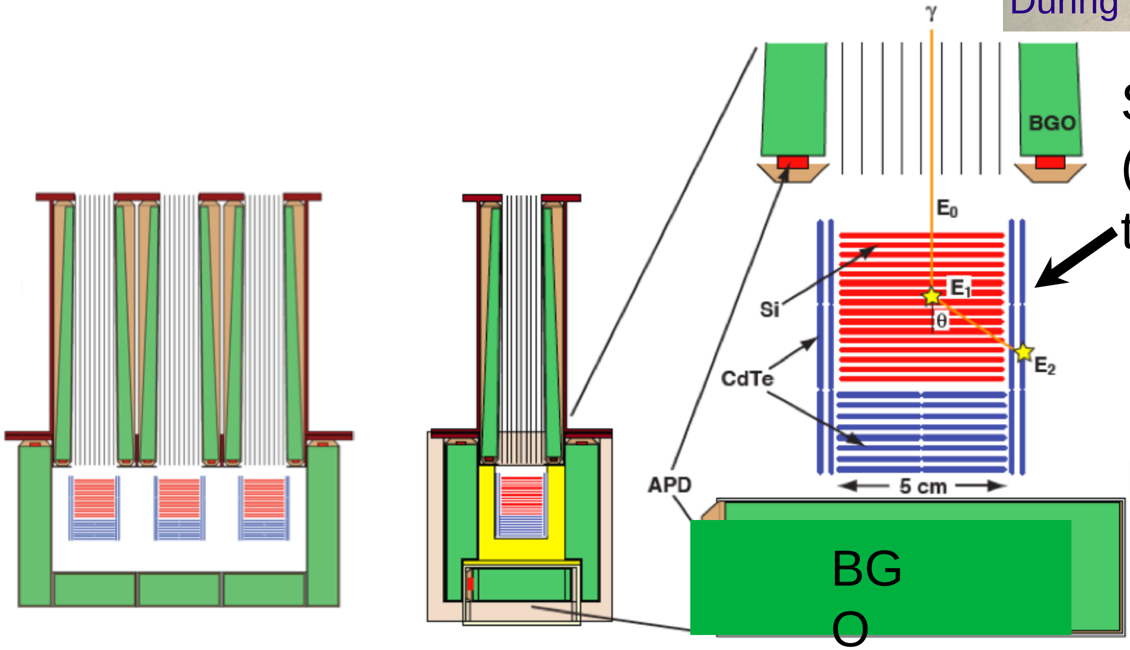
HPD requirement of < 1.7 arcmin

Soft Gamma-ray Detector (SGD)

- Si/CdTe Compton Gamma Camera and Well-type shield to achieve ultimately low background. (40 - 600 keV)
- The Compton Camera enables us to measure polarization > 60 keV.
- GRB Monitoring using BGO shield.



During Vibration Test by using a Mass Model



Si/CdTe Compton Camera (only select gamma-rays from the FOV)

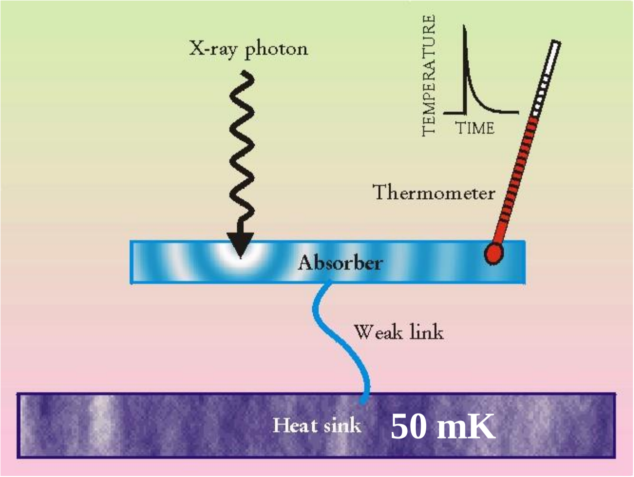
Compton Kinematics

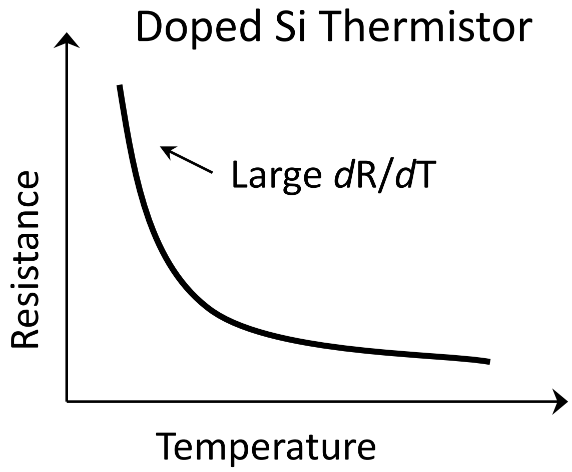
$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$

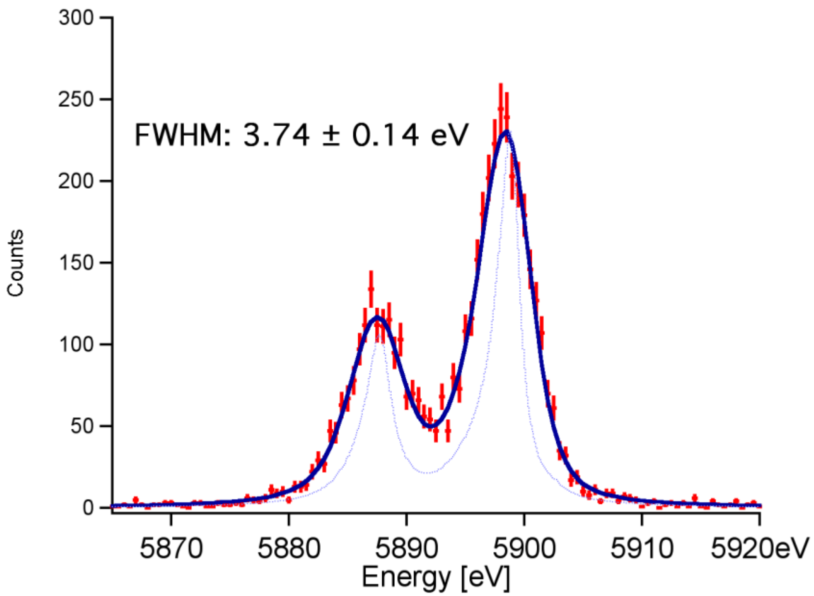
$$E_{\text{in}} = E_1 + E_2$$

The X-Ray Calorimeter

Non-dispersive spectrometer







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

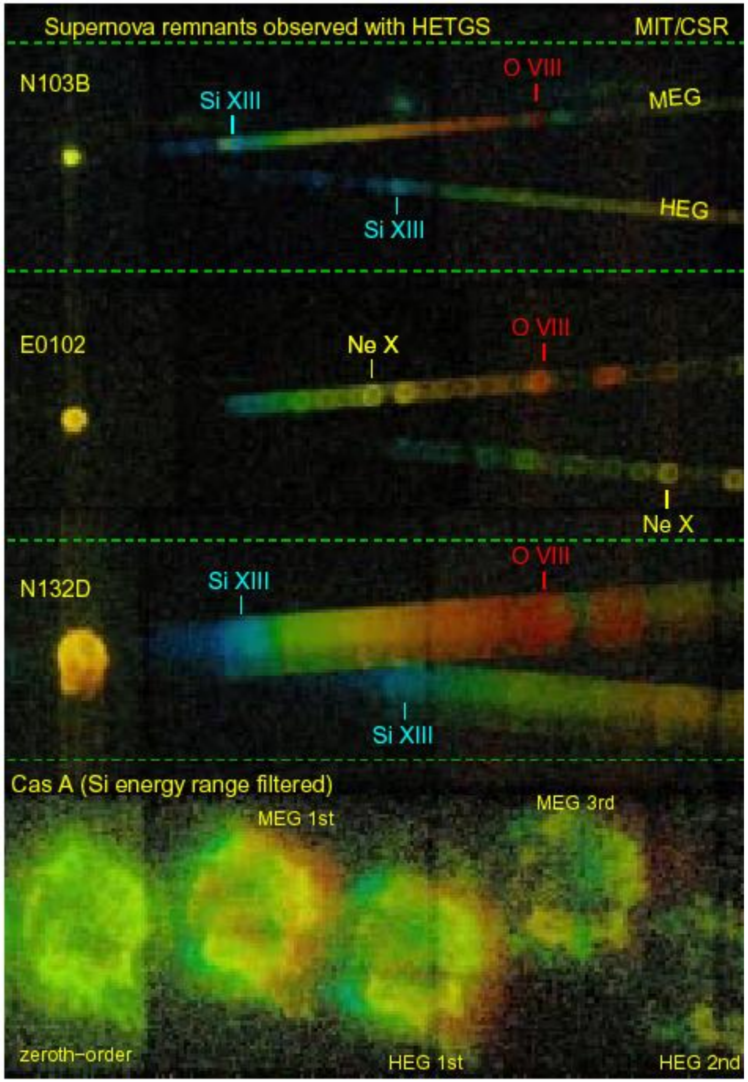
- Energy resolution is limited by thermodynamics
  - ➢ Energy resolution of several eV possible, nearly independent of energy.
- Array of calorimeters provides imaging x-ray spectroscopy.

Calorimeter offers major advantage over dispersive spectrometers

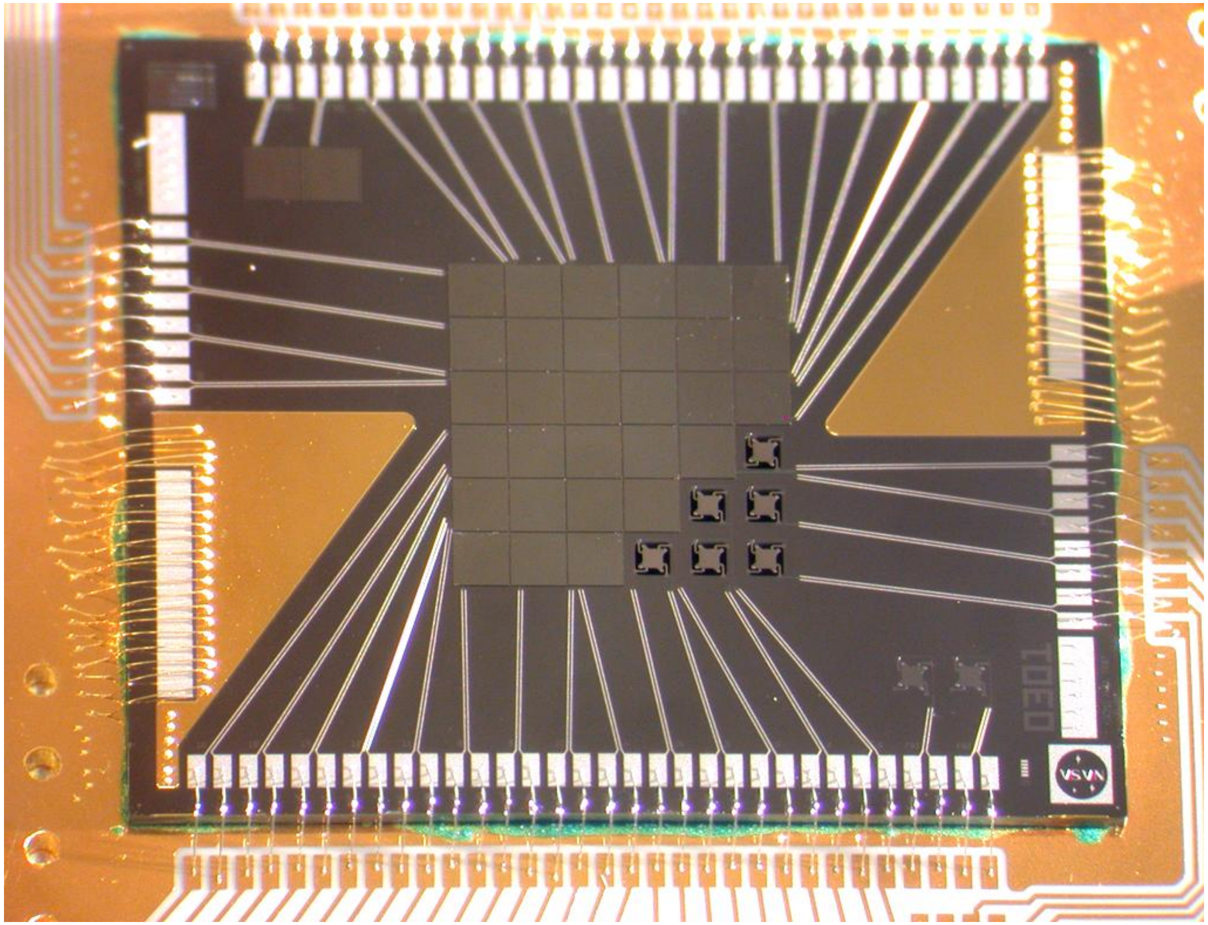
- Gratings work by dispersing the spectrum across a position sensitive detector, but at the expense of confusion in spectra from spatially extended objects (and much of what we want to observe is spatially extended).
- Gratings have a spectral resolution that is a constant $\Delta\lambda$, thus resolving power degrades with increasing energy.

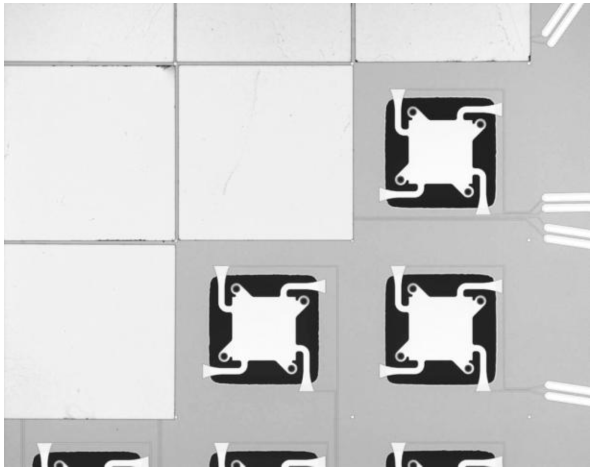
$$\mathcal{R} = \lambda/\Delta\lambda = E/\Delta E$$

- The x-ray calorimeter detects individual x-ray photons with nearly constant ΔE, so resolving power increases with energy.
- The x-ray calorimeter provides an x-ray digital camera that can distinguish thousands of x-ray colors. *SXS will pioneer this capability.*



SXS X-Ray Calorimeter Array (EM assembly)





6 x 6 calorimeter array

Ion-implanted Si thermometer

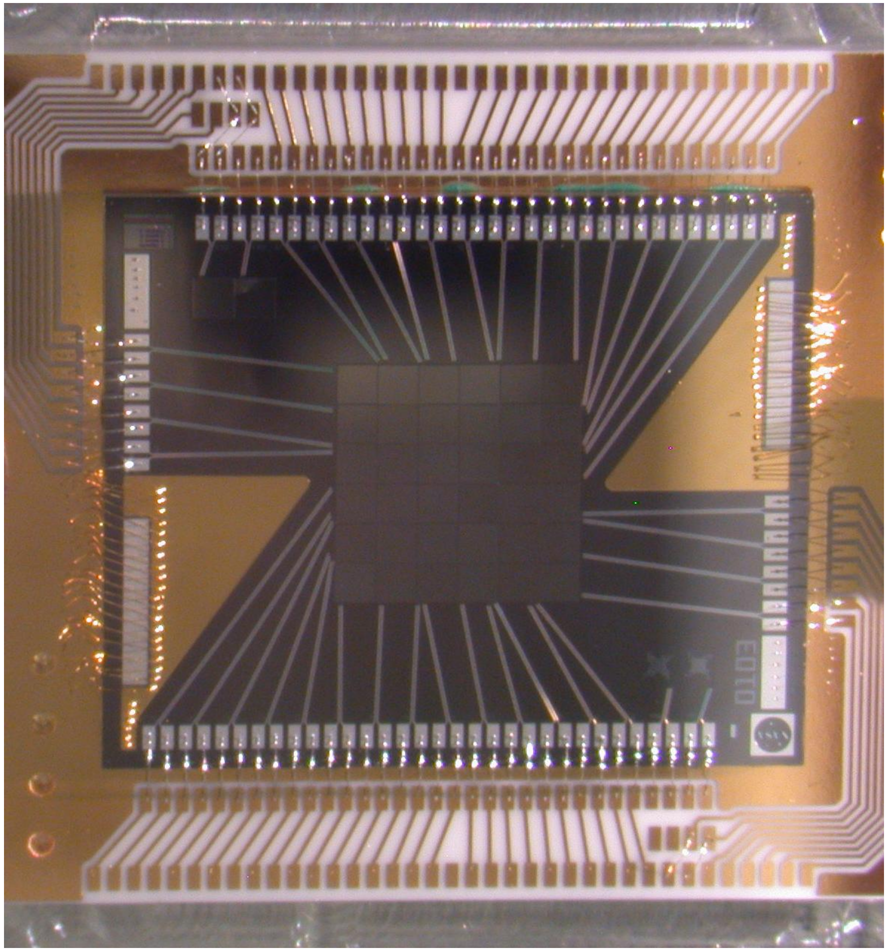
HgTe absorber
(~ 8 microns thick)

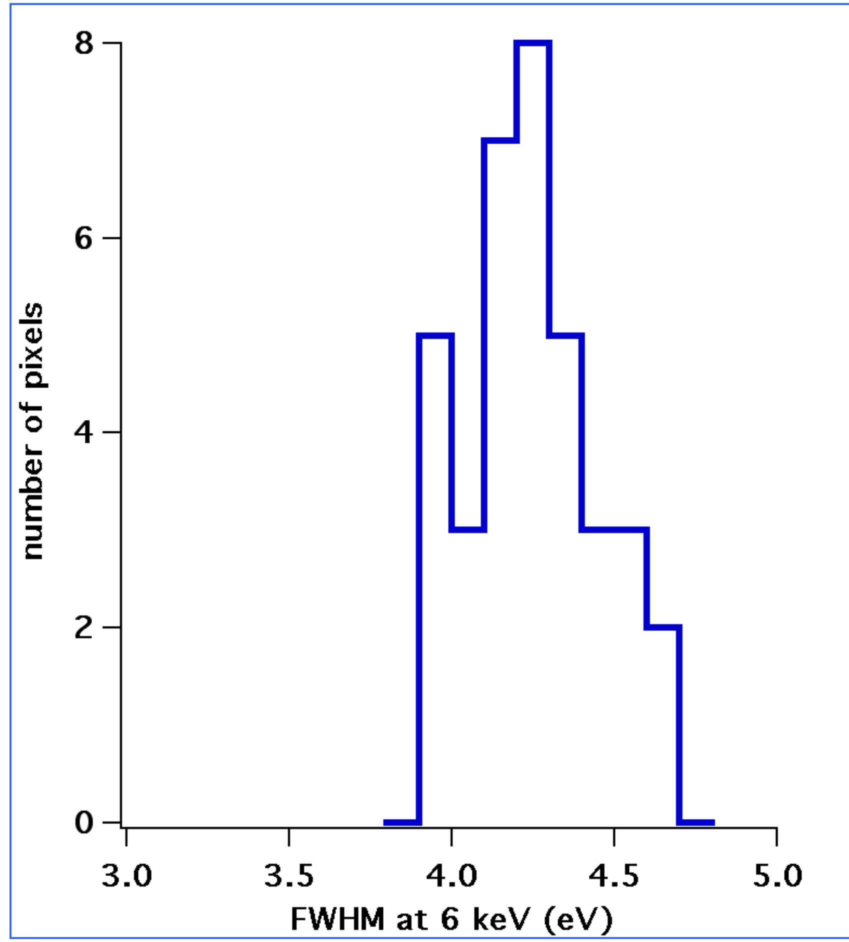
824 x 824 microns

(30 x 30 arcsec)

14

1^{st} flight model array complete and ready





Soft X-Ray Spectrometer (SXS)

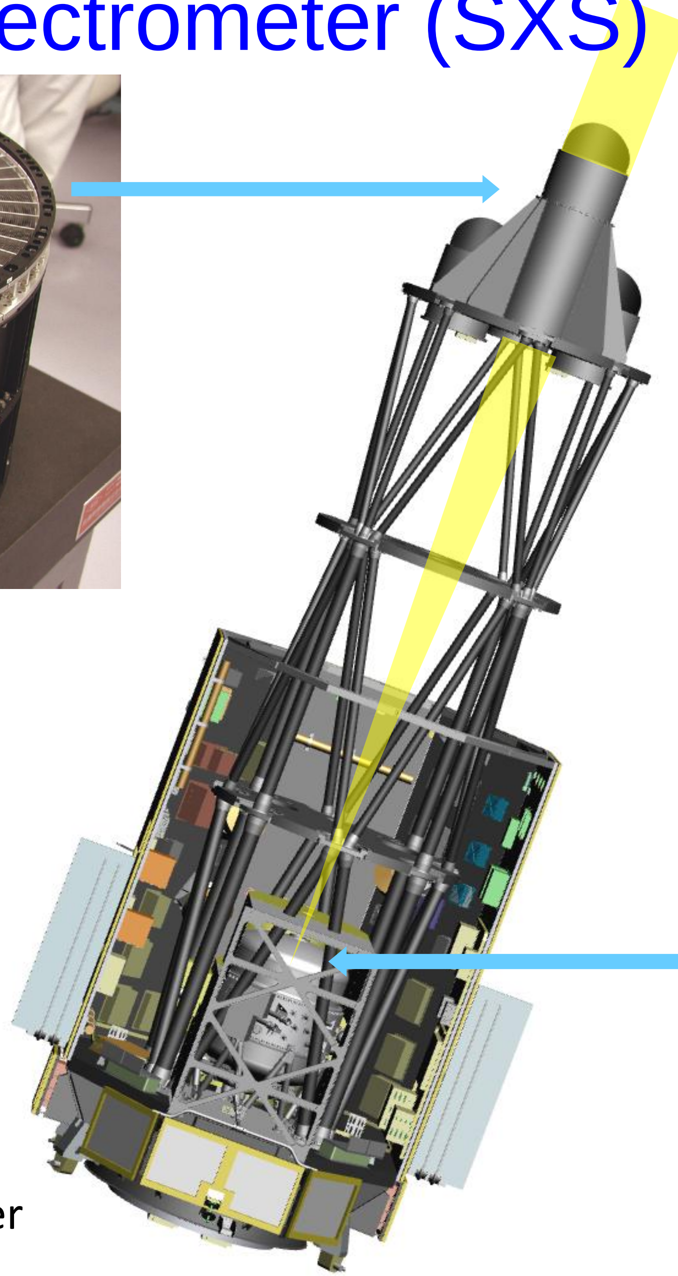
Soft X-Ray Telescope

5.6 m focal length – *fixed optical bench*

203 concentric shells (1624 individual reflectors)

Outer Diameter: 45 cm
Mass: CBE = 46 kg.

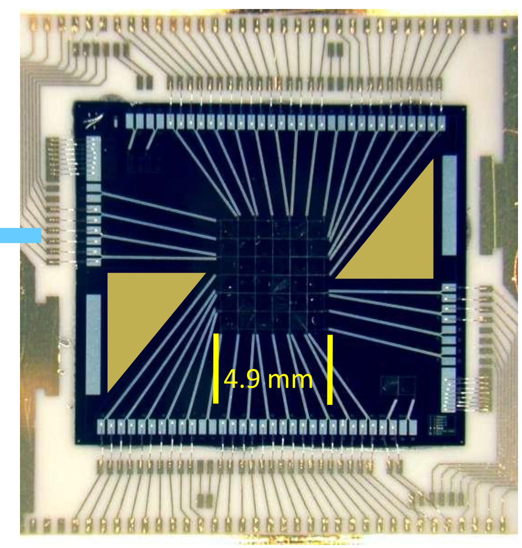
Half-Power Diameter of better than 1.7 arcmin



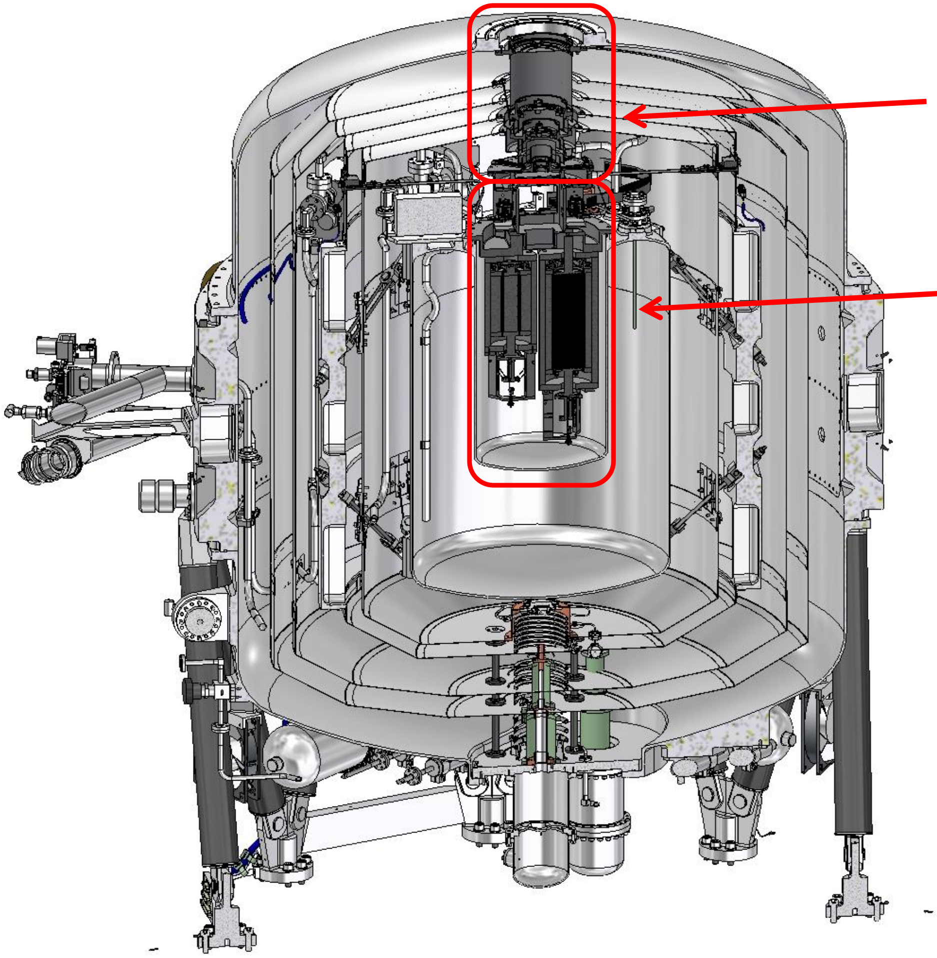
X-ray Calorimeter Spectrometer

SXS – energy resolution better than 7 eV at system level

6 x 6 array of 30” x 30” pixels (3 arcmin field of view)

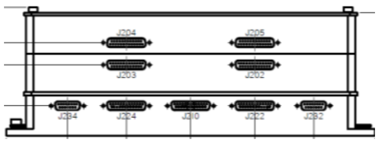


NASA components of SXS



Aperture Assembly: blocking filters, filter mounts, heaters and thermometers

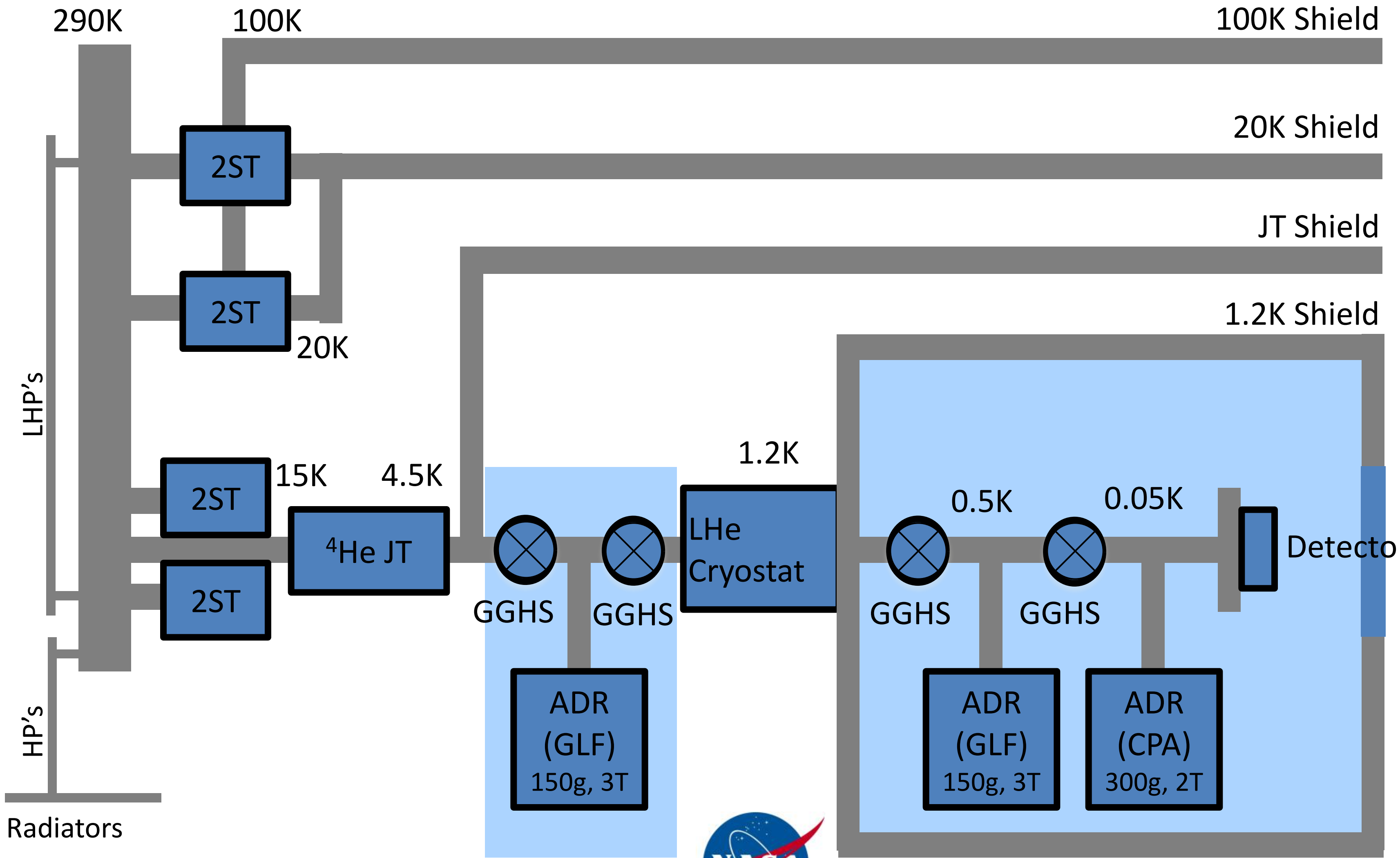
Calorimeter Spectrometer Insert (CSI): detector system and 3-stage ADR



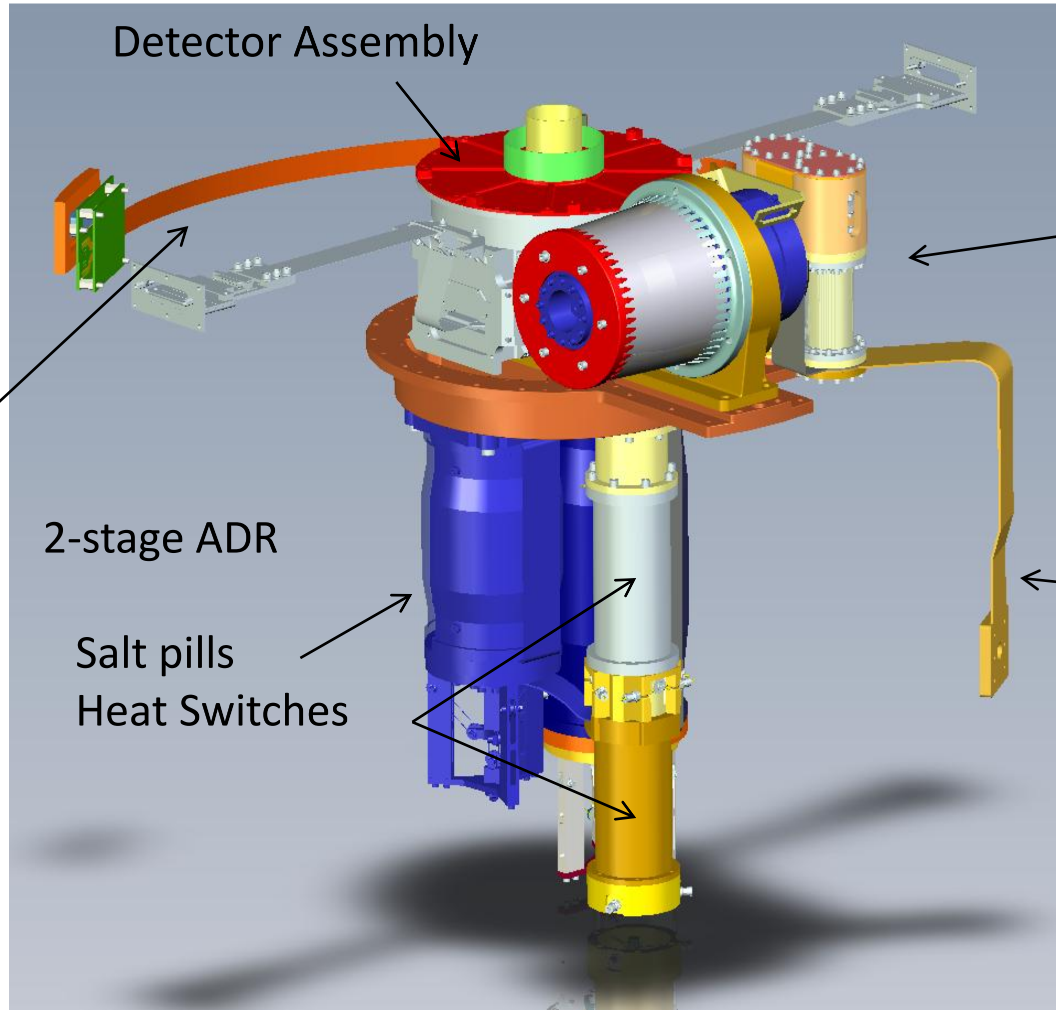
Signal amplifier and digitizer (“Xbox”)

ADR Controller

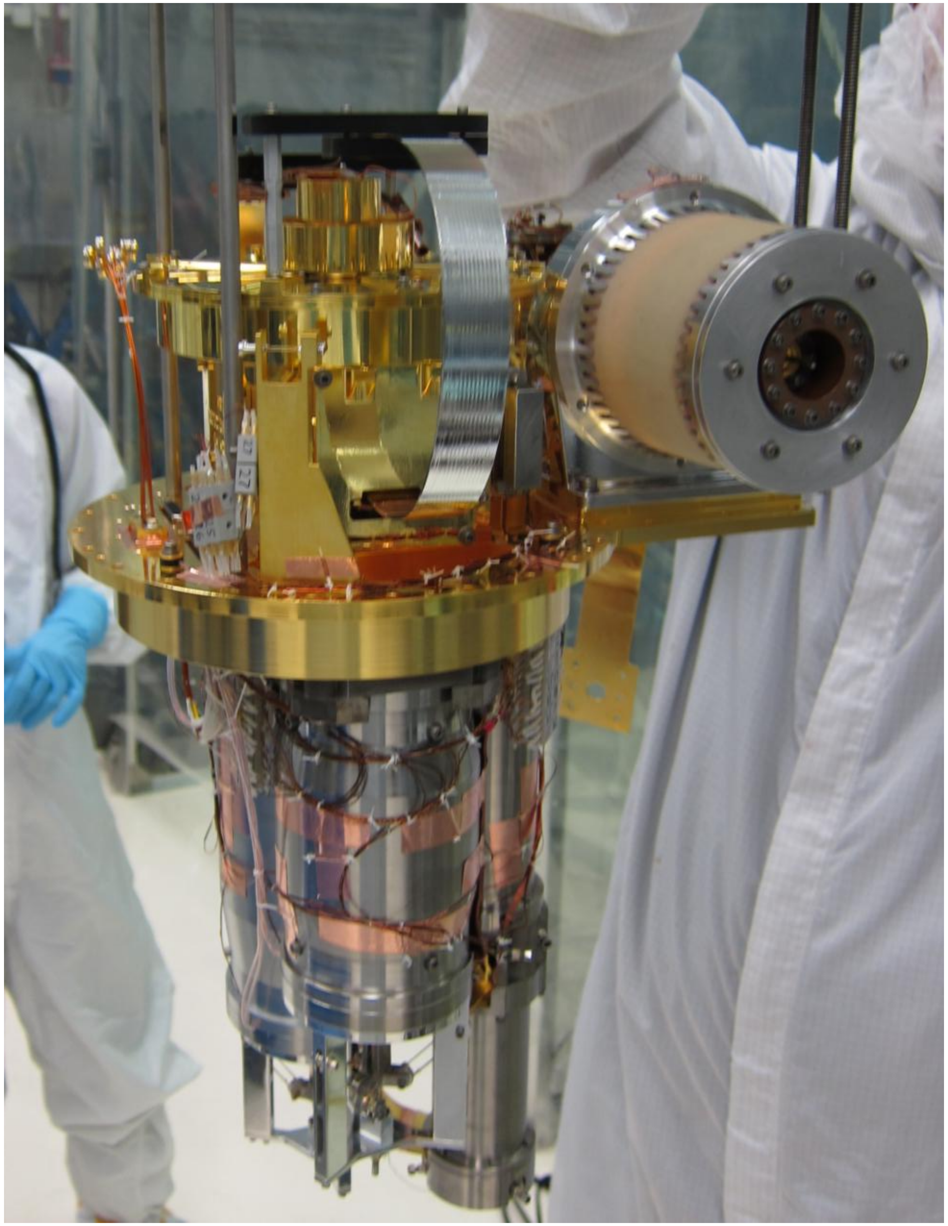
Redundant Cooling System



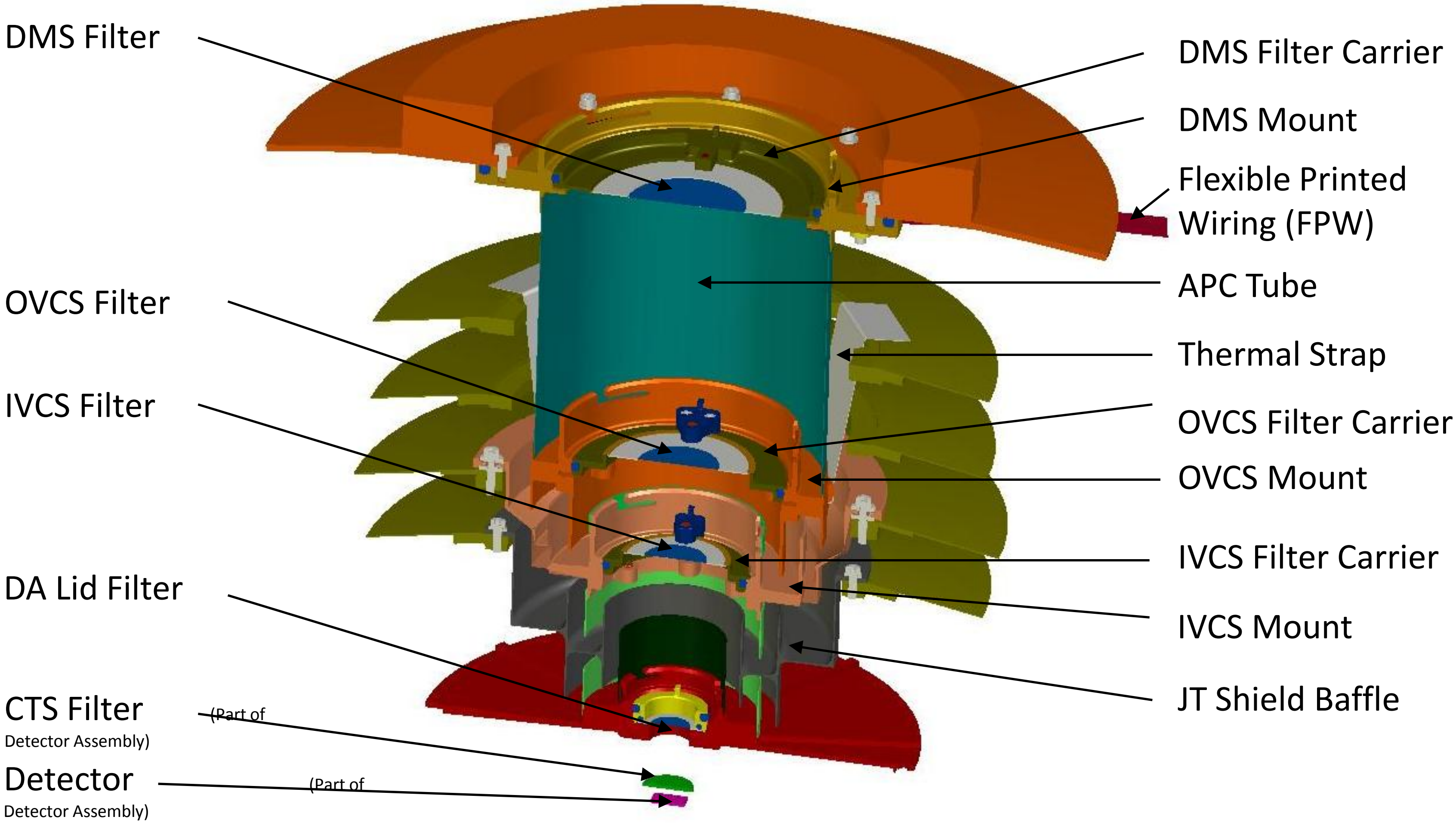
Calorimeter Spectrometer Insert (CSI)



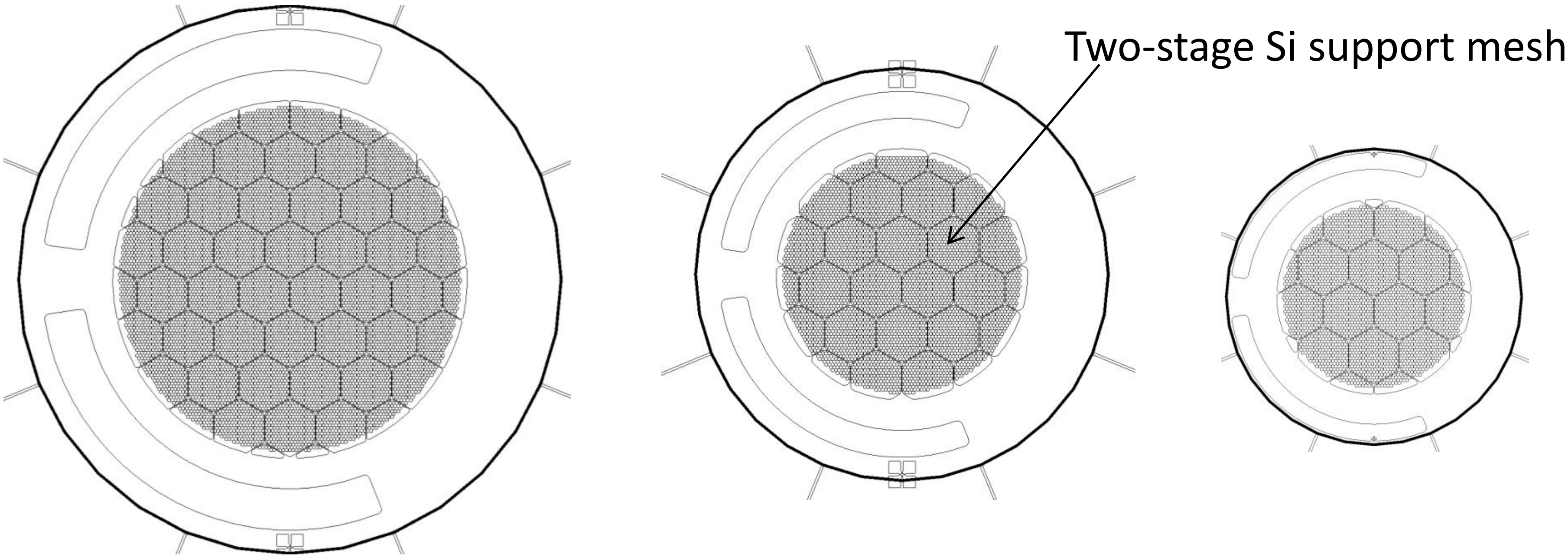
ADR – 1st and 2nd stages



Aperture Assembly & Blocking Filters

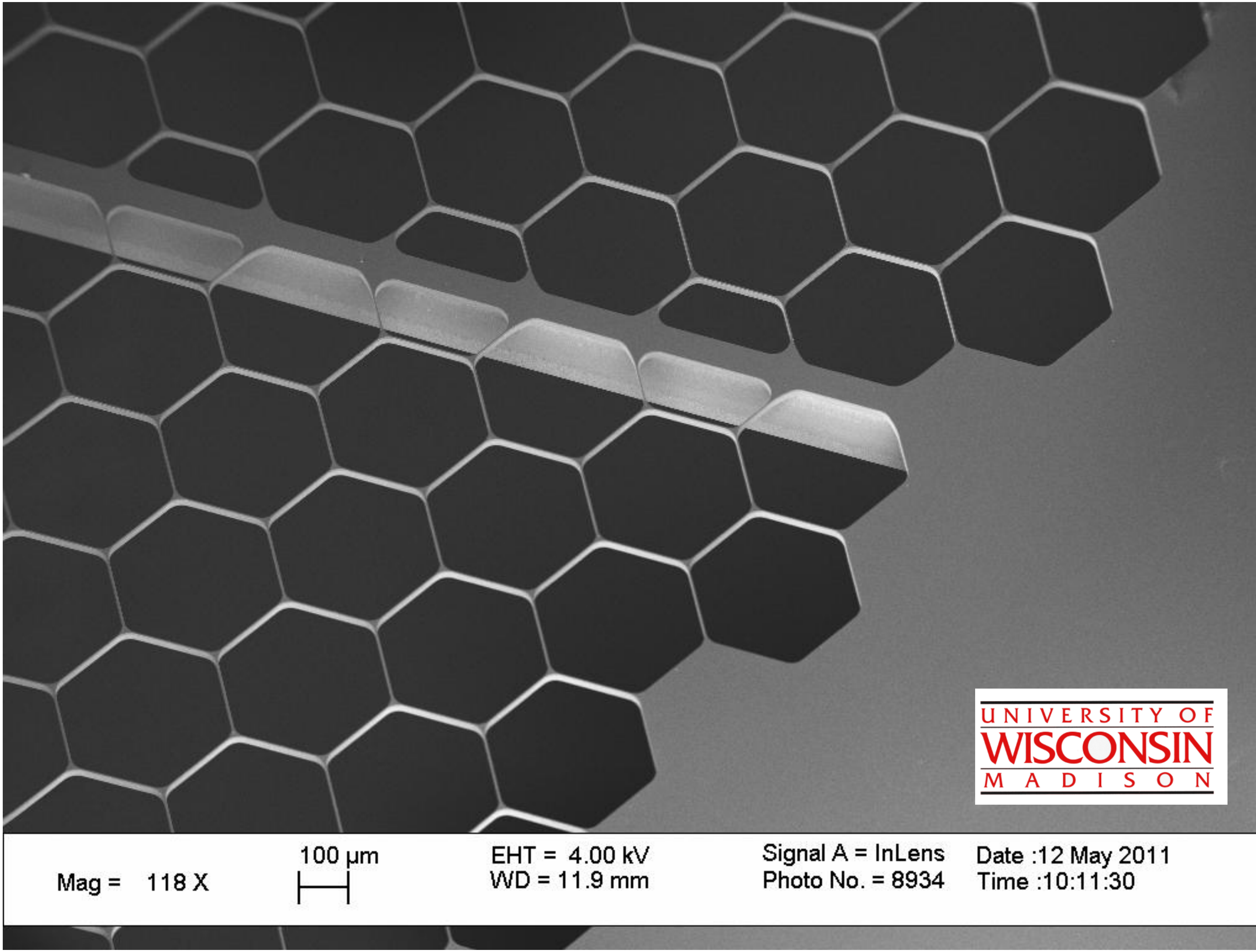


Blocking Filters

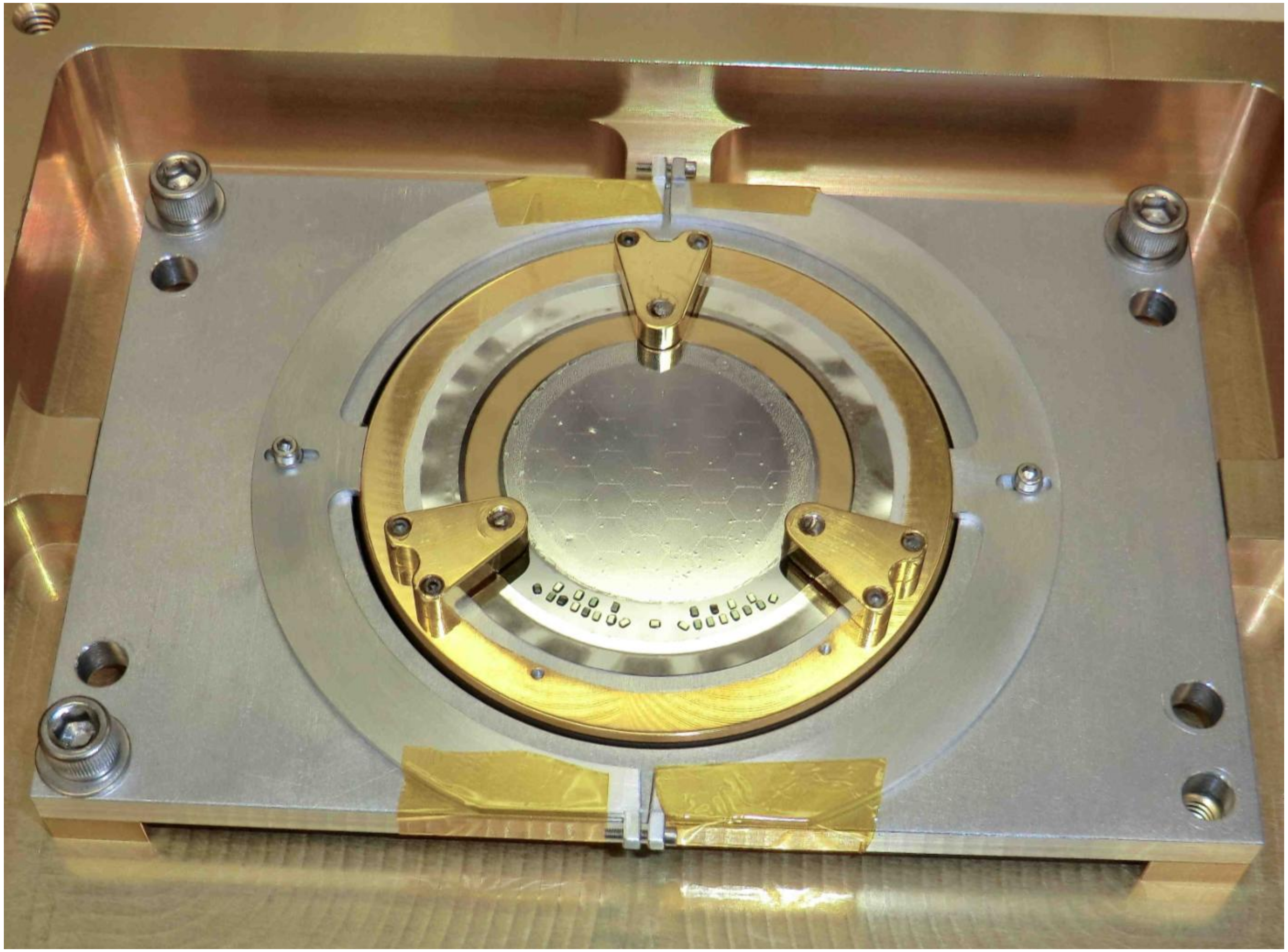


	Dewar Main Shell	OVCS	IVCS
o.d.:	56.0 mm	42.0 mm	30.5 mm
i.d.:	35.0 mm	24.0 mm	18.5 mm

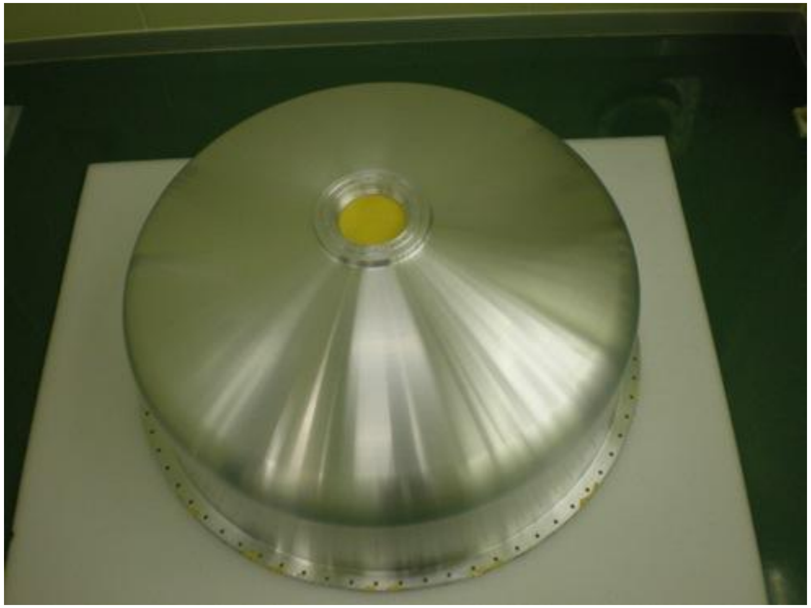
Two filters within Detector Assembly are small and are not supported on meshes, nor do they have heaters

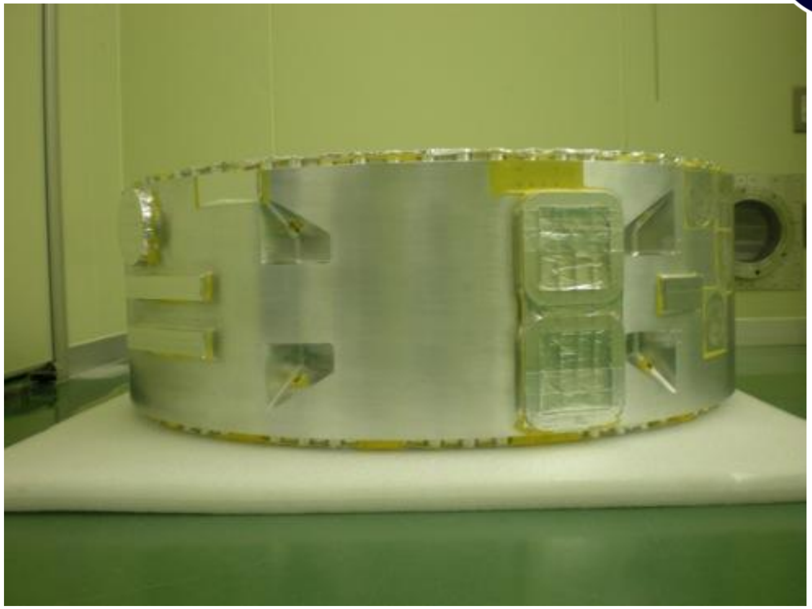

UNIVERSITY OF
WISCONSIN
MADISON
Mag = 118 X
100 µm
EHT = 4.00 kV
WD = 11.9 mm
Signal A = InLens
Photo No. = 8934
Date :12 May 2011
Time :10:11:30

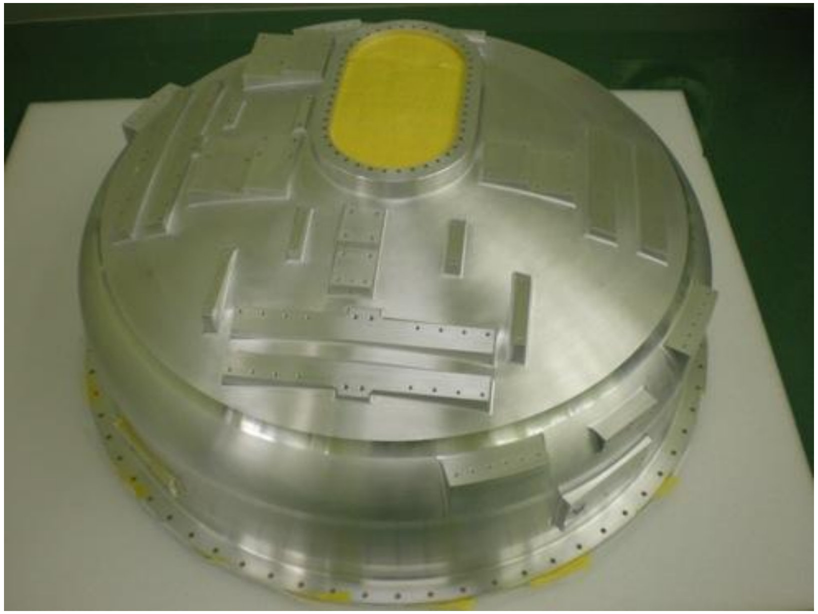
Dewar Main Shell Filter



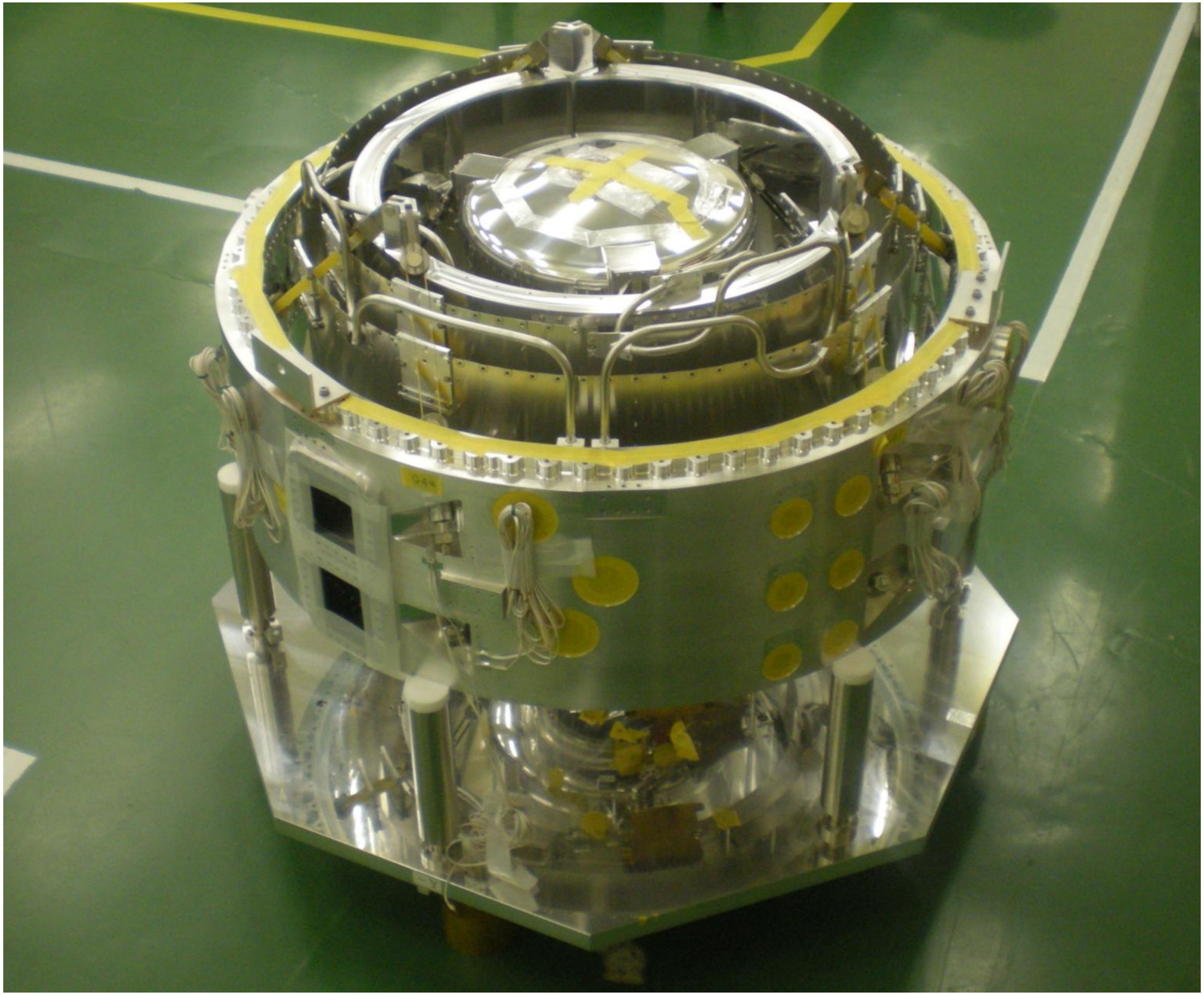
SXS EM Dewar in progress (June 2011)





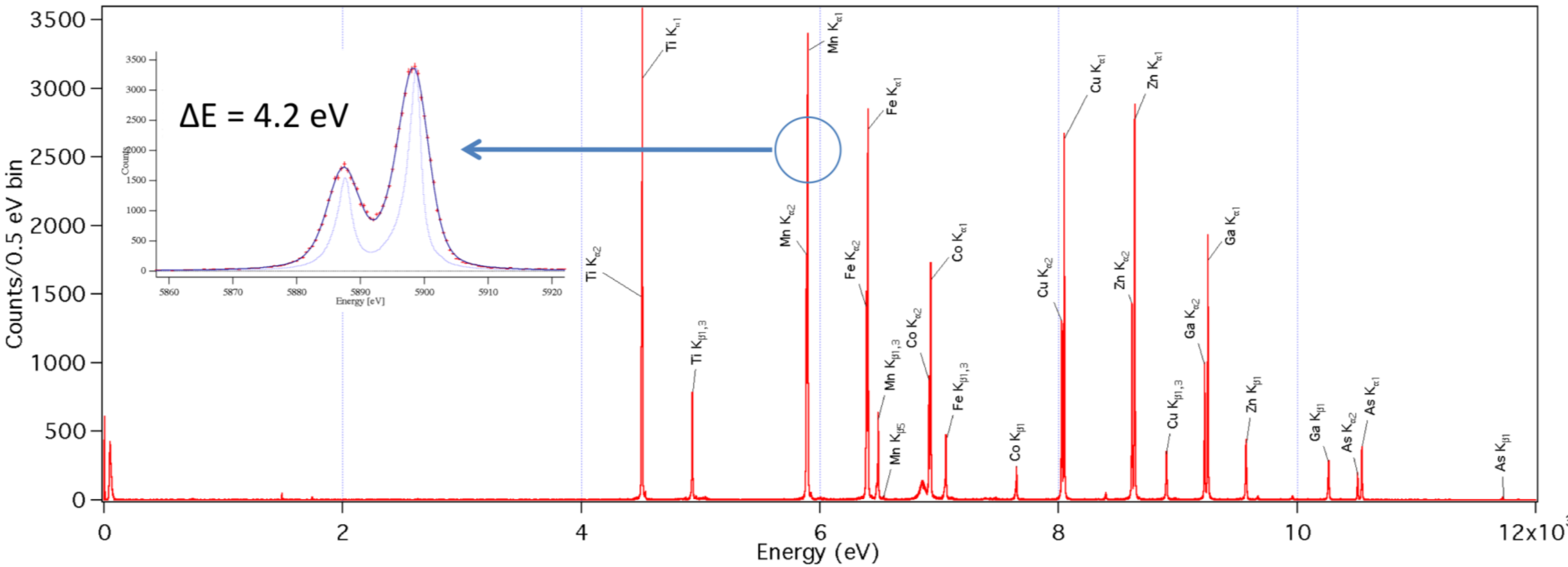


EM Dewar under construction (September 2011)



Engineering Model Detector System Performance

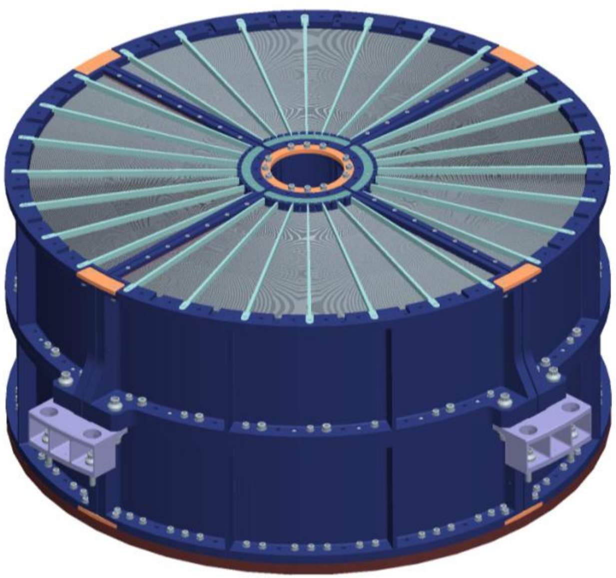
SXS Engineering Model Detector System tested at GSFC using multi-target x-ray source.



Improvement from XRS due in part to significant R&D following *Suzaku* launch to obtain new source for the absorber (HgTe) with lower specific heat and operating at lower operating temperature (60 mK -> 50 mK).

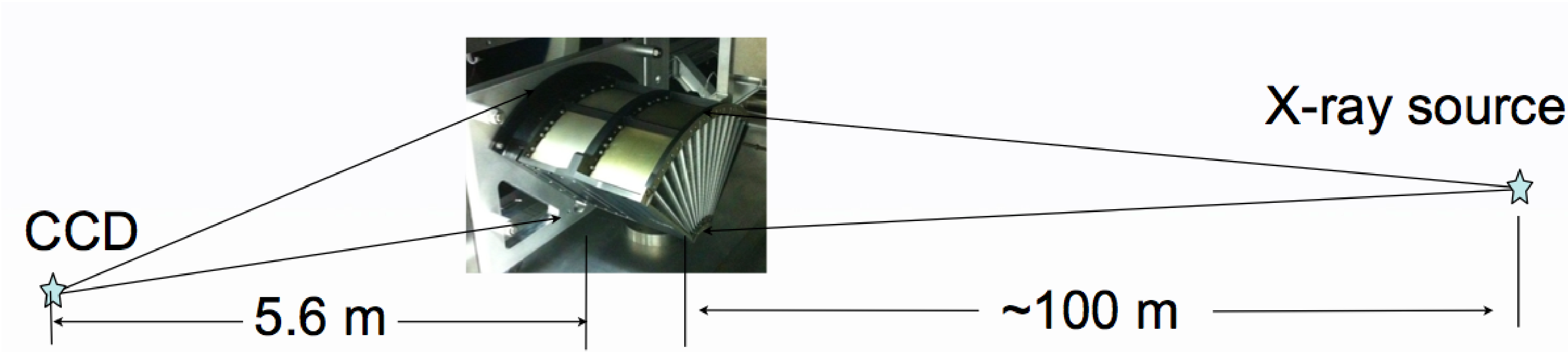
Soft X-Ray Telescope (SXT) – for SXS and SXI

- 203 concentric shells (1624 reflectors per mirror)
- Aluminum substrate reflectors are generally thicker than *Suzaku* mirrors
- Reflectors are held in place with adhesive after precise alignment



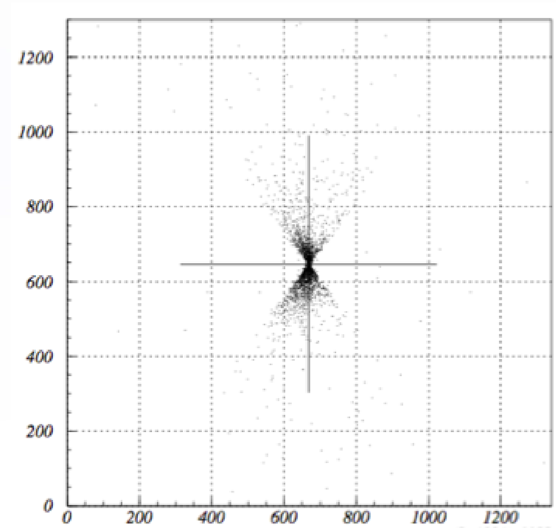
SXT Engineering Model Performance

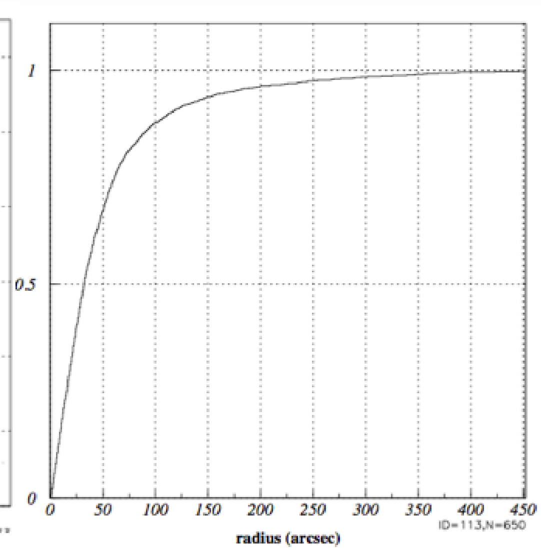
Test conducted in 100 m x-ray beam facility at Goddard



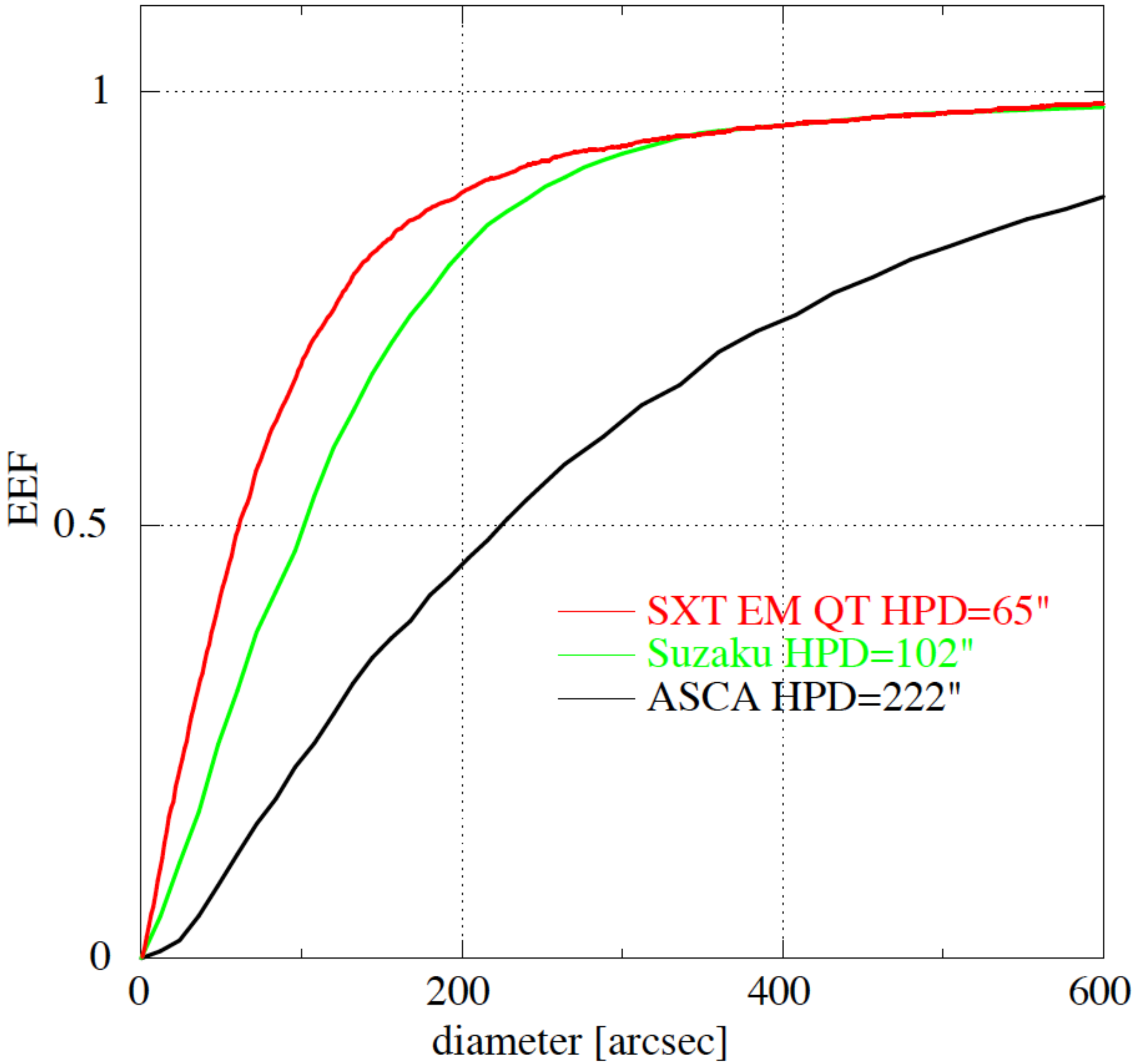
Engineering model quadrant illuminated with divergent beam 100 m away.

HPD of 1.1 arcmin measured – new record for this type of x-ray mirror.



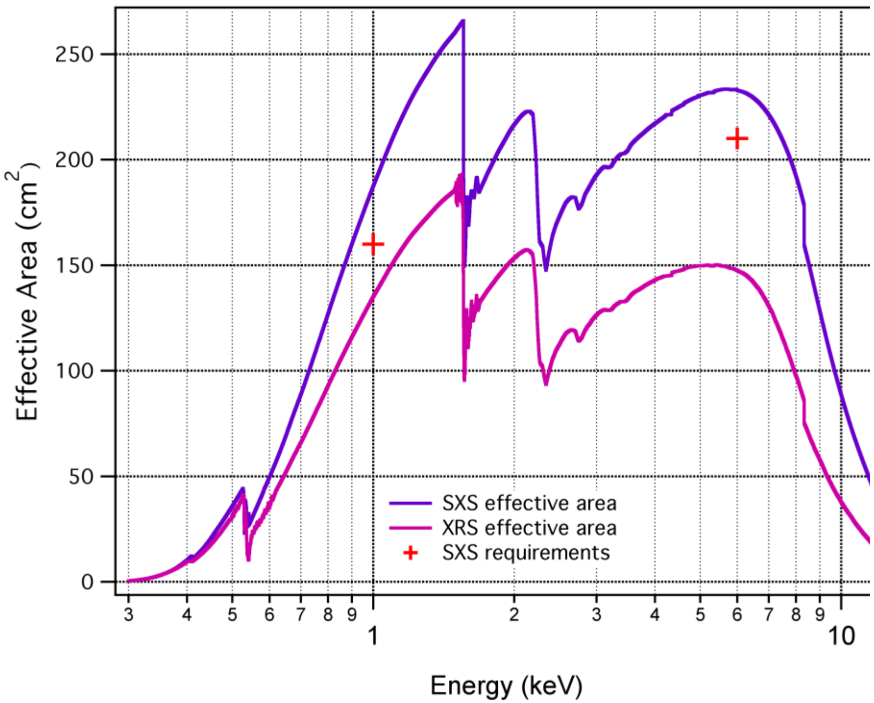


Progress with Al-foil x-ray optics

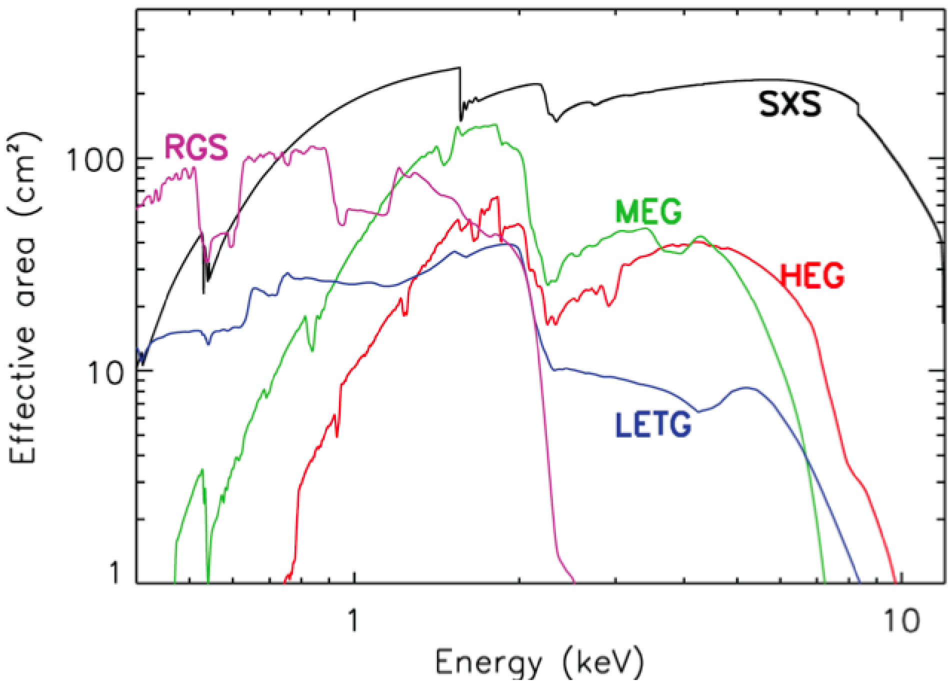


SXS Collecting Area

SXS



SXS in Comparison

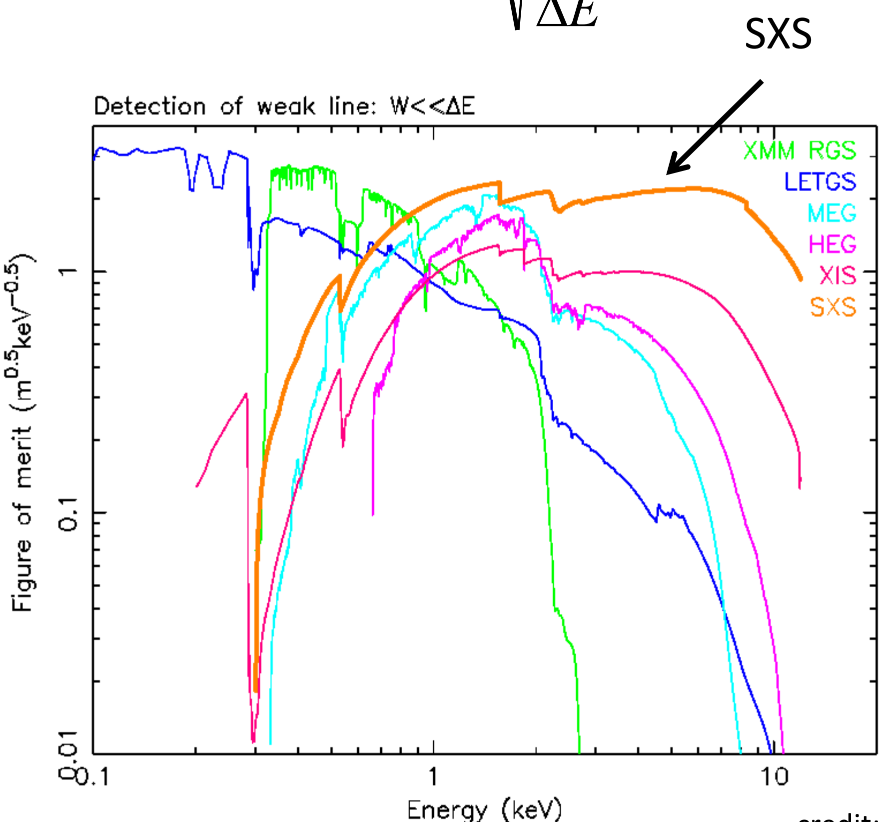


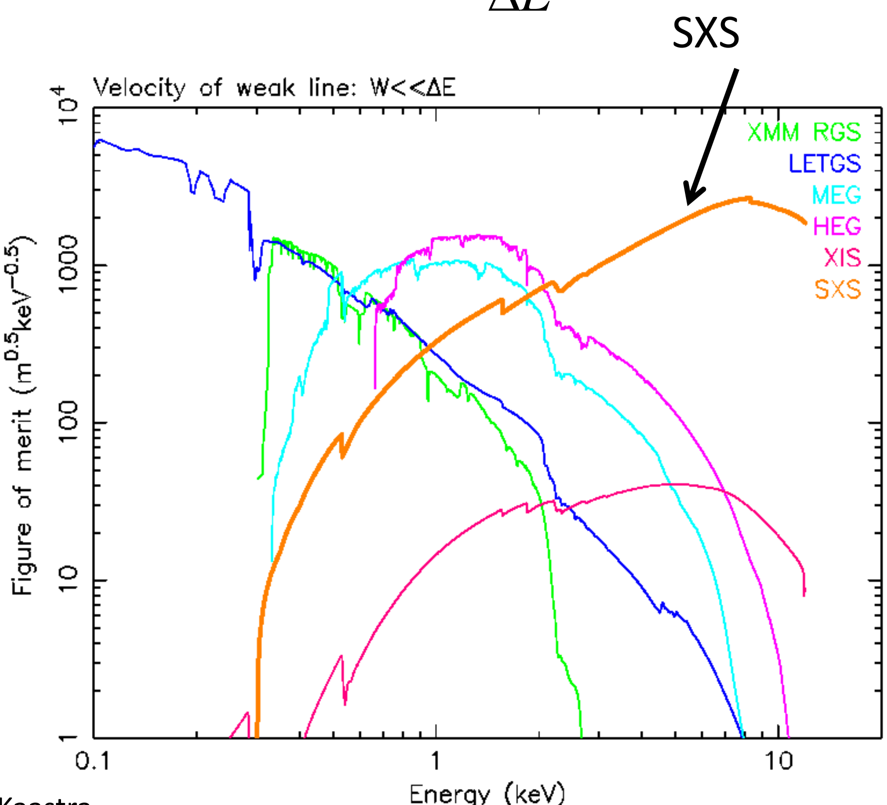
Niche filled by SXS – Complementary with Dispersive Spectrometers on Chandra and XMM-Newton

SXS sensitivity for spectroscopy compared with existing x-ray observatories

$$FOM \sim \sqrt{\frac{A}{\Delta E}}$$

$$FOM \sim \frac{E\sqrt{A}}{\Delta E^{3/2}}$$

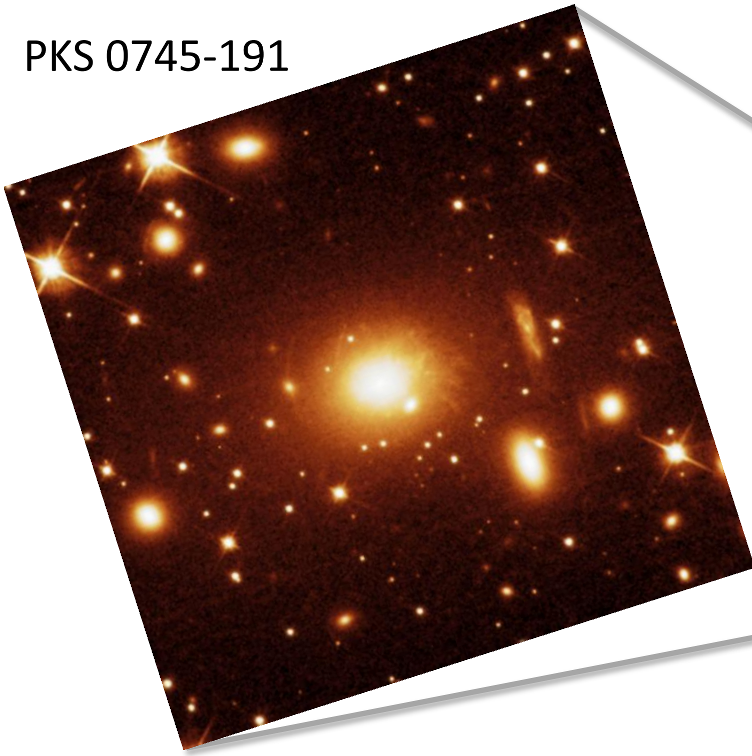




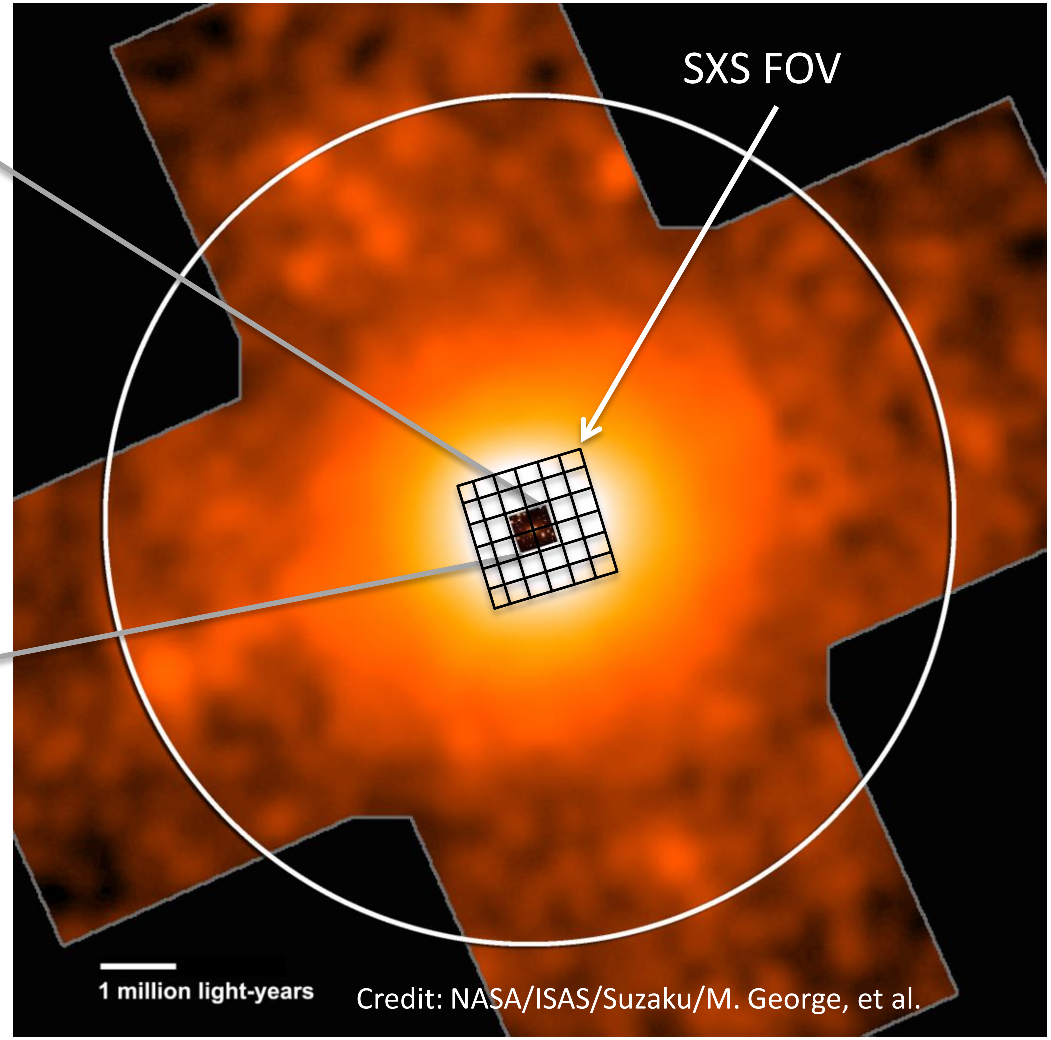
credit: Jelle Kaastra

Clusters of Galaxies

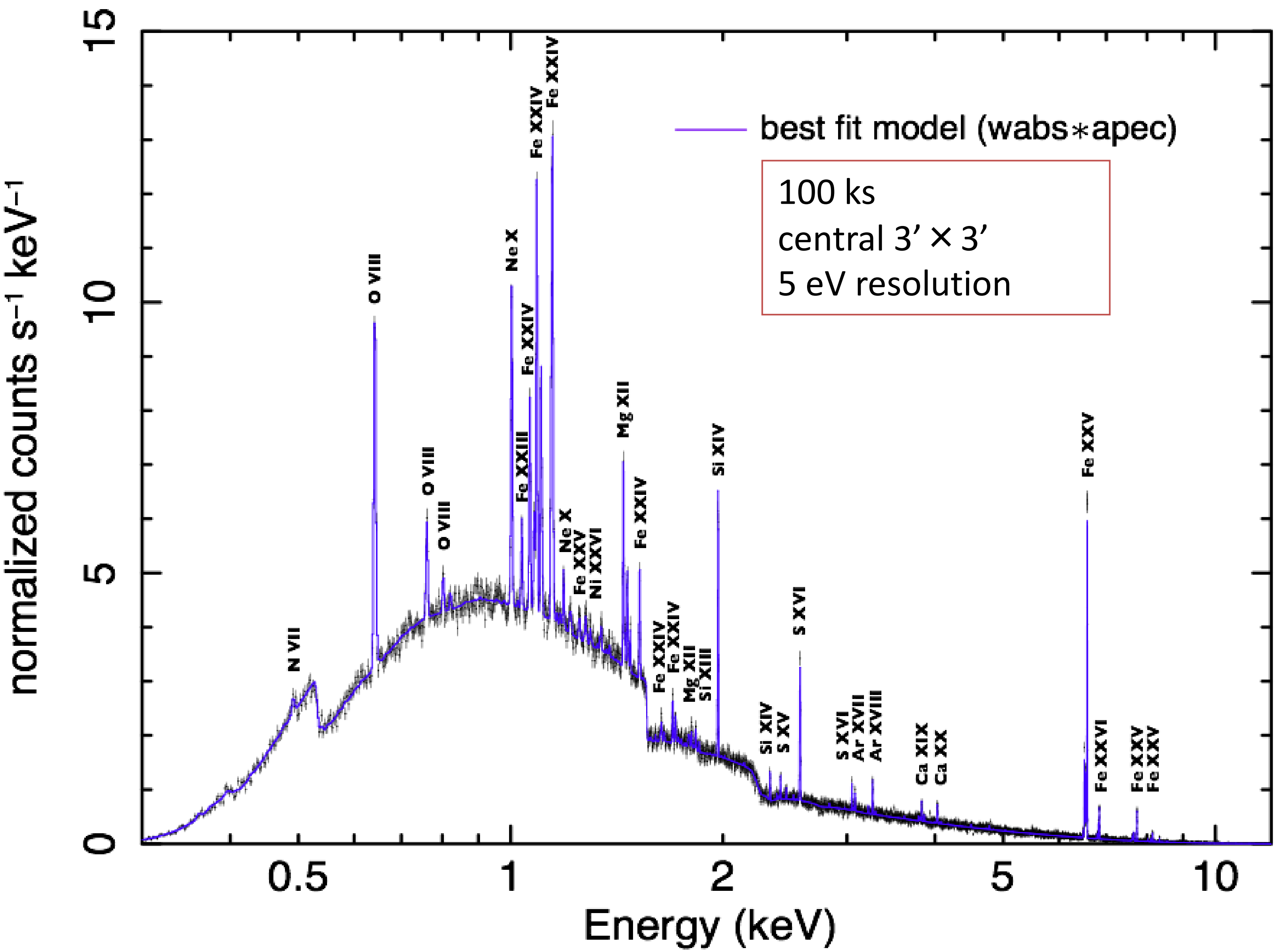
PKS 0745-191



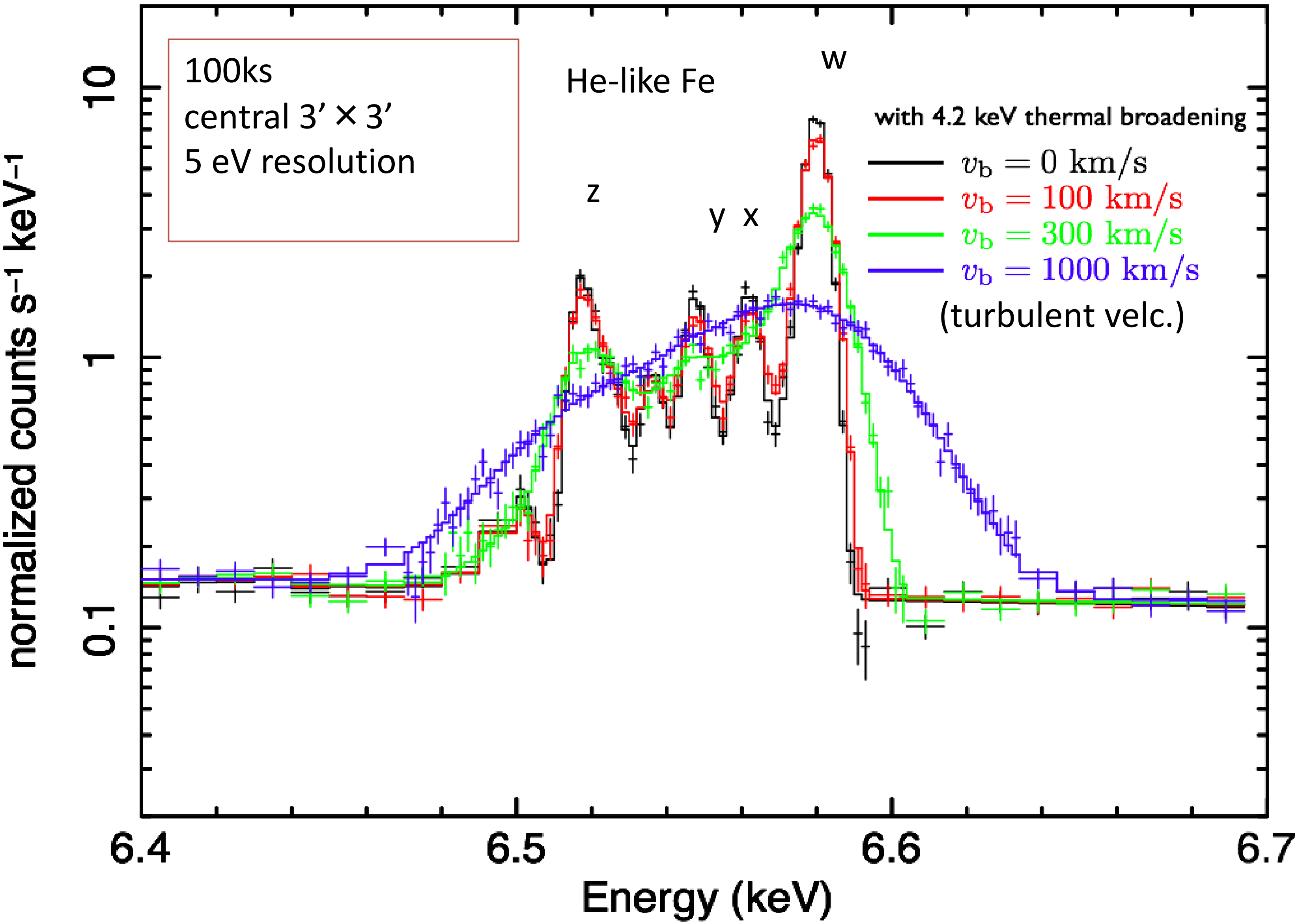
Credit: NASA/STScI/Fabian, et al.



Perseus simulated spectrum (wabs*apec)



Perseus Sim **data and folded model**



Ground Calibration Plan

Calibration is performed on components:

X-ray calorimeter array

- Energy resolution (line spread function) – fluorescent sources and monochromators
- Quantum efficiency

Anticoincidence Detector

- Timing

Filters

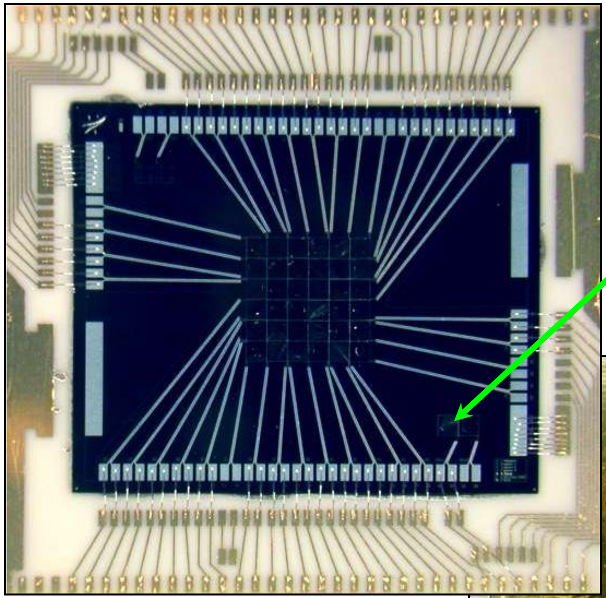
- Transmission – x-ray beam line NSLS; high resolution at edges

X-ray mirror

- Point spread function
- Effective area

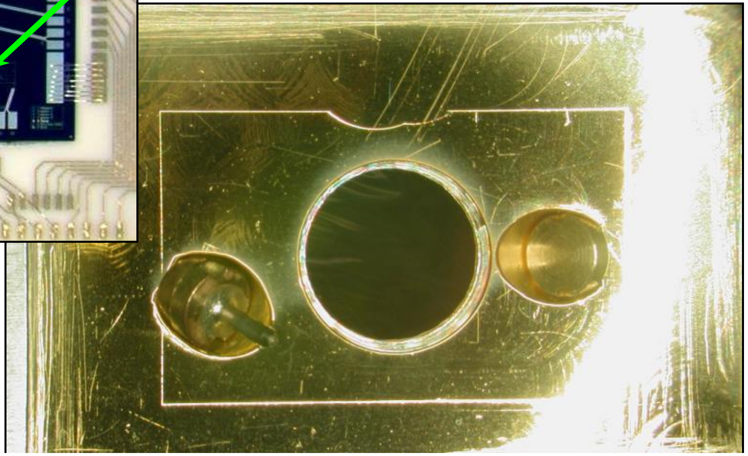
Gain Tracking – internal cal source (6 keV)

Dedicated calibration pixel to characterize gain drift of full array

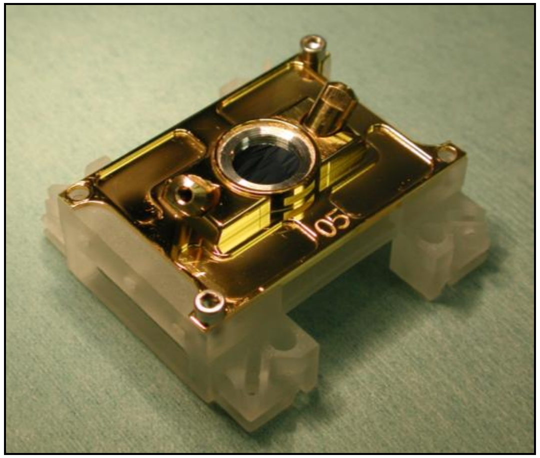


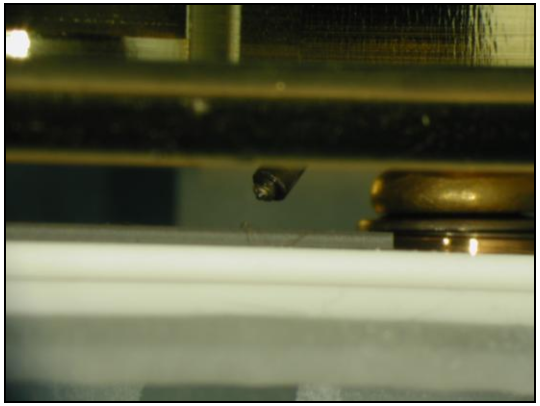
Calibration pixel

XRS flight array



Detector view of the CTS lid with the source in position. Note the blank in the other position.



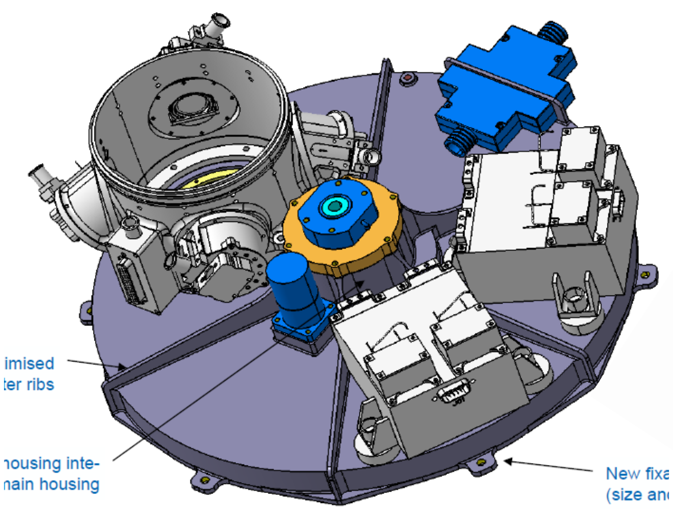


Test box with actual detector board mockup.

Flight Calibration Sources and Filter Wheel

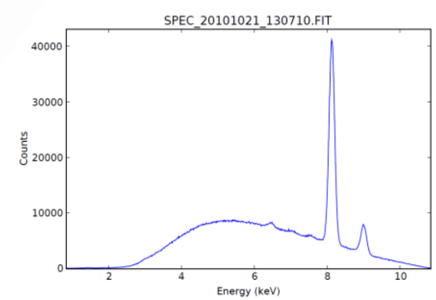
- Filter wheel with 6 positions (Be, ND, Al-polyimide, 2 open),
- Heritage from XMM-Newton, Suzaku

Filter wheel
(view from the bottom)



Filter ring
Filter with Fe55 source

Modulated X-ray Source
(Cu, Ti, ..)



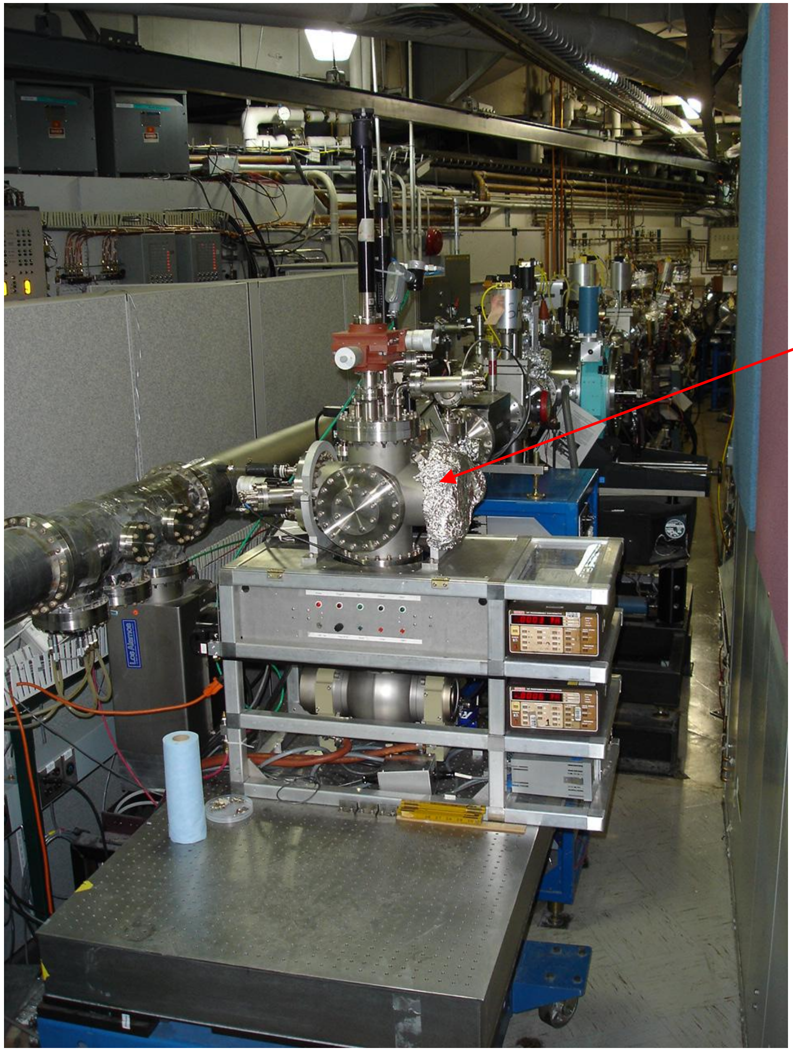
Netherlands Institute for Space Research

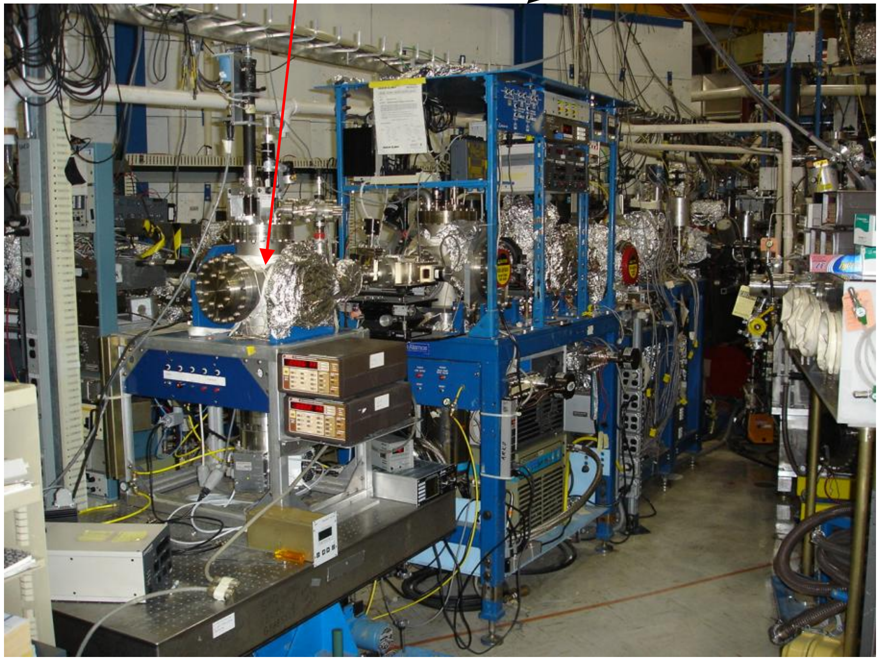
Brookhaven NSLS X-ray Beam lines

X8A – high energy

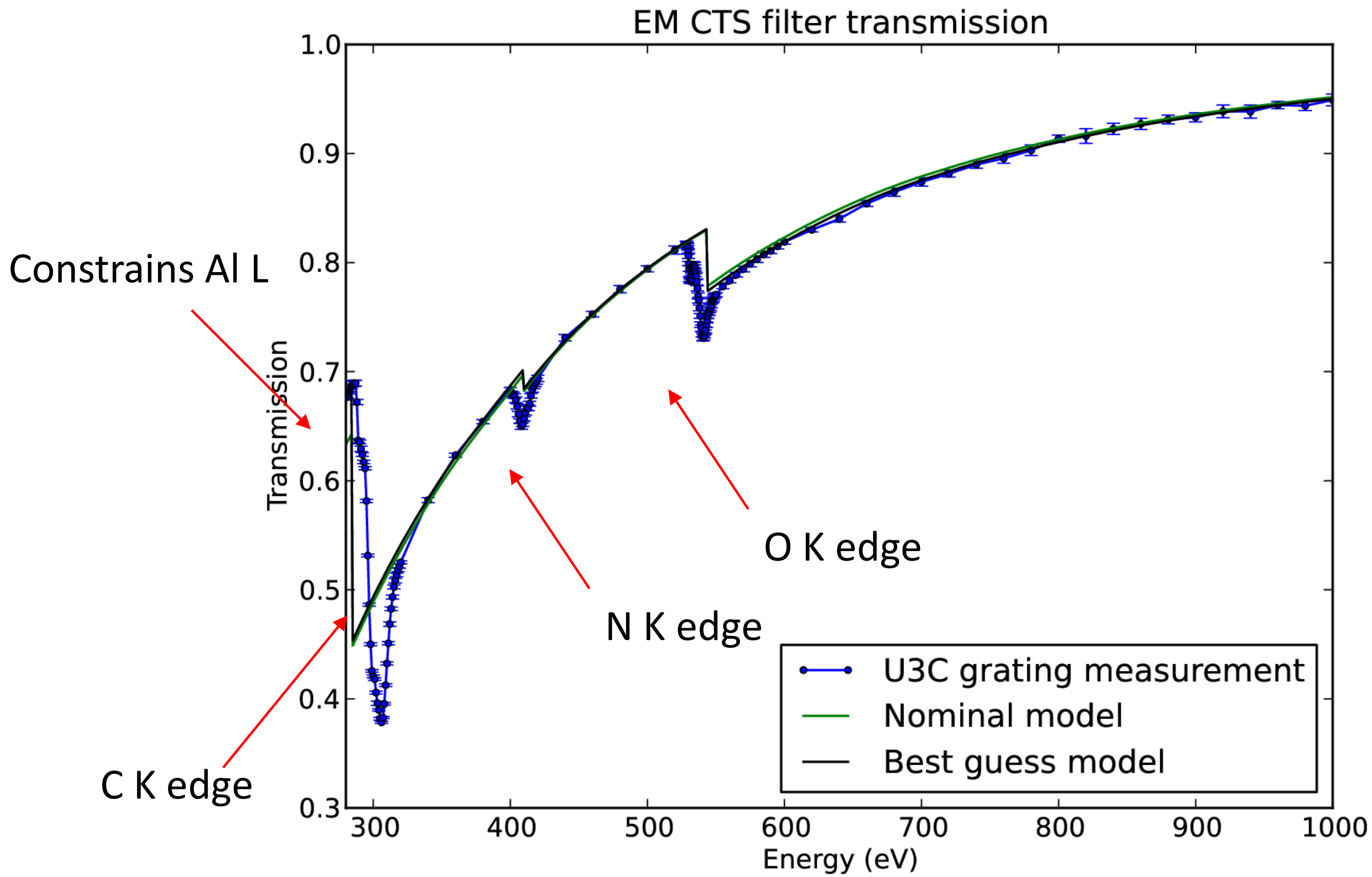
Endstations

U3C – low energy



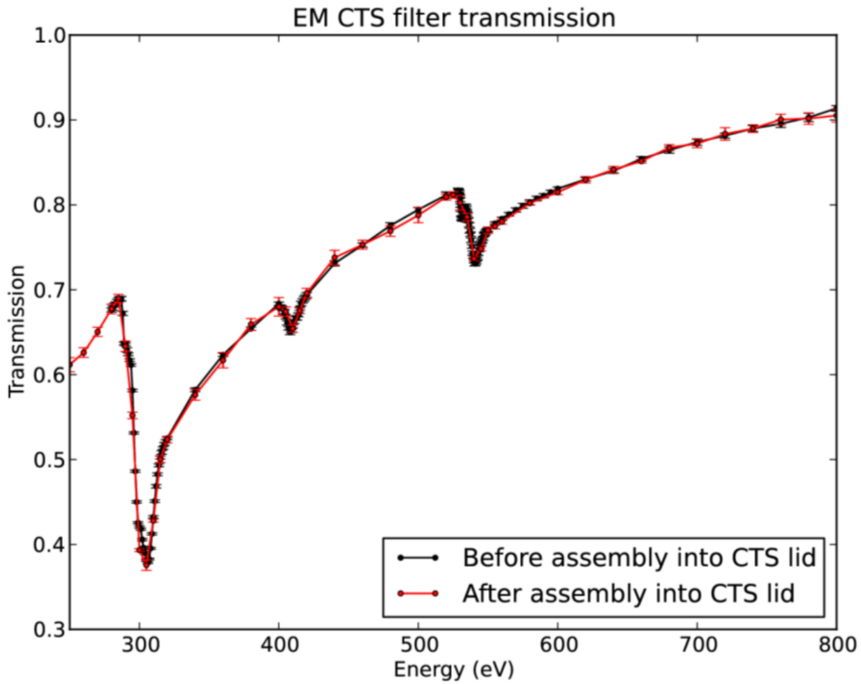


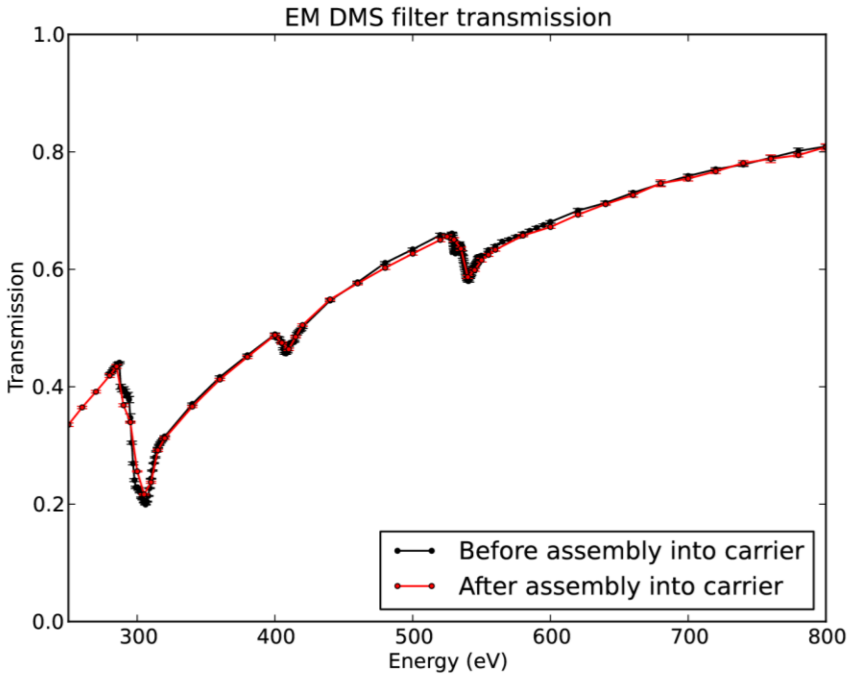
High resolution grating scan



Post carrier assembly contamination check

Comparison of filter transmission before and after filter carrier assembly process.





No discernable evidence for contamination associated with assembly process.

Astro-H Operations and Observing Time

Science operations will be similar to those of *Suzaku*, with pointed observation of each target.

All instruments are co-aligned and will operate simultaneously.

Time Allocation Phases (working plan):

Phase 0 : 3 Months : Satellite/Instruments in-orbit check out and commissioning
Phase 1 : 6 Months : SWG 100 % (PV Phase, including Calibration)
Phase 2 : 12 Months : SWG Carry Over 15%, GO 75%, Observatory 10 %
Phase 3 : Rest of the mission : Key Project 15% (TBD), GO 75%, Observatory 10 %

GO time to be divided equally (to be approved) between Japan-Europe and US, similar to *Suzaku*. But we are planning to introduce joint key-projects and/or early-data-released type observations from early phase of the mission.

NASA approved Science Enhancement Option for Astro-H to support a funded GO program. Work will start in FY12.

Summary

Astro-H will provide broad-band x-ray detection and high resolution spectroscopy

X-Ray calorimeter spectrometer will provide energy resolution as good as 4 eV

Development of NASA funded GO program underway

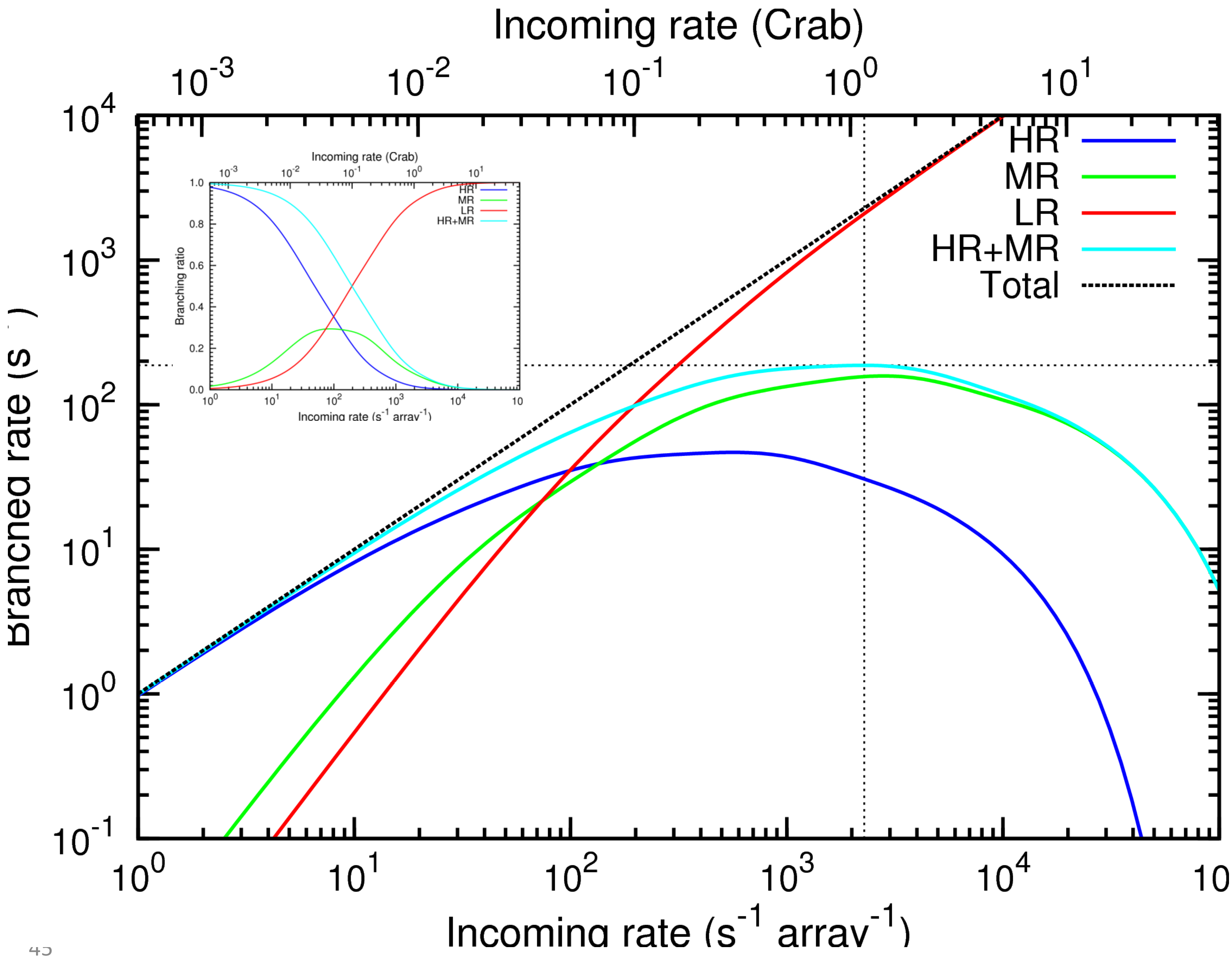
Mission CDR December 2011

EM Testing in 2012 – real indication of instrument performance

Flight hardware to start soon.

Launch in 2014

Additional Material



Incoming rate (Crab)
Branched rate (s⁻¹)
Incoming rate (s⁻¹ array⁻¹)
HR
MR
LR
HR+MR
Total
Incoming rate (Crab)
Branching ratio
Incoming rate (s⁻¹ array⁻¹)

Expected LHe Lifetime

Case	Cooler power (W)			Heat load on JT (mW)	Heat load on He tank (mW)	LHe lifetime (years)
	SC	PC	JT			
Normal	50×2	50×2	90	9.8	0.70	4.5
1 SC failure	90×1	50×2	90	36.7	1.15	2.6
JT failure	90×2	50×2	0	—	1.44	2.1
1 PC failure	90×2	90×1	0	—	1.49	2.0

SC = Shield Cooler (Stirling Cycle)
JT = Joule Thomson Cooler
PC = pre-cooler for Joule Thomson Cooler

Dewar design provides functional redundancy against premature loss of LHe, as on the XRS. If LHe is lost, the He tank temperature can be maintained below 1.3 K by operating the 3rd-stage ADR.

SXS Top-level Performance Requirements

Parameters	Requirement	CBE
Energy resolution	7 eV (FWHM)	4.2 eV
Residual Background	1.5 x 10^{-3} counts/s/keV	1.5 x 10^{-3} counts/s/keV
Field of view	2.9 x 2.9 arcmin	2.9 x 2.9 arcmin
Angular resolution	1.7 arcmin (HPD)	1.1 arcmin
Effective area (1 keV)	160 cm^2	175 cm^2
Effective area (6 keV)	210 cm^2	233 cm^2
Lifetime	3 years	> 4.5 years
Pulse Processing	150 counts/s (full array) with < 5% dead time	300 counts/sec
Energy scale accuracy	± 2 eV	± 1.5 eV

Statistical errors vs. counts