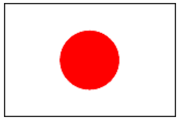
The Calibration Plan for ASTRO-H/SXS (Soft X-ray Spectrometer)

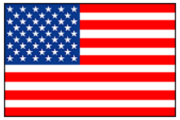
2009-04-28

Y. ISHISAKI (Tokyo Metropolitan Univ)
On behalf of the SXS team

ASTRO-H SXS Team



JAXA	High Energy Astrophy. , ISAS	K. Mitsuda, N.Y. Yamasaki, Y. Takei, M. Tsujimoto, T. Dotani
	Ir/Submm Astrophy., ISAS	T. Nakagwa
	Space Thermal Eng., IAT	H. Sugita, Y. Sato, K. Shinozaki,
	SMILES group, ISAS	K. Kikuchi
Tokyo Metro. Univ.	Grad. School of Science	T. Ohashi, Y. Ishisaki, Y. Ezoe
Kanazawa Univ.	Grad. School of Natural Sci. & Tech.	R. Fujimoto, K. Sato
Riken	Cosmic Radiation Laboratory	K. Makishima, T. Mihara, M. Kawaharada, T. Tamagawa, H. Yamaguchi
Rikkyo Univ.	Grad. School of Science	S. Kitamoto, H. Murakami
Saitama Univ.	Grad. School of Sci. & Eng.	M. Tashiro, Y.Terada
National Inst. Material Science	Innovative Materials Eng. Lab.	T. Numazawa
Tsukuba Univ.	Grad. School of Systems & Info. Eng.	M. Murakami



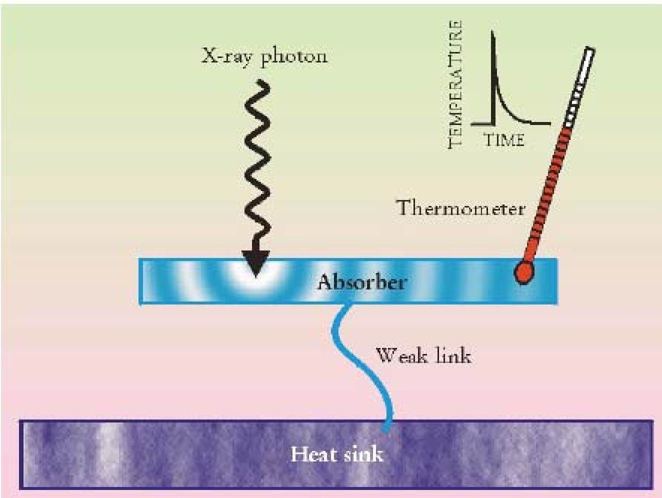
(members are not complete..)

NASA/Goddard Space Flight Center (GSFC)	R, Kelley, C.A. Kilbourne, F.S. Porter, P. Shirron, M. DiPirro
University of Wisconsin	D. McCammon
Yale University	A.E. Szymkowiak
NASA/AMES	A. Kashani

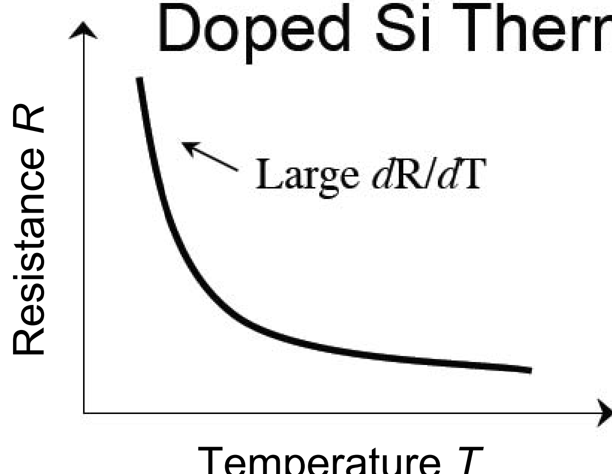
Netherlands Institute for Space Research (SRON)	J.-W. den Herder, C. Van Baren, L. Dubbedam, H. van Weers, F. Zwart, C. P. de Vries, H. Aarts

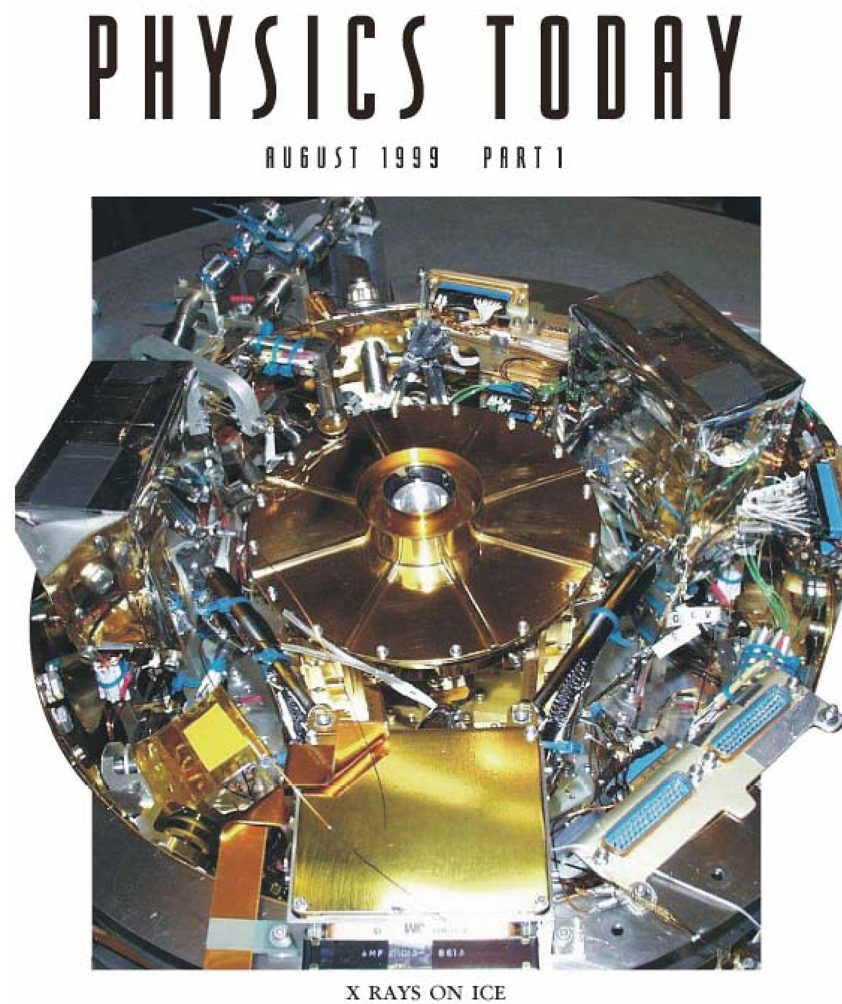
The X-ray Micro-Calorimeter Spectrometer

Non-dispersive spectrometer



Doped Si Thermistor





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

The SXS Mission & Science

Recovery of Calorimeter Science:

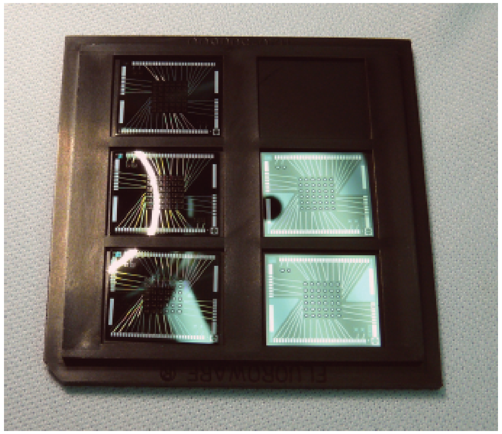
Suzaku XRS, which adopted X-ray micro-calorimeter for the first time in the world, achieved temperature of 60mK and spectral resolution of 7 eV in orbit. However, we were unable to observe X-rays from celestial objects due to the unexpected evaporation of liquid He.

We consider it our urgent responsibility to recover the mission and to meet the expectation that were not met by Suzaku.

Main Scientific Targets:

- Explore how galaxies and clusters form and evolve.
- Investigate nature of dark matter and energy on large scales in Universe.
- Probe environment close to black holes, neutron stars, and white dwarfs.

Proposed Implementation



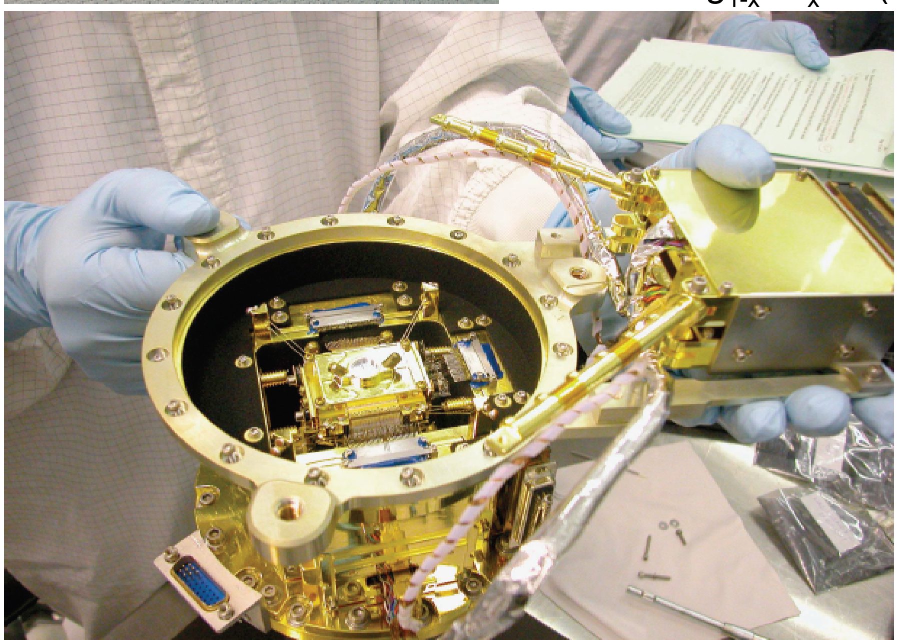
Array technology from XRS program:

- 6x6 array w/larger pixels (832 μm pitch vs. 640 μm)
- new HgTe absorbers

  $Hg_{1-x}Cd_xTe$ (x=0.16)

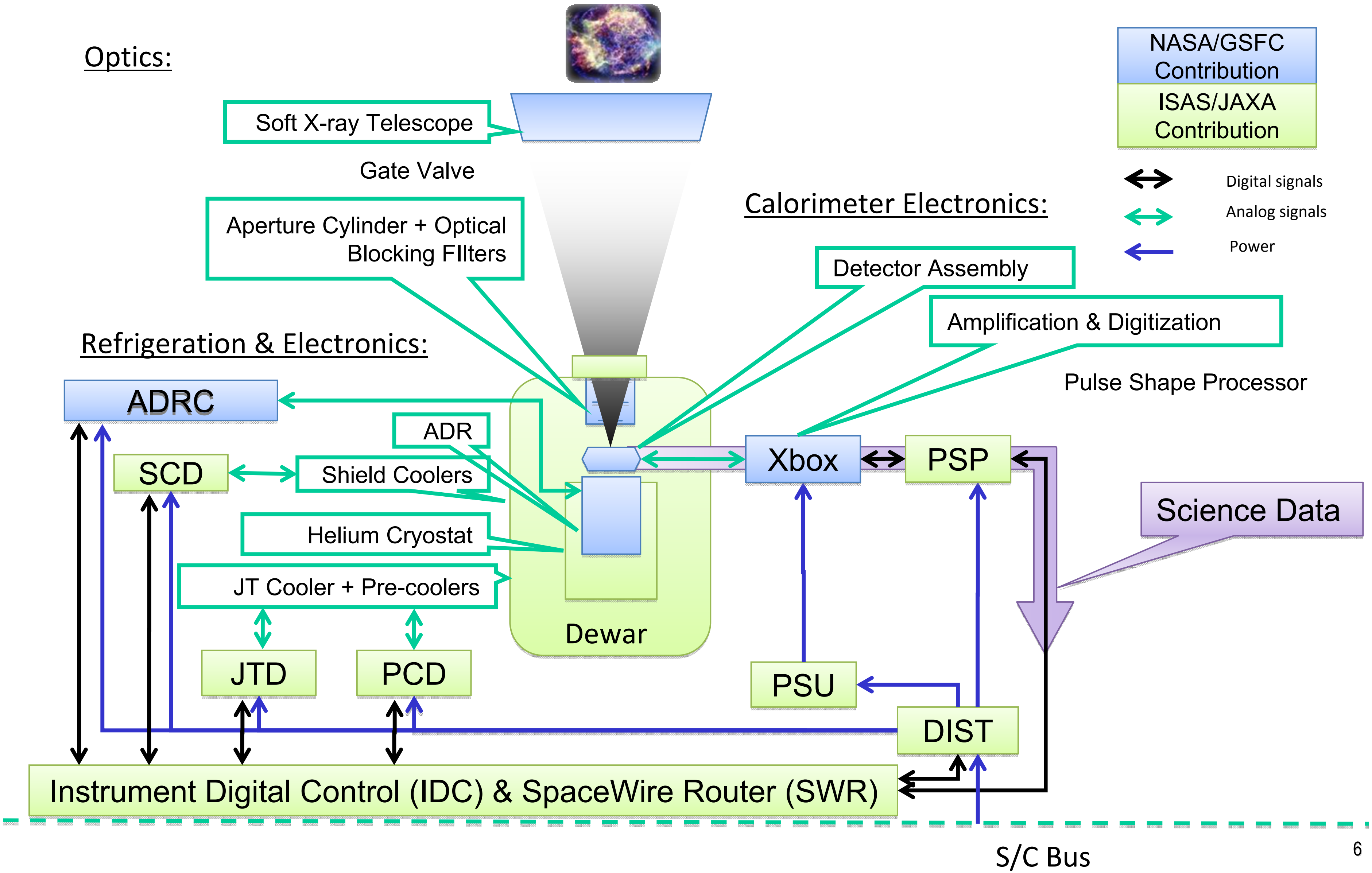
2-Stage ADR

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



Detector Assembly - heritage XRS

SXS Block Diagram



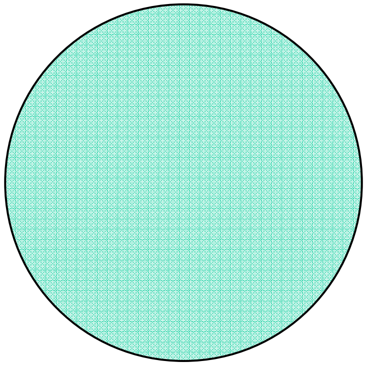
Comparison with Suzaku XRS

	XRS	SXS
Energy resolution (FWHM)	7 eV	Req. 7 eV / Goal: 4 eV
Detector array	6x6 (31 pix + 1 cal pix)	6x6 (32 pix + 4 cal/diagnostics pix)
Pixel size	624 um (28.6")	814 um (30")
FOV	2.9' (f = 4.5 m)	3.1' (f = 5.6 m)
Effective area @ 1 keV	136 cm^2	190 cm^2
Effective area @ 7 keV	132 cm^2	225 cm^2
Lifetime	(2 years)	Req. 3 years / Goal: 5 years
Cooling system	ADR (60 mK) Liquid He (1.3 K) Solid Ne (17 K) 1-stage Stirling cooler (100 K)	Double-stage ADR (50 mK) Liquid He (1.3 K) ^{3}He JT cooler (2 K) 2-stage Stirling coolers (20 K)

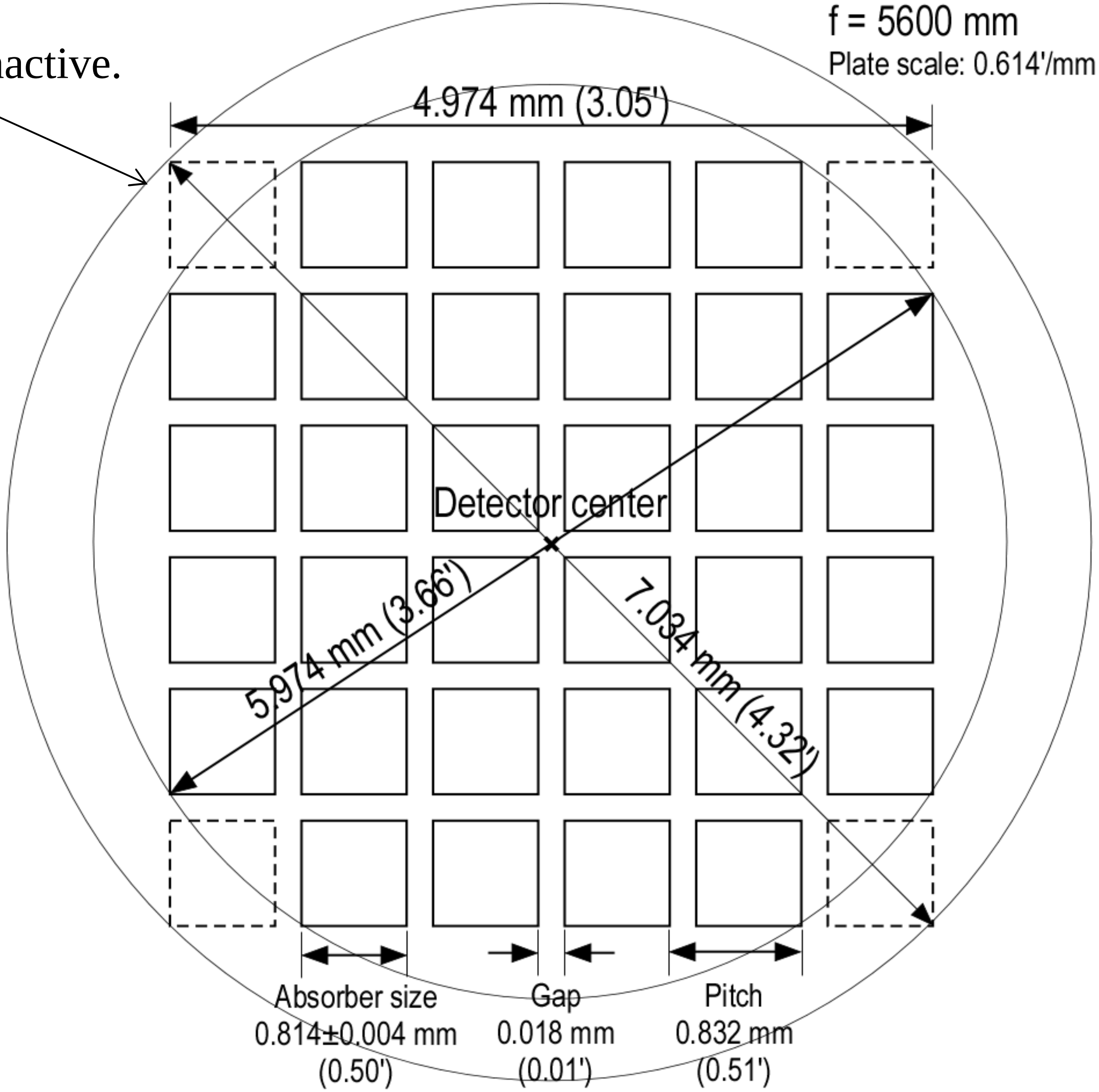
The XRS used liquid He and solid Ne as cryogens, and its lifetime was limited by the amount of solid Ne. The SXS uses liquid He, but solid Ne is replaced by cryocoolers. If the normal case, expected liquid He lifetime is > 5 years, and cryogen-free operation could be possible. Even if one cryocooler fails, liquid He lifetime would be ~ 3 years.

FOV

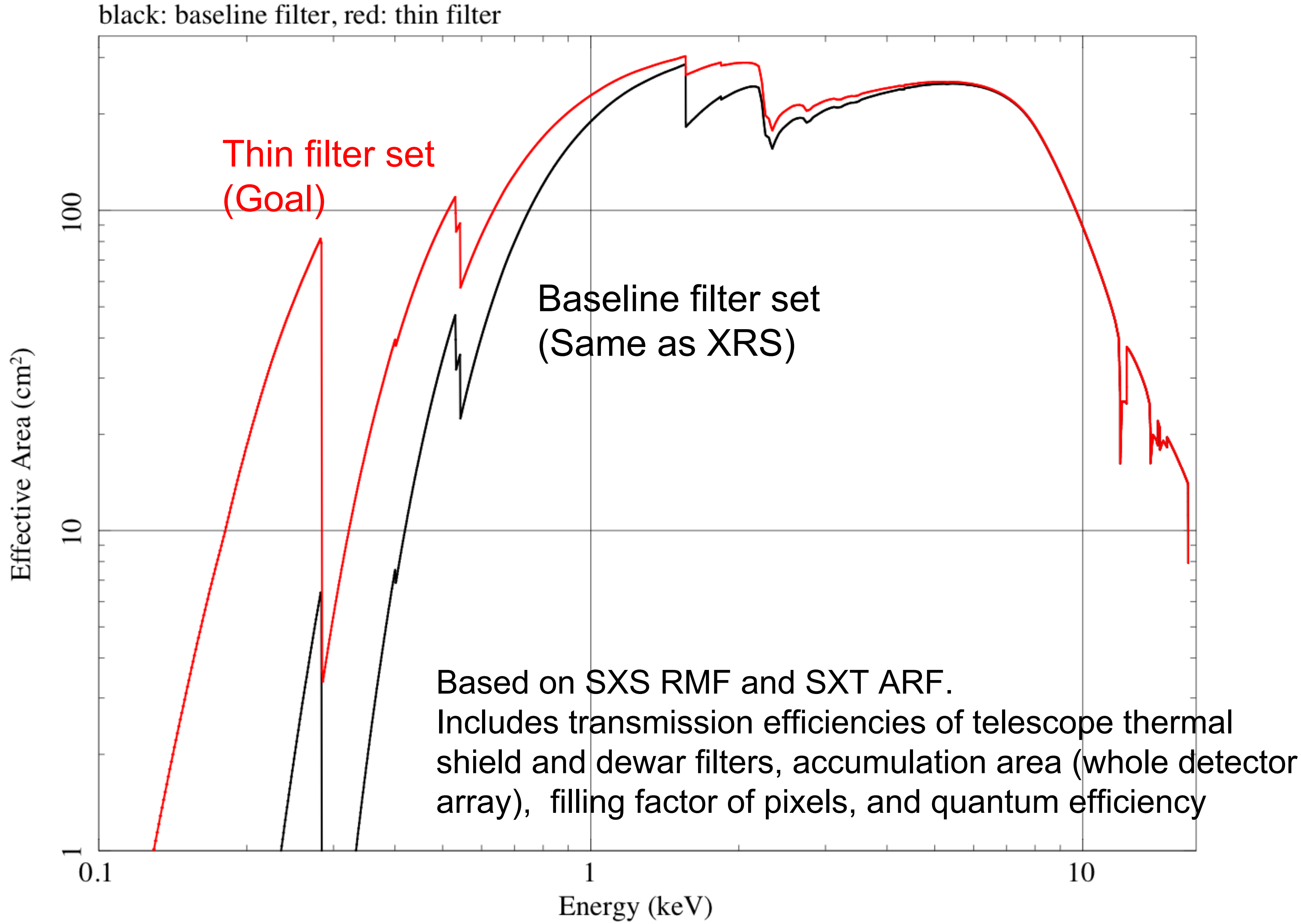
Corner pixels are inactive.



Telescope HPD ~ 1.3’



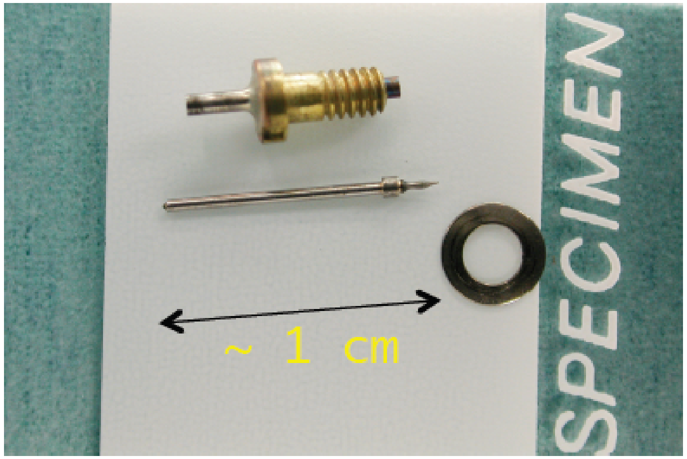
Effective Area

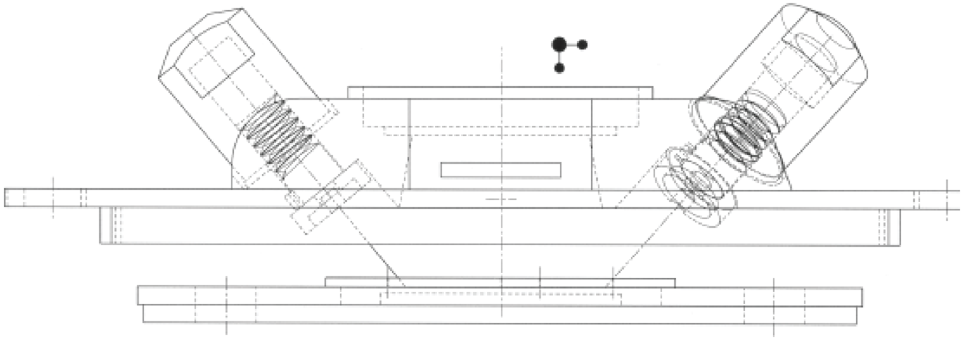


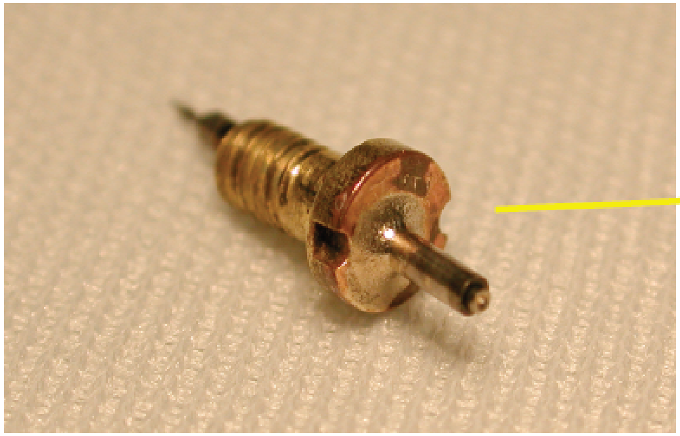
Calibration Requirements

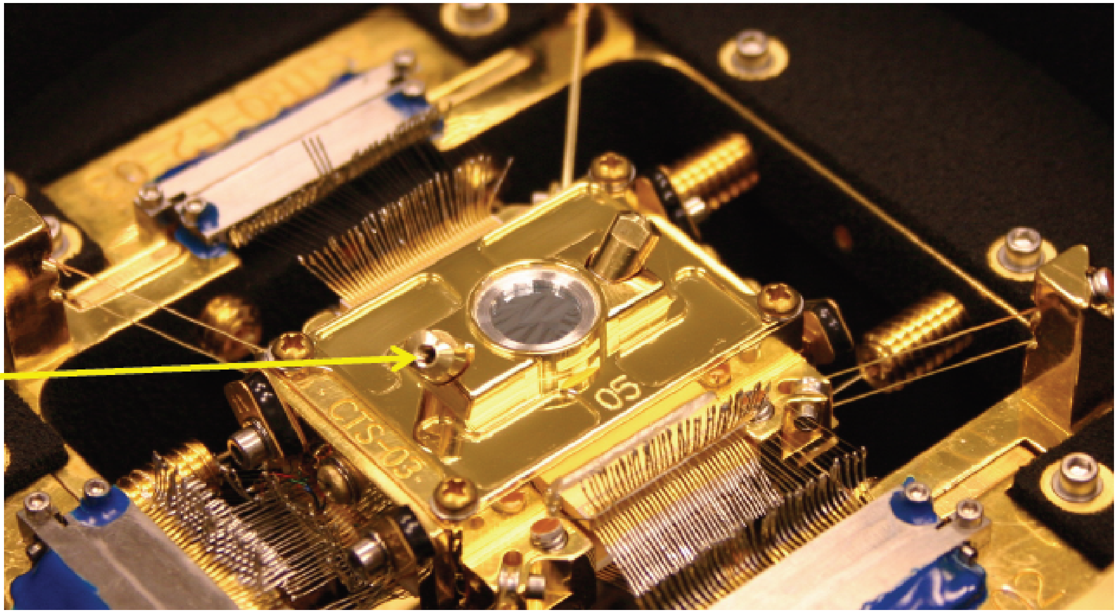
Characteristic	Knowledge Requirement
Energy Scale	$\Delta E \pm 2eV$
Line Spread Function	$\Delta E_{FWHM} \pm 1eV$
Filter Transmission	$\leq$ 5% at 0.5 keV, 1.5, and 6 keV
Detector QE	$\leq$ 5% at 6.0 keV
Absolute Throughput	$\leq$ 10% overall
Anticoincidence Detector	Determine acceptance window and threshold

Internal Calibration Sources for Dedicated Pixels





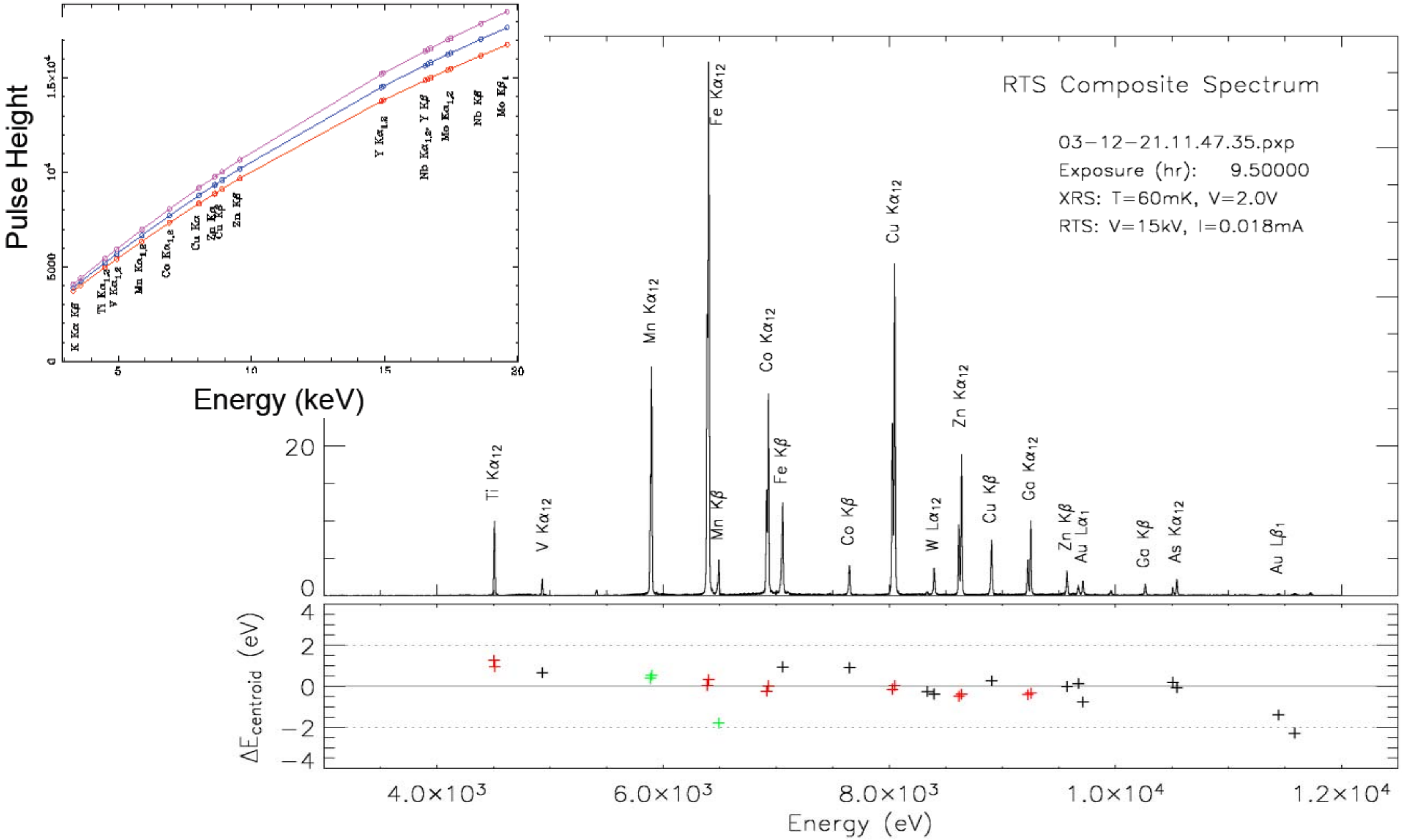




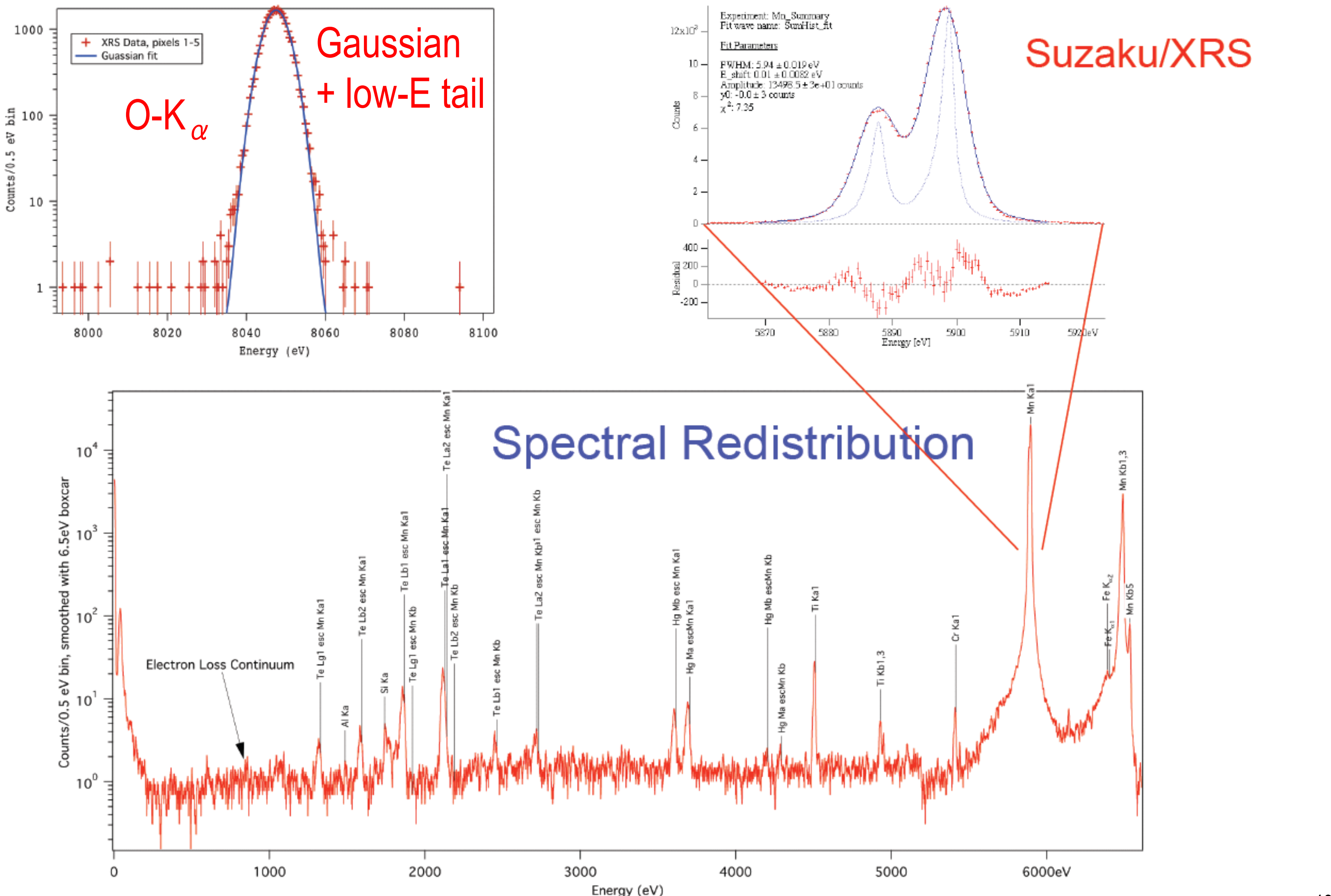
External source (FW + X-ray generator) is under consideration for SXS

Energy Scale

Suzaku XRS ground calibration with multi-target fluorescent sources : < ±2 eV



Spectral Redistribution

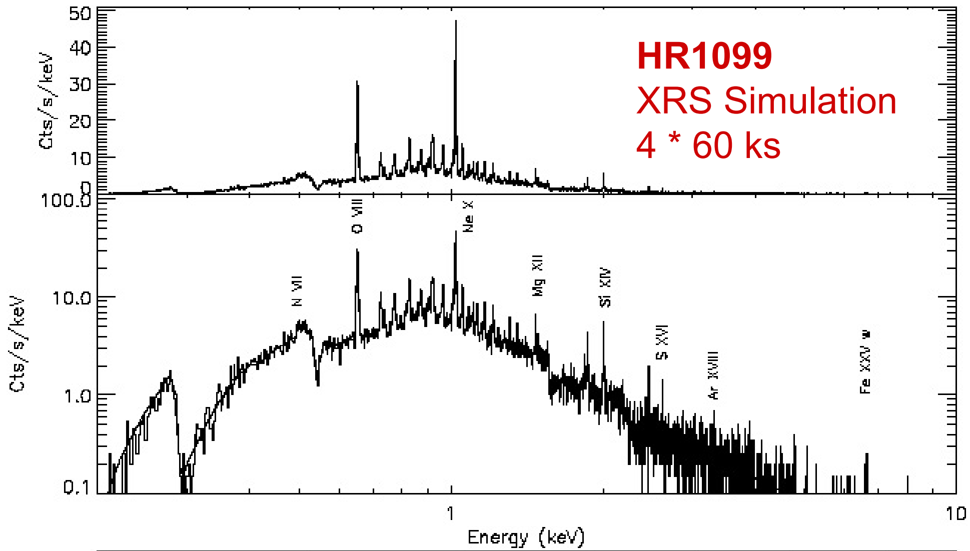


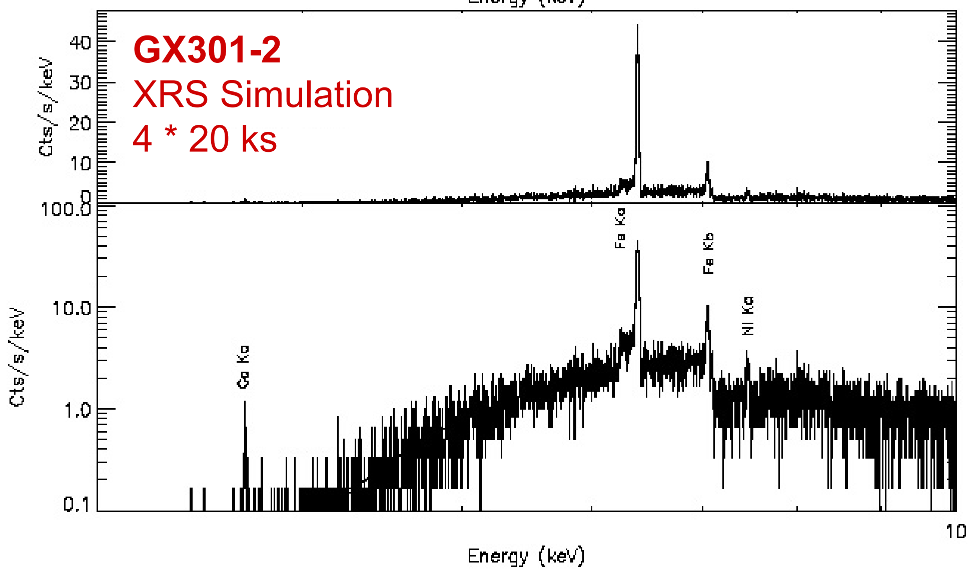
In-flight Calibration Targets for Suzaku XRS

Target	Emission Lines	Energy Coverage
• **Initial Checks**:		
Filter Wheel	K Kα, Mn Kα	3.31, 5.90 keV
• **Low-Energy Calibration**:		
Capella	N VII - Mg XII	0.50 – 1.47 keV
Algol	N VII - S XVI, Fe XXV	0.50 – 6.70 keV
HR1099	N VII - S XVI, (Fe XXV)	0.50 – 2.01 keV
• **High-Energy Calibration**:		
GX 301-2 (pre-periastron)	Fe Kα, Ni Kα (also Si, S neutral lines)	6.40, 7.46 keV

We need to measure the energy scale and LSF for each pixel independently. Thus we must use 4 slightly offset pointings of each point source to better distribute the counts among the pixels.

Energy Scale/LSF: Proposed Targets





Energy Coverage

Line	E (keV)	16 Inner	15 Outer
N VII	0.500	x	
O VIII	0.654	x	x
Ne X	1.022	x	x
Mg XII	1.473	x	x
Si XIV	2.006	x	
S XVI	2.623	x	
K Ka	3.314	x	x
Mn Ka	5.895	x	x
Fe Ka	6.400	x	x
Fe XXV	6.700	x	
Ni Ka	7.461	x	

Estimated Counts for Possible Targets

	Line	Energy (keV)	Capella 4 x 45 ks Inner Pixel	Capella 4 x 45 ks Outer Pixel	HR1099 4 x 60 ks Inner Pixel	HR1099 4 x 60 ks Outer Pixel	Algol 4 x 45 ks Inner Pixel	Algol 4 x 45 ks Outer Pixel
	N VII Lyα	0.500	105	58	95	36	157	60
	O VIII Lyα	0.654	1045	404	1800	685	600	228
	Ne X Lyα	1.022	1051	407	2500	950	1050	399
	Mg XII Lyα	1.473	279	108	280	106	300	114
	Si XIV Lyα	2.006	70	27	220	84	270	102
(^{41}Ca)	K Kα	3.314	186	186	186	186	186	186
(^{55}Fe)	Mn Kα	5.894	6200	6200	6200	6200	6200	6200
(GX301)	Fe Kα	6.400	3320	1262	3320	1262	3320	1262
	Fe XXV w	6.700			42	16	262	100
(GX301)	Ni Kα	7.461	105	40	105	40	105	40

Line Broadening

Line broadening of v ~ 150 km/s has been detected in Algol (Chung et al. 2004). We expect broadening of v ≤ 100 km/s in HR1099.

		HR1099 σ =100 km/s		Algol σ =150 km/s	
Line	Energy (keV)	Counts Inner Pix	Additional ΔEbroad	Counts Inner Pix	Additional ΔEbroad
N VII Lyα	0.500	95	0.01eV	157	0.03 eV
O VIII Lyα	0.654	1800	0.02 eV	600	0.05 eV
Ne X Lyα	1.022	2500	0.05 eV	1050	0.12 eV
Mg XII Lyα	1.473	280	0.11 eV	300	0.24 eV
Si XIV Lyα	2.006	220	0.20 eV	270	0.45 eV
Fe XXV w	6.700	42	1.97 eV	262	3.90 eV

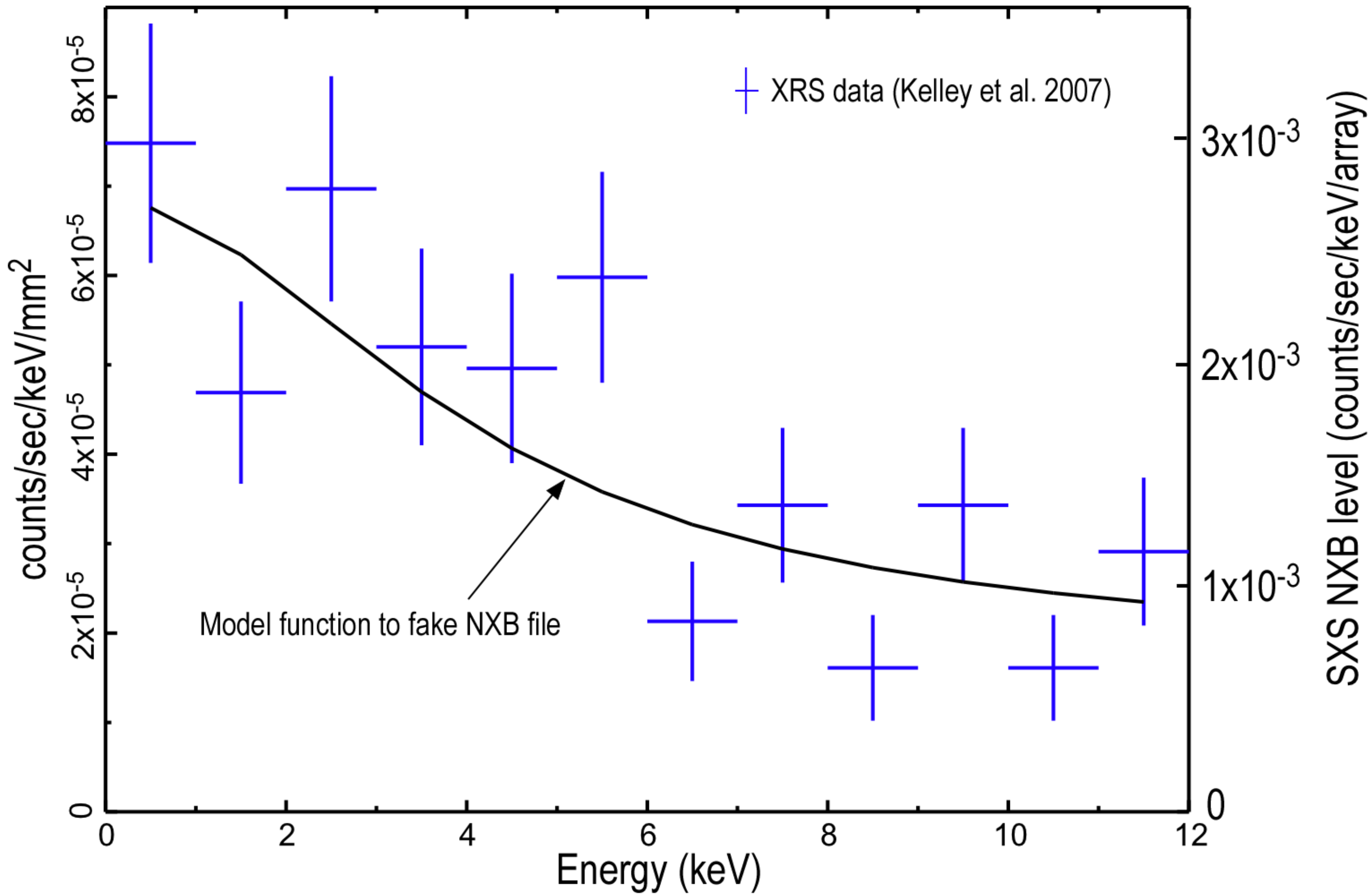
Thermal broadening may contribute an additional ΔE = 2.0-3.0 eV at Fe XXV

Target Summary of Suzaku XRS Calibration Targets

Target	RA	Dec	Exposure	Visibility in phase-0/1	Priority
Filter Wheel			62 ks		1
Capella	05 16 41.4	+45 59 52.8	4 x 45 ks	8/17 – 10/6	1
Algol	03 08 10.1	+40 57 20.3	80 ks (SWG)	6/18 - 9/18	2
HR1099	03 36 47.3	+00 35 15.9	80 ks (AO-1)	7/18 - 9/11	2
GX 301-2	12 26 37.6	-62 46 13.0	4 x 20 ks	6/28 – 9/18	1
3C273	12 29 06.7	+02 03 08.6	80 ks	6/01 - 7/23	1
E0102-72	01 04 02.4	-72 01 59.9	6 x 20 ks + 8 x 50 ks	always	1
N132D	05 25 02.9	-69 38 56.0	4 x 10 ks	always	1
PSR B1509-58 (150 ms pulsar)	15 13 54.2	-59 08 06.0	80 ks	7/30 – 9/30	2
Cen A	13 25 28.0	-43 01 09.0	60 ks (SWG)	6/29 - 8/30	2
3C 273 (ND)	12 29 06.7	+02 03 08.6	32 ks	6/01 - 7/23	2

Non X-ray background (NXB)

- The SXS non X-ray background is estimated by scaling the XRS NXB obtained in orbit.



Summary

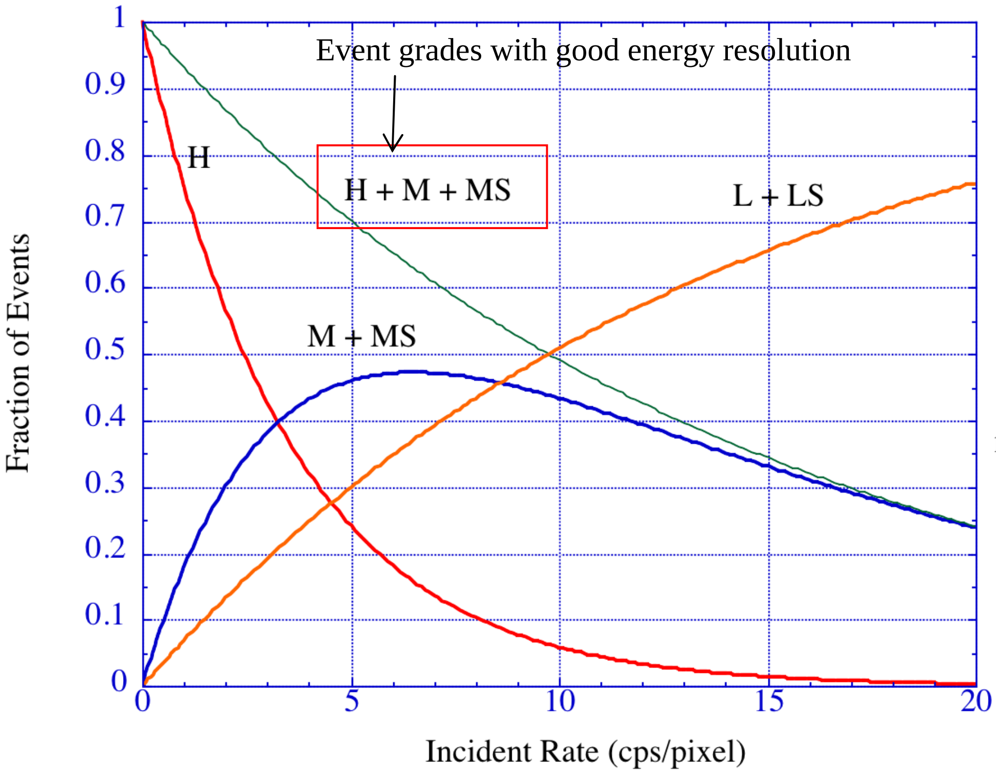
- ASTRO-H SXS is a micro-calorimeter: $\Delta E_{FWHM} = 2.35\,\zeta\sqrt{kT^2C}$
- Recovery of calorimeter science is a top priority.
- 6x6 pixel, 3 arcmin FOV, better $\Delta E < 7$ eV (4 eV goal), larger EA.
- Calibration requirements: energy scale < 2 eV
  energy resolution < 1 eV
- Internal ^{55}Fe cal source & cal pixel,
  external source under consideration.
- Celestial calibration targets are based on Suzaku XRS plan:
  Capella, Algol, HR1099, GX301-2, E0102-72, N132D, etc.

Pile-up and event grades

- The SXS pulse-height is calculated by optimal filtering method.
- Event grade, and hence energy resolution, is determined by relative arrival times:
  - Δt > 142ms: full template (H-res)
  - 35ms < Δt < 142ms: truncated template (M-res)
  - Δt < 35ms: simple PHA (L-res)

  These numbers are based on XRS, and may be optimized for SXS.
- Energy resolution of M-res events is similar to that of H-res events, while energy resolution of L-res events will be several time worse.

Fraction of event grades with good resolution (TBR)



Event grade vs counting rate per pixel

(S=secondary. High-res, mid-res, and mid-res secondary events achieve good energy resolution.)

Note: These plots are based on the XRS numbers, and will be revised for the SXS.

Fraction of good events vs total rate on array for a point source