Analyses school: Suzaku(朱雀)/Hitomi(瞳) satellites

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Lecture plan

Part I. (Introduction)

1. Audience assumed
2. X-ray astrophysical detectors
3. Suzaku and Hitomi satellites and on bard instruments ß We skip details of spacecraft

Part II. (Analyses)

1. Preparation of analyses
2. Analyes software/caldb structure of Suzaku/Hitomi/XRISM
3. Instration of FTOOLs/CALDB
4. Suzaku/XIS analyses walk through
5. Suzaku/HXD analyses walk through
6. Hitomi/HXI analyses walk through

Part I. Introduction

1. Audience assumed

Audience assumed:

Beginners of Suzaku / Hitomi analyses,
X-ray astrophysics educated.

Q1. Knowledge on X-ray astrophysics:

under-graduated — graduated — Ph.D

No paper — 1-2 paper(s) — >5 paper(s)

Q2. Knowledge on X-ray detectors:

nothing — user — developer

Q3. Analyses skills

nothing — user — developer

Please learn more.

My targets, enjoy the school !

Enjoy ~~sightseeing~~ Poster session,
See you in banquet.

2. X-ray astrophysical detectors

Q. What is detector?

E (energy)
q (direction)

→ Detector →

Q (charge) = PH (pulse height)
x (position)

what we want to know

A. converter !

what we can get

Physics process in conversion from *E* to *Q*

- *Photo absorption*
- *Compton scattering*
- *e+ e- pair creation*

In *Suzaku* area, we mainly use the photo absorption process.
In Hitomi, the Compton scattering process is used in hard band

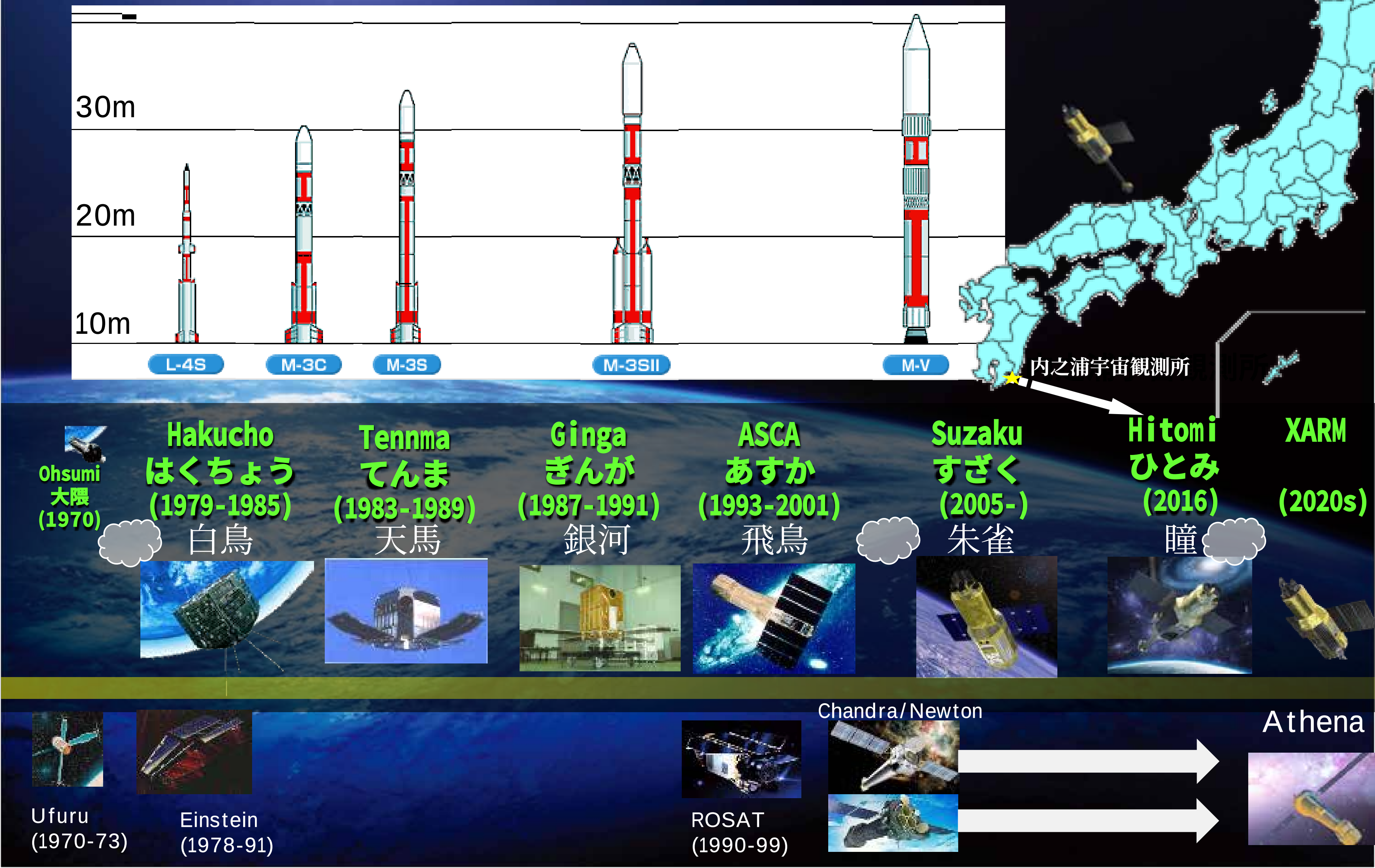
Havier materials can detect X-rays in higher energy band

Materials	Gas (Xe,Ar,..)	$_{14}$Si,	$_{32}$Ge,	$_{48}$Cd,	$_{53}$I,	$_{83}$Bi
Energy band (keV)	0.1	10		100		500
Detectors	PC GSPC	Photo Diode DSSD Si pixel CCD	Ge	CdZTe CdTe	Scintillators (NaI, CsI)	(GSO, BGO)

Suzaku XIS/Hitomi SXI — Suzaku HXD — Hitomi HXI/SGD

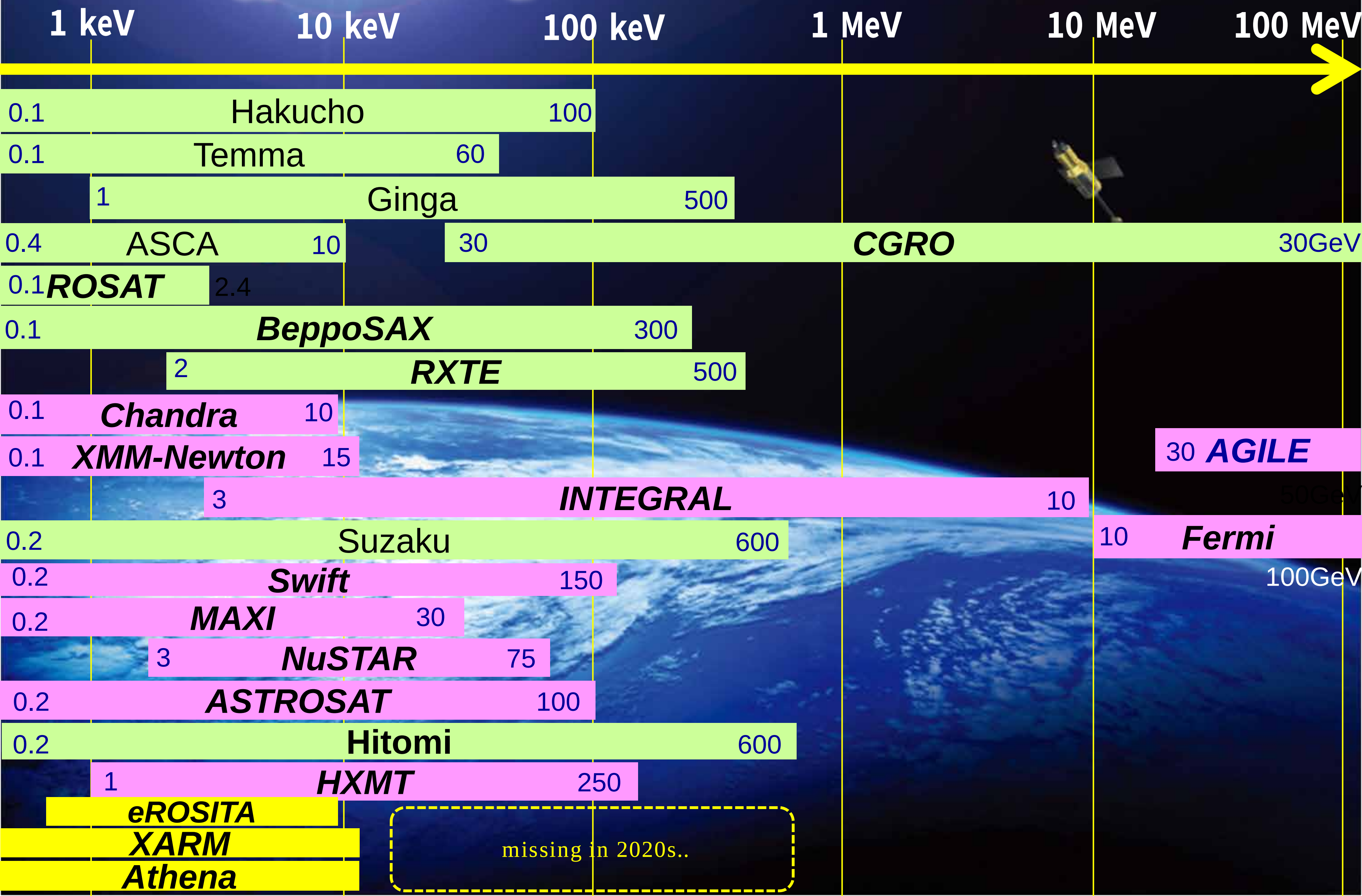
3. Suzaku and Hitomi satellites

The 5th and 6th series of the Japanese X-ray satellite



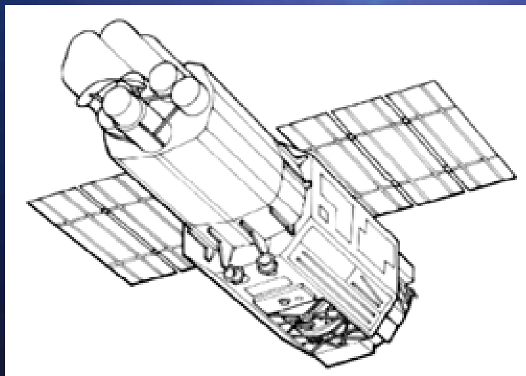
Japan-China X-ray Astronomical Workshop @ ISAS/JAXA, Japan 19-21 Nov 2018

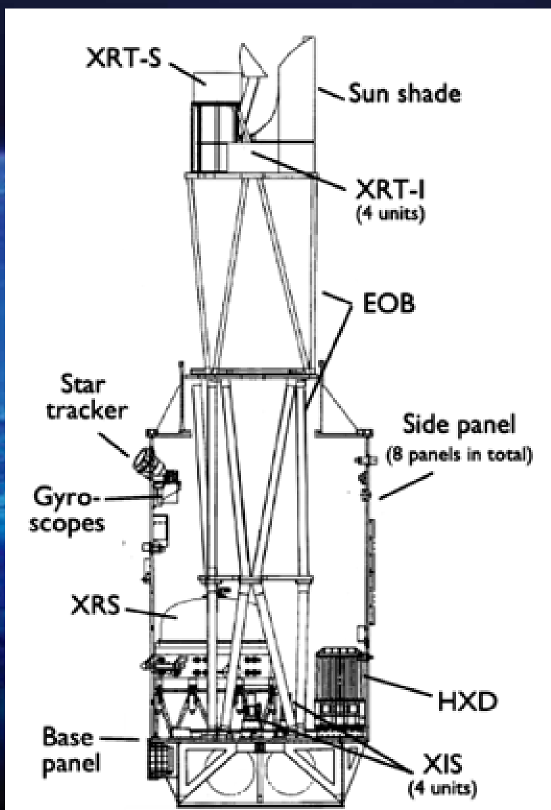
Energy coverage



3.1 *Suzaku* satellite

SKIP: Covered by Ishida-san's talk





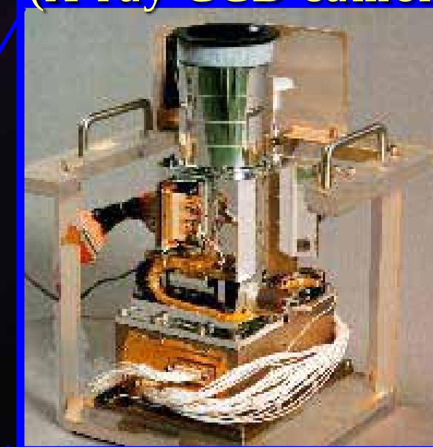
S/C	Orbit apogee	568 km
	Orbital period	96 min
	Observing efficiency	$\sim$43%
XRT	Focal length	4.75 m
Mirror	Field of view	17′ at 1.5 keV
		13′ at 8 keV
	Plate scale	$0\overset{\prime}{.}724\,\mathrm{mm}^{-1}$
	Effective area	$440\,\mathrm{cm}^2$ at 1.5 keV
		$250\,\mathrm{cm}^2$ at 8 keV
	Angular resolution	2′ (HPD)
XIS	Field of view	$17\overset{\prime}{.}8 \times 17\overset{\prime}{.}8$
CCDs	Bandpass	0.2–12 keV
	Pixel grid	1024×1024
	Pixel size	$24\,\mu\mathrm{m} \times 24\,\mu\mathrm{m}$
	Energy resolution	$\sim$130 eV at 6 keV (FWHM)
	Effective area	$330\,\mathrm{cm}^2$ (FI), $370\,\mathrm{cm}^2$ (BI) at 1.5 keV
	(incl XRT-I)	$160\,\mathrm{cm}^2$ (FI), $110\,\mathrm{cm}^2$ (BI) at 8 keV
	Time resolution	8 s (normal mode), 7.8 ms (P-sum mode)
HXD	Field of view	$4\overset{\circ}{.}5 \times 4\overset{\circ}{.}5$ ($\gtrsim$ 100 keV)
Scintillator	Field of view	$34' \times 34'$ ($\lesssim$ 100 keV)
	Bandpass	10–600 keV
	– PIN	10–70 keV
	– GSO	40–600 keV
	Energy resolution (PIN)	$\sim$3.0 keV (FWHM)
	Energy resolution (GSO)	$7.6/\sqrt{E_{\mathrm{MeV}}}$ % (FWHM)
	Effective area	$\sim 160\,\mathrm{cm}^2$ at 20 keV, $\sim 260\,\mathrm{cm}^2$ at 100 keV
	Time resolution	$61\,\mu\mathrm{s}$
HXD-WAM	Field of view	2π (non-pointing)
	Bandpass	50 keV–5 MeV
	Effective area	$800\,\mathrm{cm}^2$ at 100 keV / $400\,\mathrm{cm}^2$ at 1 MeV
	Time resolution	31.25 ms for GRB, 1 s for All-Sky-Monitor

Mitsuda et al. 2007 PASJ 59 S1

Suzaku Payload

XRT (X-ray mirror)

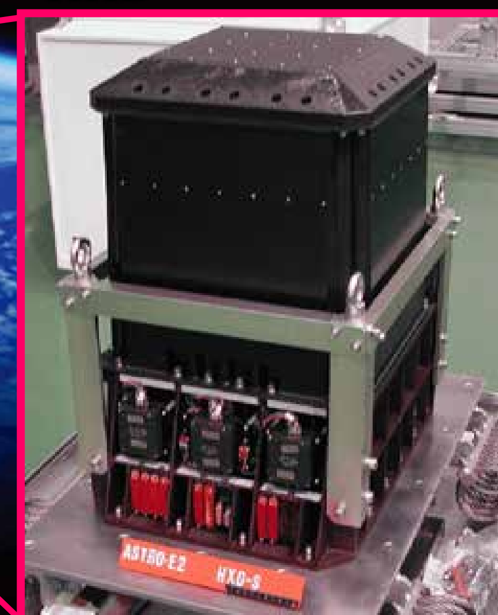
XIS
(X-ray CCD camera)



XRS
(X-ray micro calorimeter)

Suzaku Payload in ISAS/JAXA

HXD



Suzaku detector team

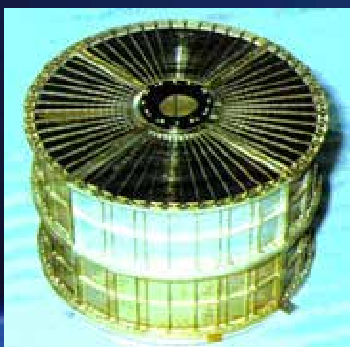
Suzaku Payload in ISAS/JAXA

3.2 *Suzaku* XIS: Mirror + X-ray CCD

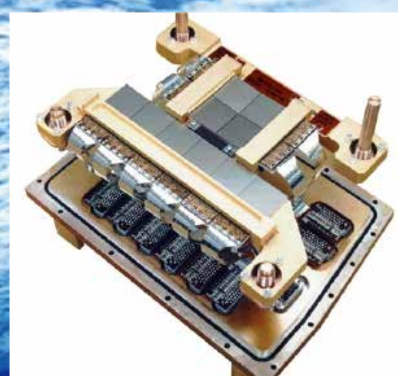
(SKIP: we may skip details)

Suzaku XIS is one of typical optical systems with a mirror + CCDs

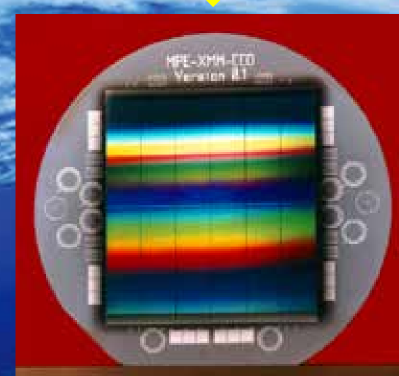
ASCA



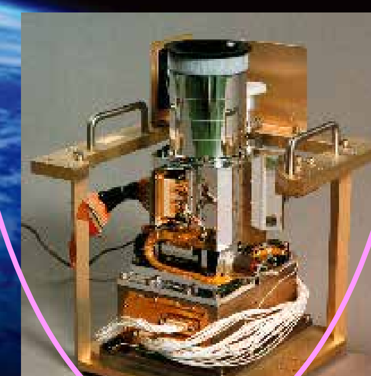
Chandra



XMM-Newton



Suzaku



XIS0, XIS1, XIS3: Front Illuminated (FI) CCD

XIS2: Backside Illuminated (BI) CCD (better for lower energy band)

Suzaku X-ray telescope (XRT)

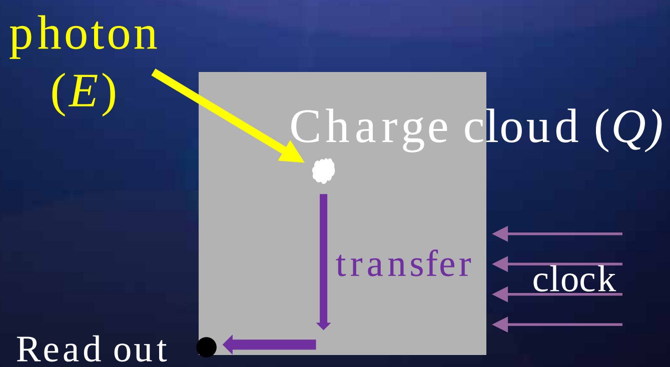
(SKIP: we may skip details)

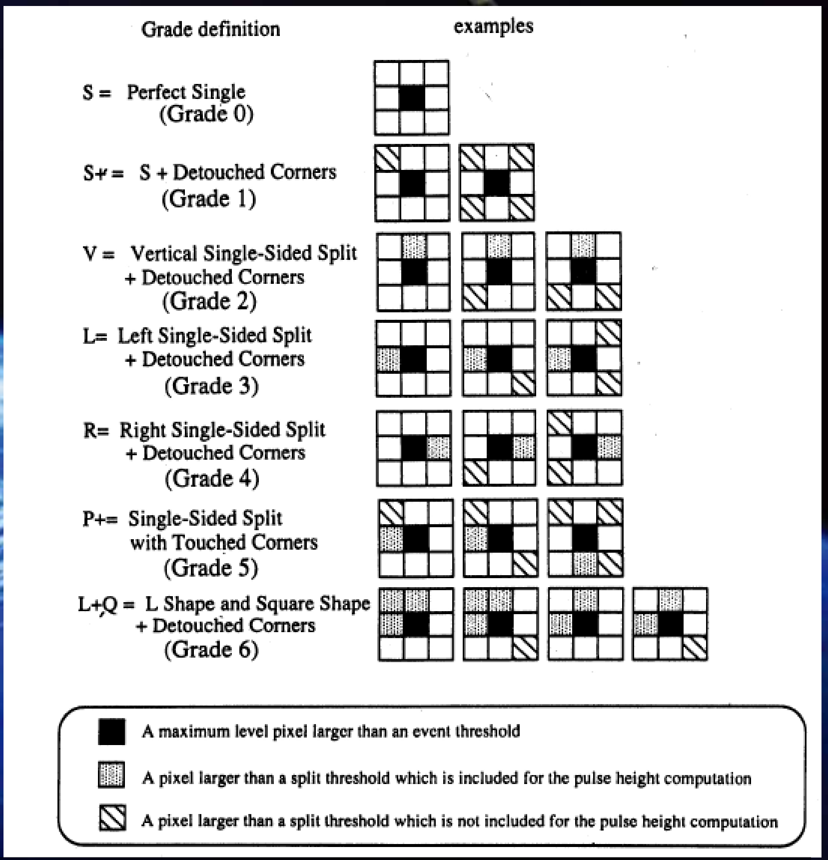
X-ray Mirror	
Diameter	40cm
Focal length	4.75m (XRT-I)
	4.5m(XRT-S)
FOV (FWHM)	17'@1.5keV
	13'@8keV
Plate scale	0.724 arcmin/mm
Effective area	440cm^2@1.5keV
	250cm^2@8keV
Angular resolution	2' (HPD)

(ref) X-ray CCDs, general

(SKIP: this is just an reference)

Charge Coupled Device (CCD)





What is different from optical CCDs?

CCD for optical observation

1 cloud = many optical photons ($Q \propto$ Flux)

à Obtain Frame Image

CCD for X-ray observation

1 cloud = 1 X-ray photon ($Q \propto$ Energy)

à Event detection process on board.

à Pick up events (3x3 or 5x5 pixels)

Charge could be splited

à Assign GRADE par each event

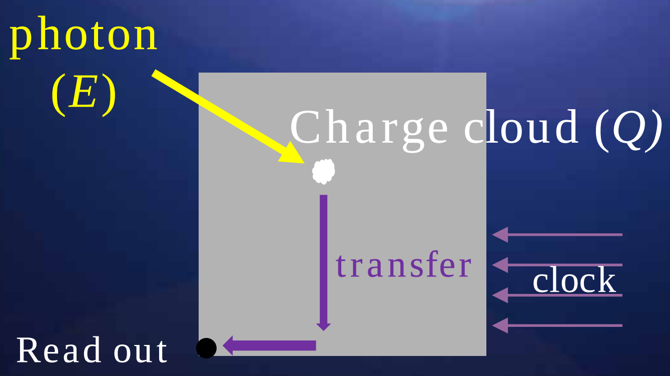
We get (0) Time (1) center position and (2) PHs of neighbor & deposit pixels

à RA,DEC

à Energy

Clocking modes of *Suzaku* XIS

(SKIP: we may skip details)



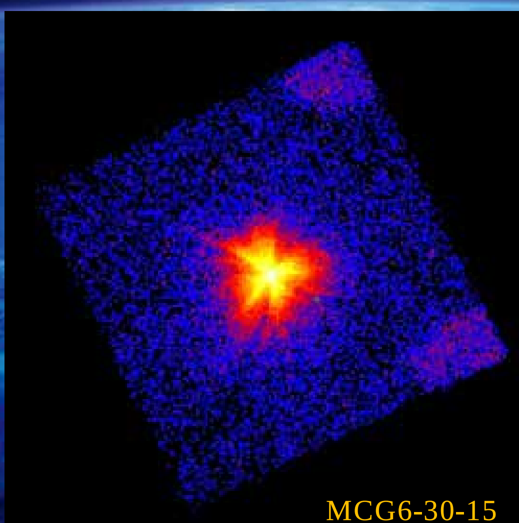
Clocking mode	Options	Readout	Area (pixels)	t_{exp} frame^{-1} [a] (s)	Obs eff. [b]
Normal	none	full	1024×1024	8	1.0
	$1/w$ win	partial in space	$1024/w \times 1024$	$8/w$	1.0
	b s bst	partial in time	1024×1024	b	$b/8$
	$1/w$ win+b s bst	partial n space & time	$1024/w \times 1024$	b	$wb/8$
P-sum	—	stacked	1×1024	—	1.0

[a] Effective exposure time per frame.

[b] Observing efficiency, not including events falling outside of a window for the window options.

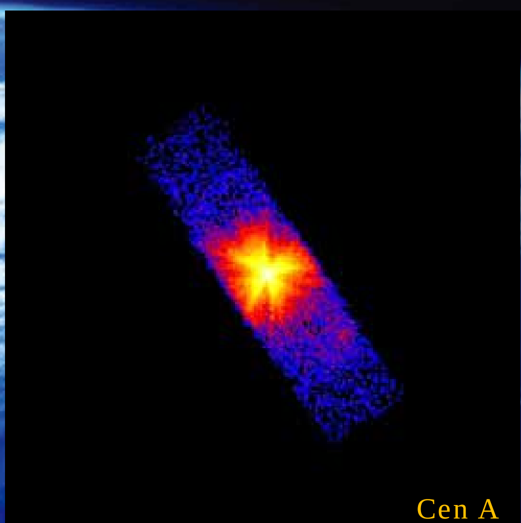
Currently, the Suzaku team does not operate P-sum Mode

Full Window



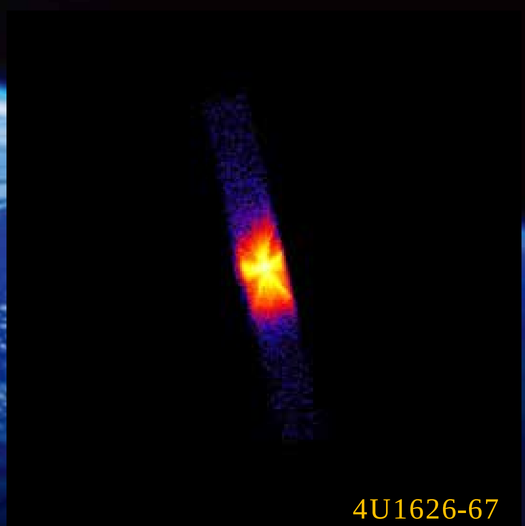
Time resolution = 8 sec

1/4 Window option



Time resolution = 2 sec

1/8 Window option

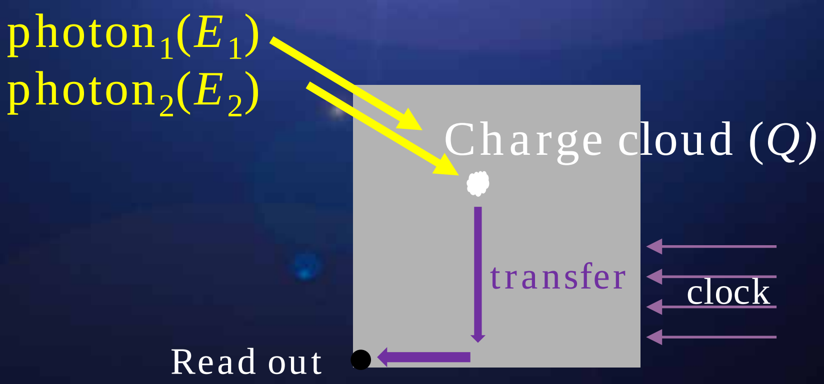


Time resolution = 1 sec

Clocking mode and pile-up limit

(SKIP: we may skip details)

Pile Up



Pile-up occurs when two photons comes almost simultaneously. $Q \propto E_1 + E_2$

Option	none	win		burst				win+burst				
Window	1/1	1/4	1/8	1/1	1/1	1/1	1/1	1/4	1/4	1/4	1/4	1/8
Burst (s)[a]	8.0	8.0	8.0	2.0	0.62	0.5	0.1	1.0	0.5	0.3	0.1	0.5
XIS0	x	x	x	x			x	x	x	x	x	x
XIS1	x	x	x		x	x	x	x	x	x	x	x
XIS3	x	x	x	x			x	x	x	x	x	x
Pile-up limit (s^{-1})	12	48	96	48	155	192	960	96	192	320	960	192
Obs efficiency[b]	1.0	1.0	1.0	0.25	0.08	0.06	0.01	0.5	0.25	0.15	0.05	0.5

[a] The approximate burst time. The exact time may be different; e.g., 0.297 s for 0.3 s burst due to restrictions in the design of the clock pattern.

[b] The observing efficiency. This does not include the loss of events outside of the window in the window and window+burst options. This does not include the loss of effective exposure time by charge transfer of 156 ms.

smaller pile-up effect ß quicker read out

ß smaller imaging size or lower efficiency

Suzaku XIS: Charge injection technique

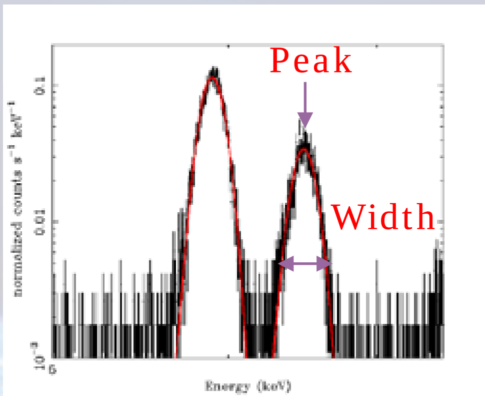
(SKIP: we may skip details)

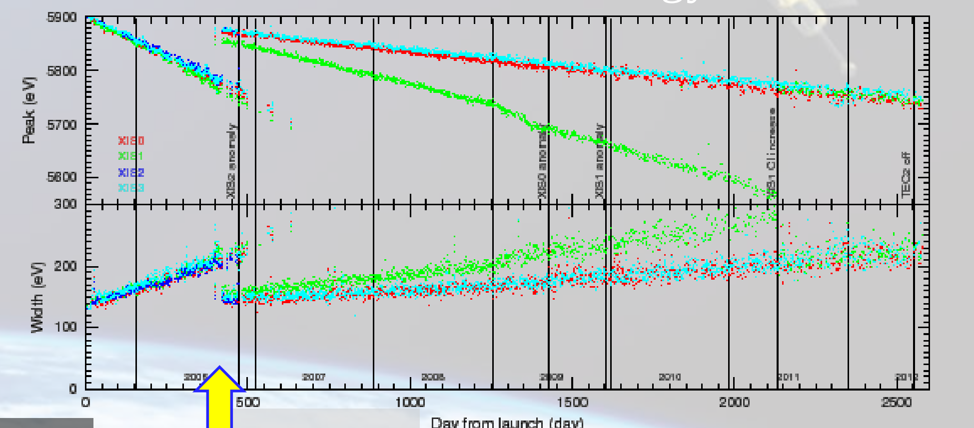
Space Environment (Cosmic-ray irradiation) à degradation of CCD sensor

Charge Transfer Inefficiency (CTI)

Ozawa et al., 2009; Bautz et al., 2004; Uchiyama et al., 2009; Nakajima et al., 2008

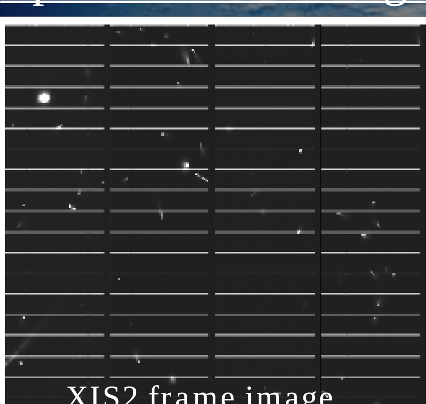
Degradation of Charge transfer à lower PH & worse energy resolution





From 2006

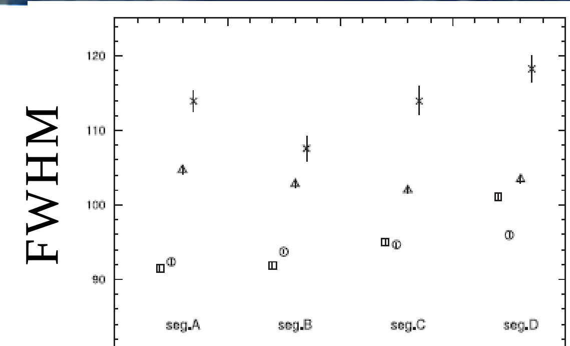
Spaced-row Charge Injection (SCI)



XIS2 frame image

(Artificial lines are removed in the off-line analyses)

Idea) Degradation of charge transfer ß increase of charge trap
ß Put artificial charge before transferring a signal charge!



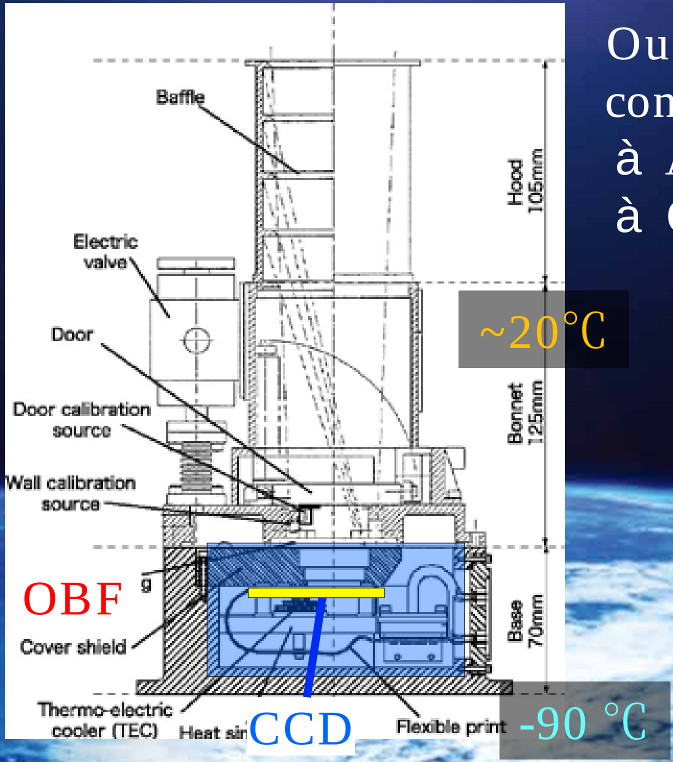
Nakajima et al., 2008

The gain (energy scale) is well calibrated within 5 eV errors!

Suzaku XIS: contamination

(SKIP: we may skip details)

XIS sensor

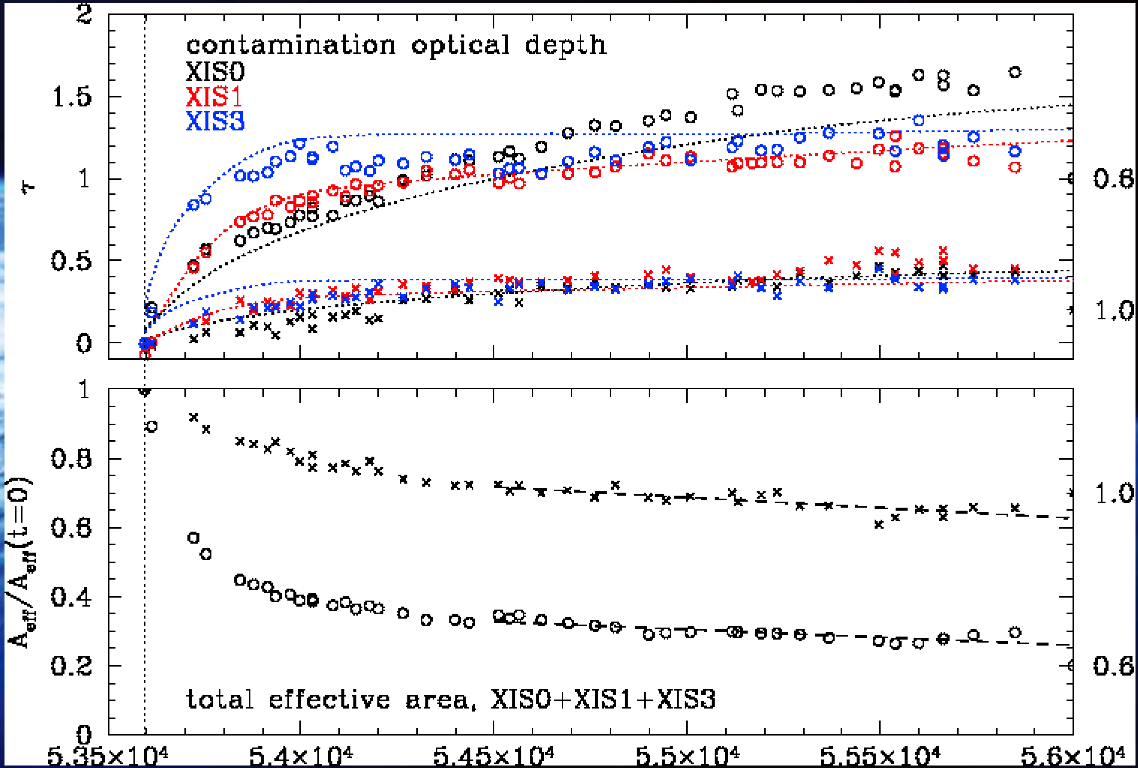


Out gas from onboard instruments (C, N, O, H) will contaminated on the XIS optical blocking filter (OBF).

à Absorb X-rays !

à Quantum efficiency below 2 keV decreases.

Koyama et al., 2007



This effect should be taken into account in the analyses (Ishisaki et al. 2007).

Suzaku XIS Operation

Date	Sensor	Description
2005-08-11	All	First light with 1E0102.2–7219
2006-01-18	All	Onboard software update to remove grade 7 events onboard.
2006-02-17	XIS023	Event threshold was changed to 100.
2006-10	All	SCI operation started.
2006-11-09	XIS2	A micro-meteorite hit. The entire imaging area became dysfunctional.
2008-01-30	All	MPU0 is lost and replaced with MPU2.
2009-06-23	XIS0	A micro-meteorite hit. A 1/8 of the imaging area became dysfunctional.
2009-04-01	All	P-sum clocking mode officially supported.
2009-11-02	All	MPU1 reset after a ROM update.
2009-12-18	XIS1	A micro-meteorite hit. No major impact in scientific capability.
2009-04-01	All	SCI off operation support terminated.
2010-04-01	All	Edit mode selection automated.
2011-03-09	All	XIS halted due to non-maskable interruption and was restarted.
2011-06-01	XIS1	Injection charge increased to 6 keV for Normal (no option).
2011-08-22	XIS1	Injection charge increased to 6 keV for Normal (1/4 win).
2011-09-01	XIS1	Injection charge increased to 6 keV for Normal (0.1s burst).
2011-09-29	All	The default PPU ratio changed to the optimum for each editing mode combination.
2011-10-06	XIS1	Injection charge increased to 6 keV for Normal (1/4 win+1.0s burst, 1/8 win).
2011-10-11	XIS1	Injection charge increased to 6 keV for Normal (1/4 win+0.1s, 0.3s, & 0.5s burst).
2011-10-25	XIS1	Injection charge increased to 6 keV for Normal (0.5s, & 0.62s burst).
2011-10-25	XIS1	Support for XIS1 2.0s burst with CI=6 keV terminated.
2012-01-26	All	XIS restarted after the satellite UVC. TEC2 power terminated to save power.
2012-04-01	All	Choice of using the HXD nominal position was removed.
2012-07-11	All	XIS stopped during the satellite ejection of RCS hydrazine,
2012-07-14	XIS2	TEC2 for the XIS2 was terminated permanently for saving power.

3.3 *Suzaku* HXD: Design concept

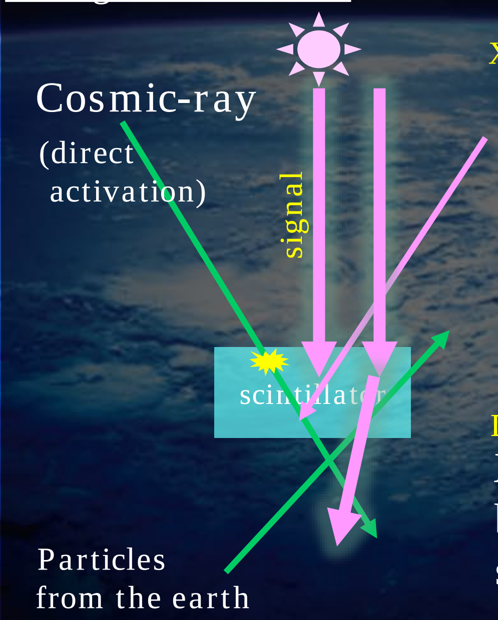
(SKIP: Covered by Fukazawa-san)

The HXD is a scintillation counter

Non-Imaging Spectrometer

High sensitive scintillator = Reduce Background

Background in orbit



Non X-ray background(NXB)

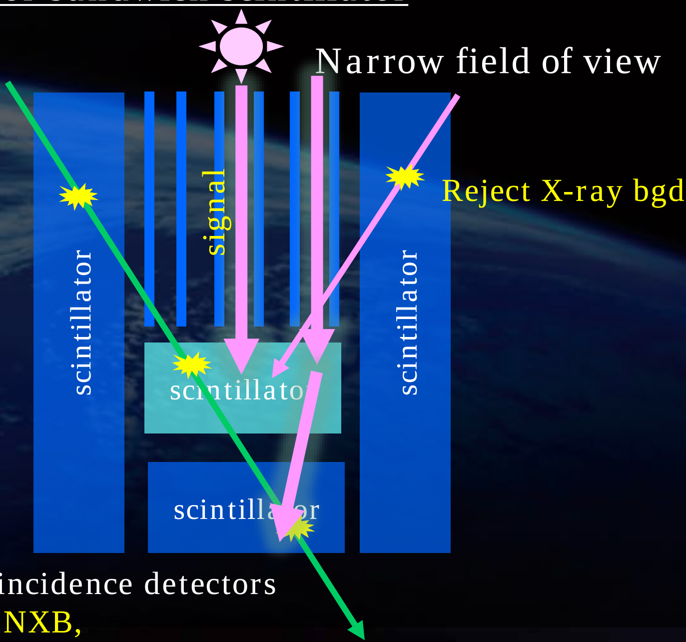
X-ray background

X-rays from other object
(Cosmic X-ray background
Galactic diffuse
stray from other objects etc)

Detectors response

X-ray from the object,
but escaped by Compton scattering

Phosphor sandwich scintillator

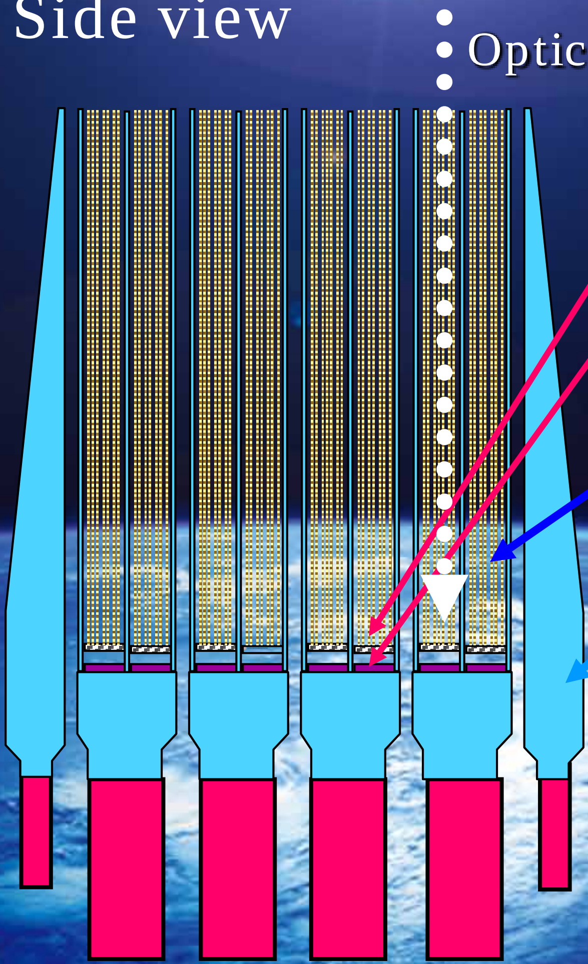


Anti coincidence detectors
(Reject NXB,
reject Comptonized events)

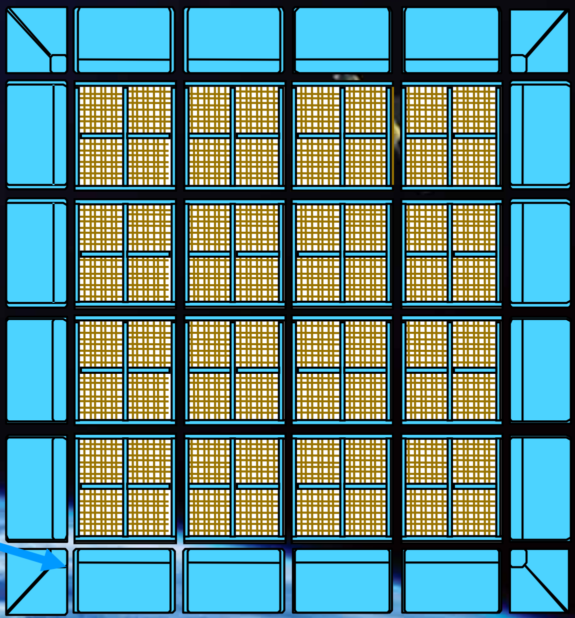
Suzaku HXD Sensor

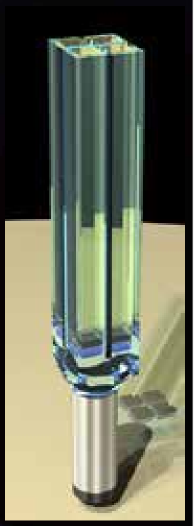
(SKIP: Covered by Fukazawa-san)

Side view



Top view



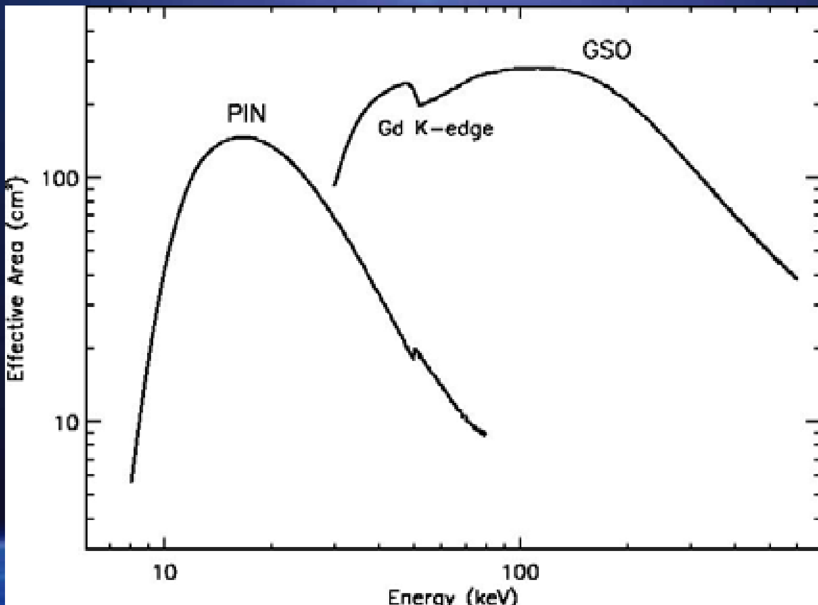


Takahashi et al PASJ 2007
Kokubun et al PASJ 2007

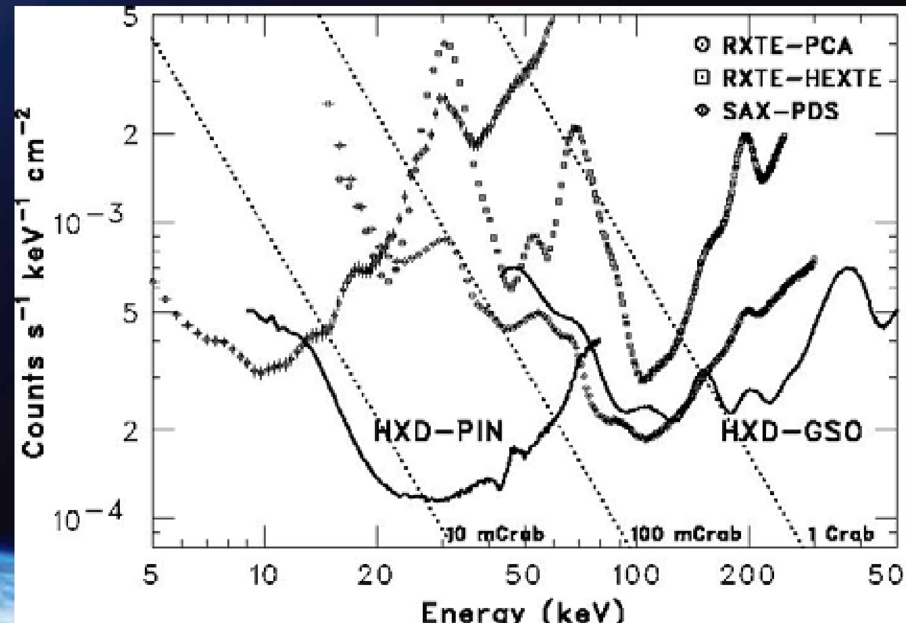
Suzaku HXD Performance

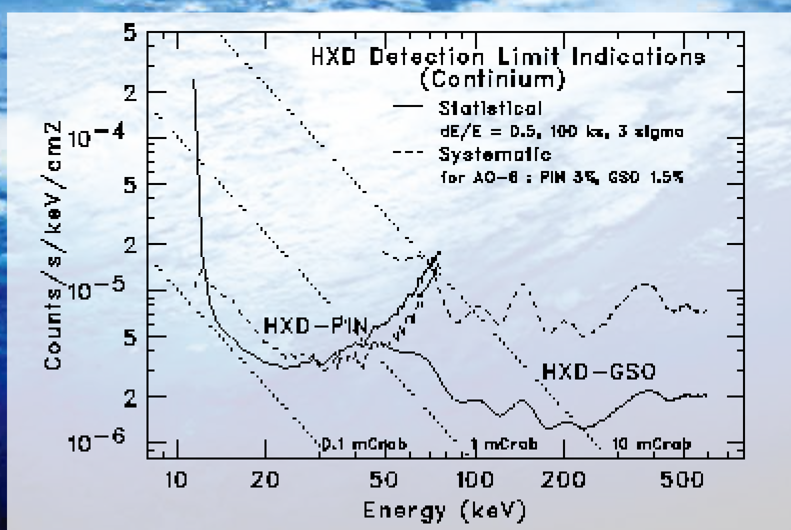
(SKIP: Covered by Fukazawa-san)

Takahashi et al PASJ 2007



Kokubun et al PASJ 2007

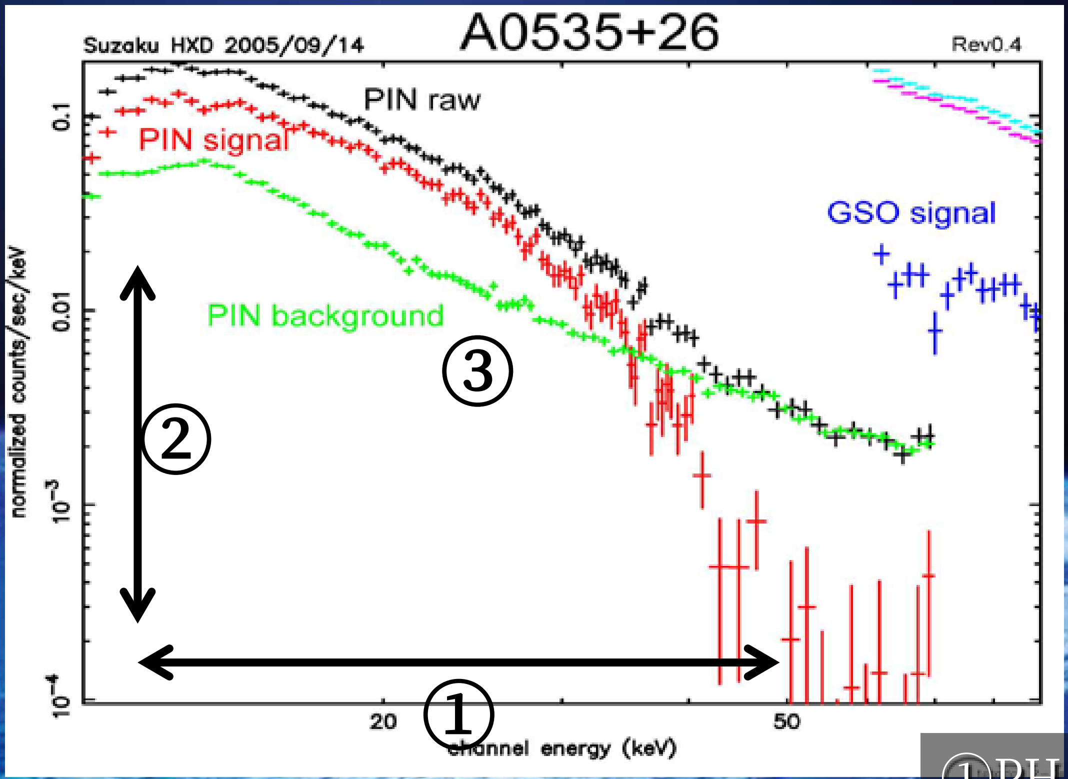




Sensitivity at 10^{-6} level.

Suzaku HXD data (cleaned)

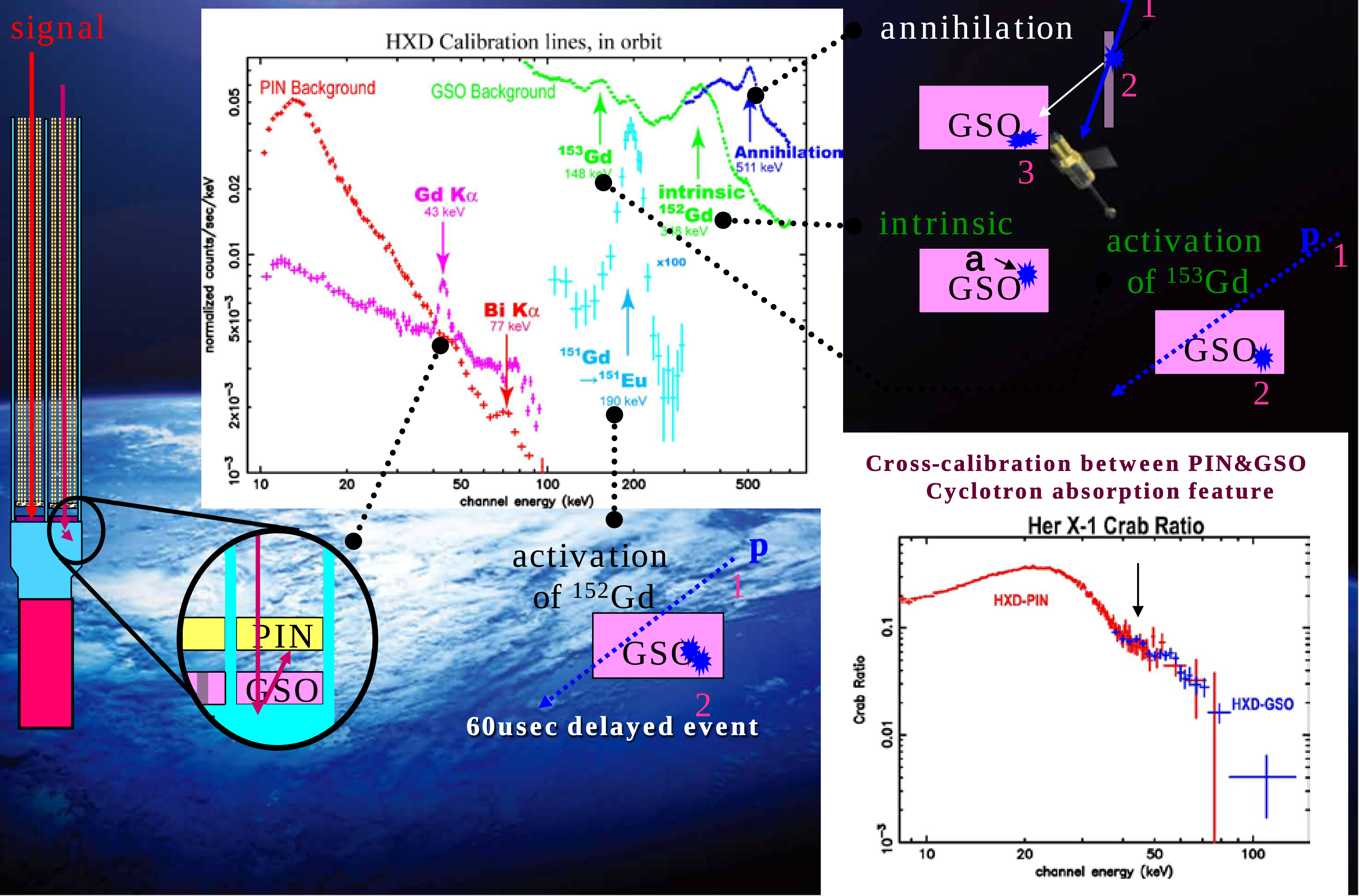
What you get is the hard X-ray spectrum.



①PHA to Energy
(gain calibration, non-linearity correction)
②Effective area and efficiency
Energy response
③Estimation of non X-ray background

(SKIP: we may skip details)

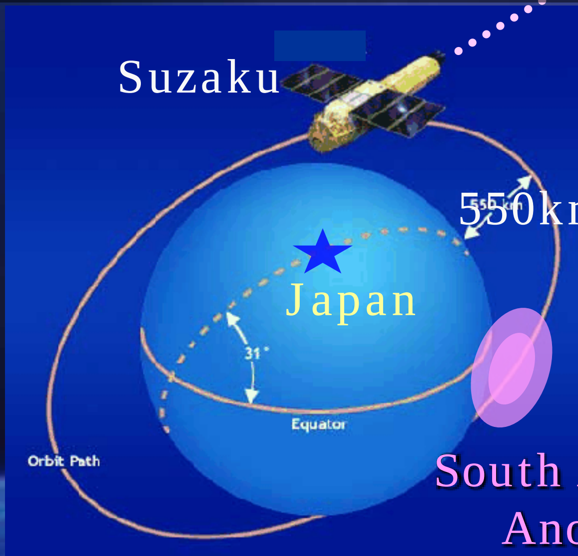
Suzaku HXD: ① Energy scale calibration



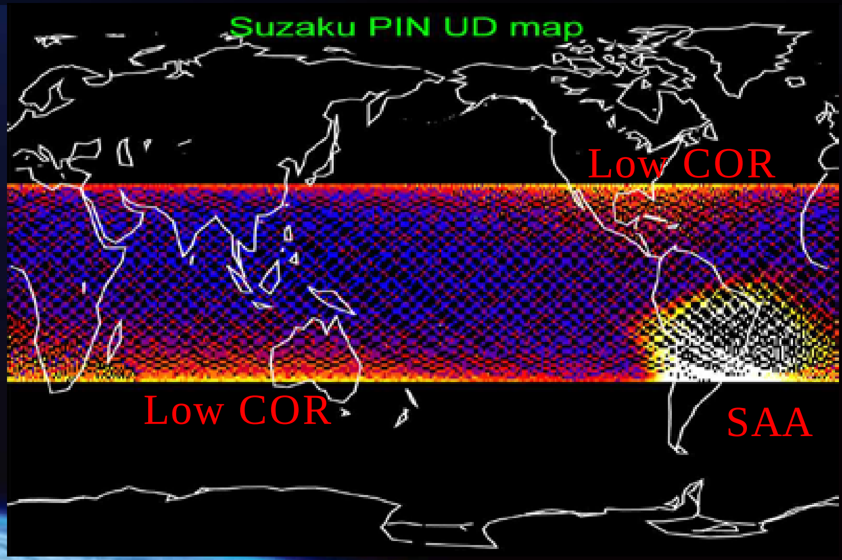
Suzaku HXD: ③ Variable NXB

(SKIP: covered by Fukazawa-san's talk)

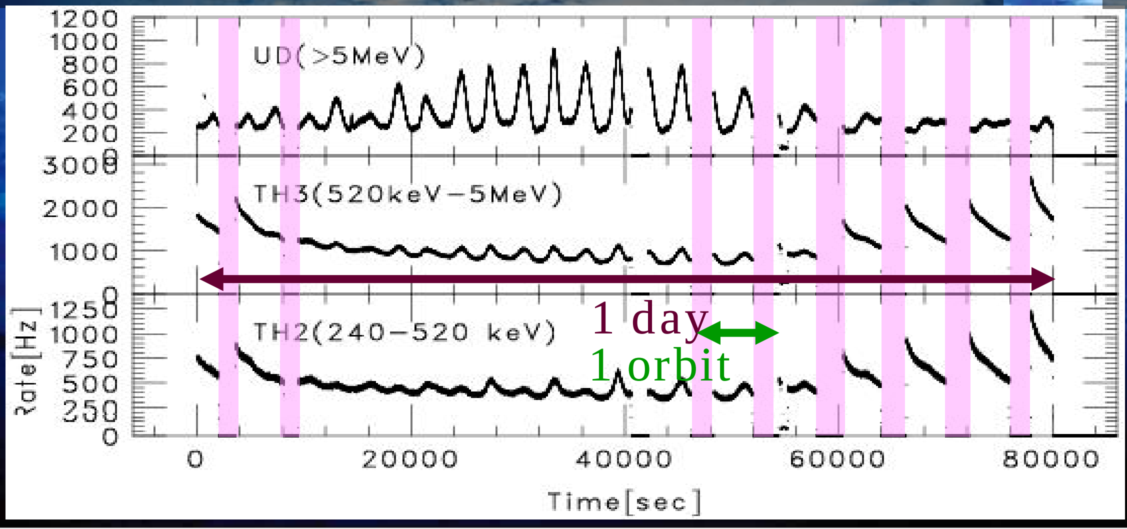
Suzaku orbit: SAA passage



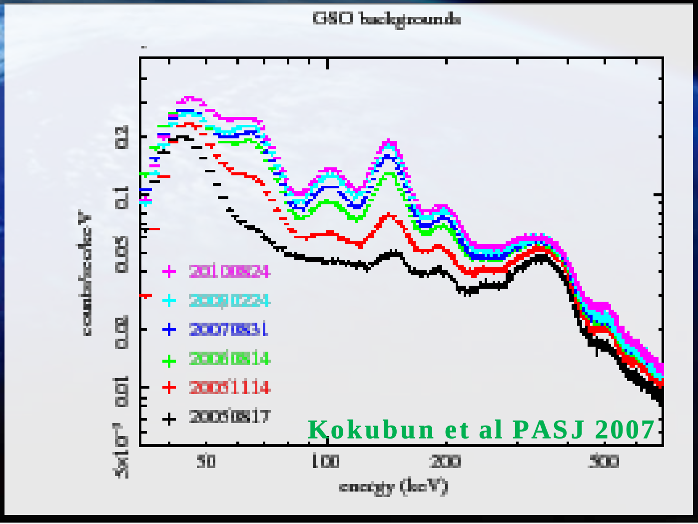
Map of *Suzaku* HXD-PIN UD count rate



One-day Light Curves of surrounding units



Accumulation of activation BGD

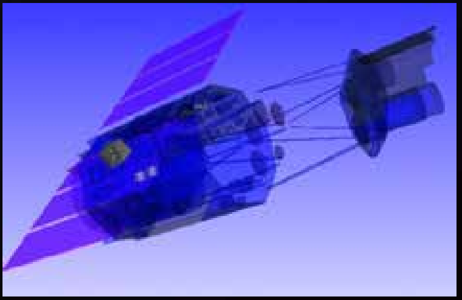


Suzaku HXD: NXB modeling

(SKIP: Covered by Odaka-san's talk/Fukazawa-san's talk)

Variable NXB à No rocking system (src ⇔ bgd) = No real time data

à Estimation of NXB



Terada et al IEEE 2005

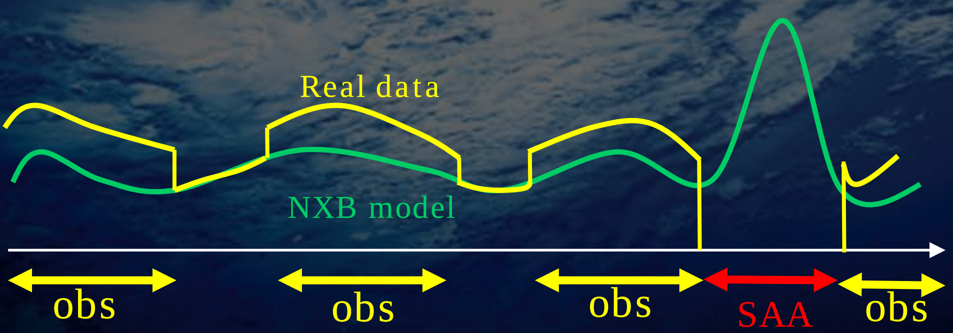
Two approaches in estimation of NXB

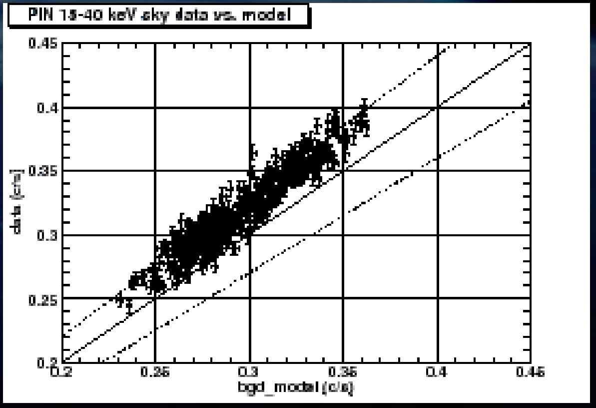
1. physical modeling & Monte Carlo simulation
2. Empirical modeling

NXB modeling (Fukazawa et al PASJ 2010)

CR irradiated (PIN UD count)
Satellite position & COR, SAA
Attitude & Earth elevation
GSO count rate @ earth occultation etc

NXB event list, estimated (time, PHA)





Read data = NXB model at Earth Occultation

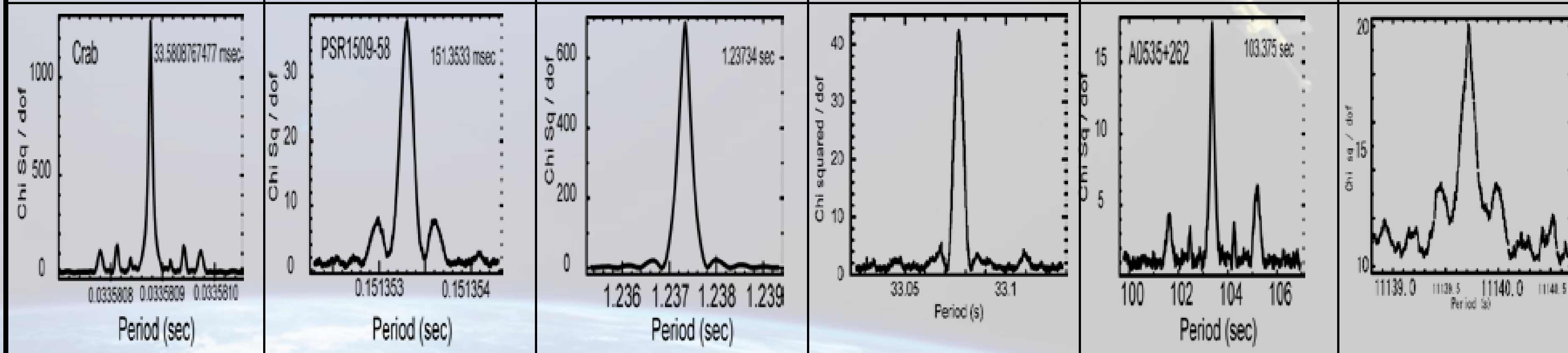
Systematic error < 5%

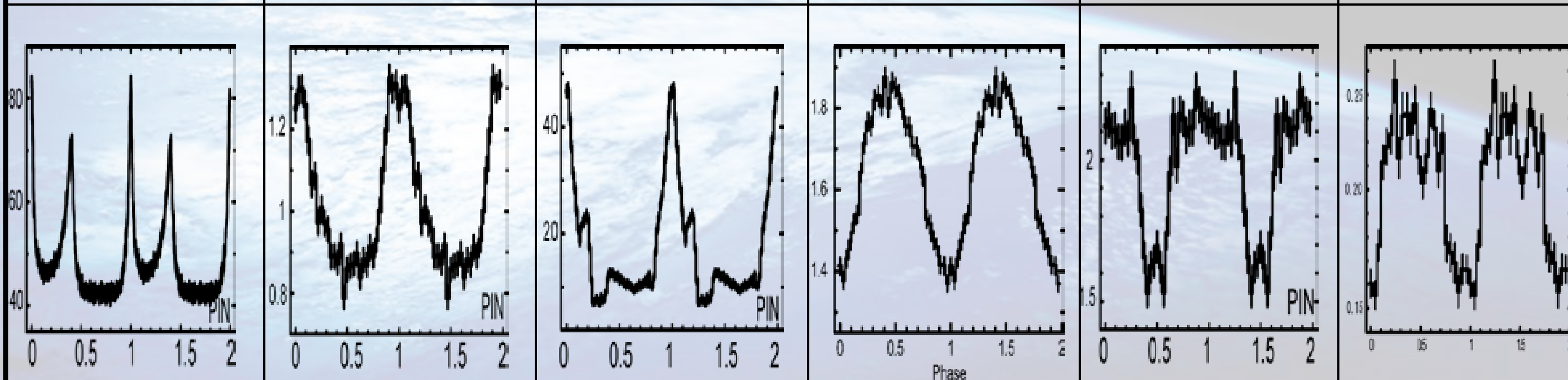
Suzaku HXD Timing

Terada et al 2008

(SKIP: we may skip details)

Crab	PSR B1509-58	Her X-1	AE Aqr	A0535-262	AM Her
33ms	151 ms	1.24 s	33 sec	103.4 s	11139s
Terada et.al 2008a	Terada et.al 2008a	Enoto et.al 2008	Terada et.al 2008b	Terada et.al 2006	Terada et.al 2010



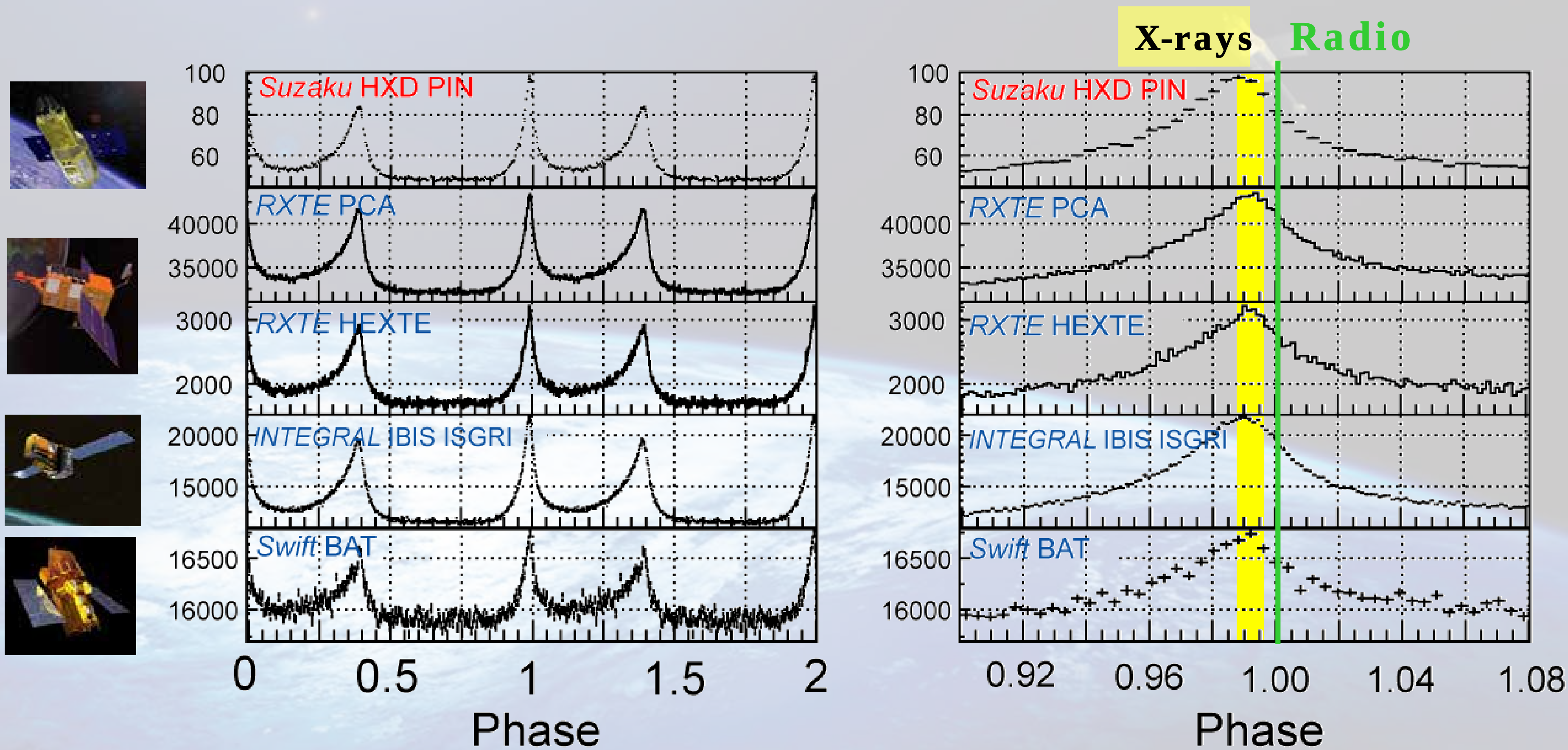


Suzaku HXD Timing calibration

(SKIP: we may skip details)

March 17-20, 2007, simultaneous observation of Crab (Y.Terada et.al 2008a)

One of the successful results of IACHEC activities.



·Consistent within ~ 100 μ sec

·Systematic errors in time ~ 300 usec in maximum

Suzaku HXD operation

Date	Instrument	Description
2005/07/11	HXD all	Failure of heat pipe
2005/08/19	HXD all	First light, Cen A
2005/10/30	all	HXD nominal position
2006/05/24-27	HXD W0	W01-PIN3 noisy: High voltage for W0* PIN, 500V à 400V
2006/09/20, 10/3	HXD W1	W10-PIN0 noisy: High voltage tentatively 0V and recovered
2007/07/28	HXD W1	W10-PIN0 noisy: High voltage for W0* PIN, 500V à 400V
2009/09/13	HXD W0	W01-PIN3 noisy: High voltage tentatively 0V and recovered
2012/04/21	HXD W1	W10-PIN1 noisy: High voltage tentatively 0V and recovered
2012/07/23	HXD all	PIN HV set 400/400/500/500 V à 500/500/400/400V (mistake)

The energy response changed by the settings of the PIN high voltage, and thus we have to take care of the settings. à definition of EPOCH (tomorrow)

3.3 Hitomi satellite

(SKIP detail: covered by Tsujimoto-san’s talk)

ASTRO-H/Hitomi Mission

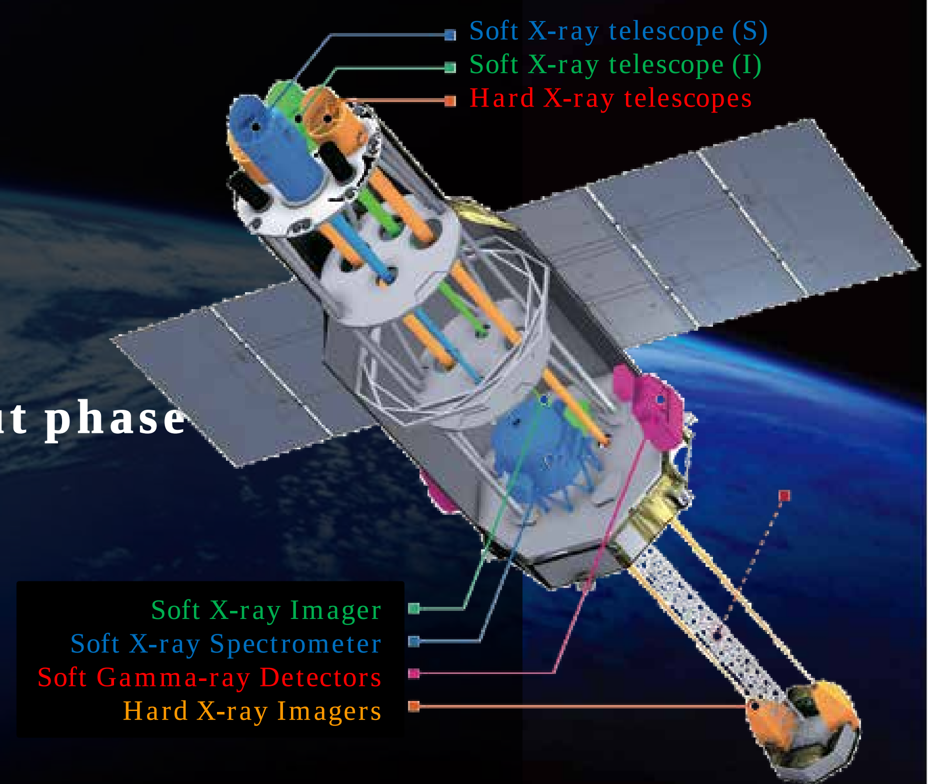
- The 6th series of Japanese X-ray mission in 0.3 ~ 600 keV
  - ü Micro-calorimeter (5 eV resolution, 3’x3’)
  - ü Wide-FOV CCD camera (38’x38’)
  - ü Hard X-ray imager (up to 70 keV,9’x9’)
  - ü Soft gamma-ray detector (super high sensitivity)

History

- 2003 NeXT project
- 2005~ ASTRO-H mission
- 2016.2.17 Launch
- 2016.3.26 lost communication
- 2016.4.28 Operation terminated

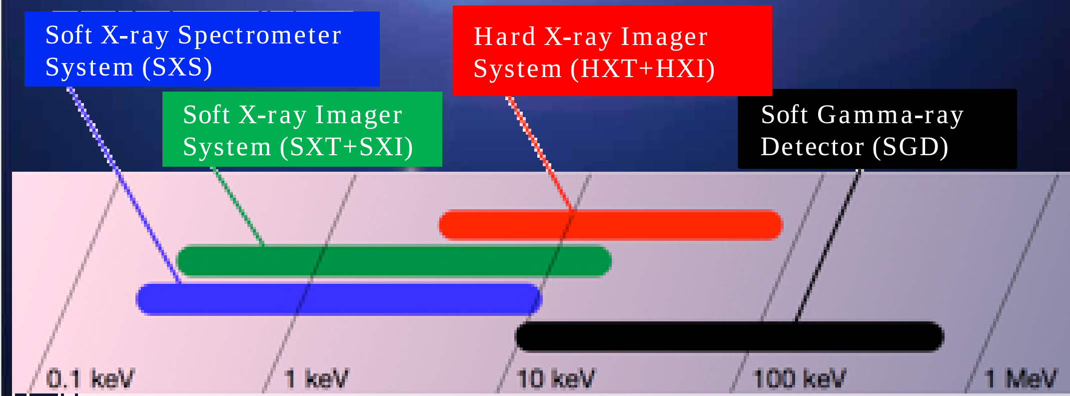
Objects observed during the check-out phase

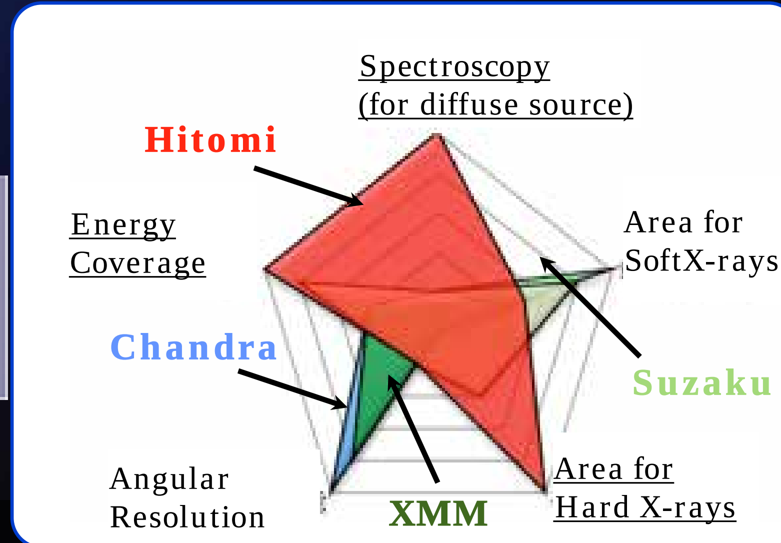
- Perseus Cluster of galaxies
- N132D
- IGR J16318-4848
- RX J1856.5-3754
- G21.5-0.9
- Crab



Hitomi Instruments

(SKIP detail: covered by Tsujimoto-san's talk)





SXT-S (telescope) | SXS

Soft X-ray Spectrometer System

- 0.3-12 keV
- Large Area Soft X-ray Telescope
- X-ray micro calorimeter
- super resolution (<7eV at 6 keV)

SXT-I (telescope) | SXI

Soft X-ray Imaging System

- 0.5-12 keV
- Large Area Soft X-ray Telescope
- Large FOV 38x38 arcmin^2
- CCD spectroscopy

HXT (telescope) | HXI

Hard X-ray Imaging System

- Hard X-ray Telescope (5-80 keV)
- Focal Length 12 m
- New CdTe Imager (Fine Pitch Cross Strip)

SGD

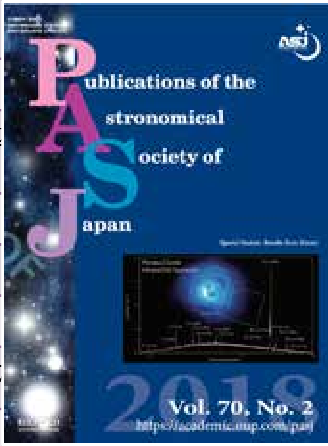
Soft Gamma-ray Detector

- 10-600 keV non-imaging
- Si/CdTe Compton Camera with Narrow FOV Active Shield
- most sensitive gamma-ray detector ever
- Hard X-ray Polarization

Hitomi Science papers

(SKIP : covered by Matsushita-san's talk)

Perseus Cluster			
The Quiescent Intracluster Medium in the Core of the Perseus Cluster	A.Fabian	Nature	2016 July
Hitomi constraints on the 3.5 keV line in the Perseus galaxy cluster	M. Markevitch	ApJL	2016 July
Solar abundance ratios of the iron-peak elements in the Perseus cluster	H.Yamaguchi	Nature	2017 Nov
Measurements of resonant scattering in the Perseus cluster core with Hitomi SXS	K.Sato	PASJ	1710.04648
Atmospheric gas dynamics in the Perseus cluster observed with Hitomi	Y.Ichinohe	PASJ	1711.00240
NGC1275			
Hitomi Observation of Radio Galaxy NGC 1275: The First X-ray Microcalorimeter Spectroscopy of Fe-K{alpha} Line Emission from an Active Galactic Nucleus	H.Noda	PASJ	1711.06289
N132D			
Hitomi Observations of the LMC SNR N132D: Highly Redshifted X-ray Emission from Iron Ejecta	E.Miller	PASJ	1712.02
RXJ1856-3754			
(calibration paper only)	--	--	--
IGR J16318-4848			
Glimpse of the highly obscured HMXB IGR J16318–4848 with Hitomi	H.Nakajima	PASJ	1711.07
G21.5-0.9			
Hitomi X-ray Observation of the Pulsar Wind Nebula G21.5$-$0.9	H.Uchida	PASJ	1802.05068
Crab			
Search for Thermal X-ray Features from the Crab nebula with Hitomi Soft X-ray Spectrometer	M.Tsujimoto	PASJ	1707.00054
Hitomi X-ray studies of Giant Radio Pulses from the Crab pulsar	Y.Terada	PASJ	1707.08801

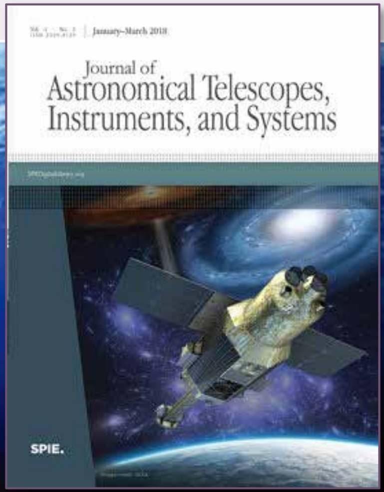


Hitomi Instruments papers

	Title	Author	Special Issue
AH	The Hitomi (ASTRO-H) x-ray astronomy satellite	T. Takahashi	JATIS
SXS	Thermal analyses for initial operations of the soft x-ray spectrometer onboard the Hitomi satellite	H. Noda	JATIS
	Porous plug phase separator and superfluid film flow suppression system for the soft x-ray spectrometer onboard Hitomi	Y. Ezoe	JATIS
	Calibration sources and filters of the soft x-ray spectrometer instrument on the Hitomi spacecraft	Cor P. de Vries	JATIS
	In-orbit operation of the soft x-ray spectrometer onboard the Hitomi satellite	M. Tsujimoto	JATIS
	Performance of the helium dewar and the cryocoolers of the Hitomi soft x-ray spectrometer	R. Fujimoto	JATIS
	Design, implementation, and performance of the Astro-H SXS calorimeter array and anticoincidence detector	C. Kilbourne	JATIS
	Design, implementation, and performance of the Astro-H soft x-ray spectrometer aperture assembly and blocking filters	C. Kilbourne	JATIS
	Vibration isolation system for cryocoolers of soft x-ray spectrometer on-board ASTRO-H (Hitomi)	Y. Takei	JATIS
	In-flight performance of pulse-processing system of the ASTRO-H/Hitomi soft x-ray spectrometer	Y. Ishisaki	JATIS
	In-flight performance of the soft x-ray spectrometer detector system on Astro-H	F. S. Porter	JATIS
	In-flight calibration of Hitomi Soft X-ray Spectrometer. (1) Background	C. A. Kilbourne	PASJ
	In-flight calibration of the Hitomi Soft X-ray Spectrometer. (2) Point spread function	Y. Maeda	PASJ
	In-flight calibration of Hitomi Soft X-ray Spectrometer. (3) Effective area	M. Tsujimoto	PASJ
SXI	Soft X-ray Imager aboard Hitomi (ASTRO-H)	T. Tanaka	JATIS
	In-orbit performance of the soft X-ray imaging system aboard Hitomi (ASTRO-H)	H. Nakajima	PASJ

Hitomi Instruments papers

	Title	Author	Special Issue
SXT	Ground-based x-ray calibration of the Astro-H/Hitomi soft x-ray telescopes	R. Iizuka	JATIS
HXI	The hard x-ray imager onboard Hitomi (ASTRO-H)	K. Nakazawa	JATIS
	In-orbit performance and calibration of the hard x-ray imager onboard Hitomi (ASTRO-H)	K. Hagino	JATIS
HXT	Supermirror design for Hard X-Ray Telescopes on-board Hitomi (ASTRO-H)	K. Tamura	JATIS
	On-ground calibration of the Hitomi Hard X-ray Telescopes	H. Mori	JATIS
	In orbit performance of the Hard X-ray Telescope (HXT) on board the Hitomi (ASTRO-H) satellite	H. Matsumoto	JATIS
CAMS	In-flight performance of the Canadian Astro-H Metrology System	L. Gallo et al.	JATIS
SGD	Design and performance of Soft Gamma-ray Detector onboard the Hitomi (ASTRO-H) satellite	H. Tajima	JATIS
Time	Time assignment system and its performance aboard the Hitomi satellite	Y. Terada	JATIS
Soft	Astro-H/Hitomi data analysis, processing, and archive	L. Angelini	JATIS



You can refer them, free access

Part II. Analyses

1. Preparation of analyses
2. Analyes software/caldb structure of Suzaku/Hitomi/XRISM
3. Instration of FTOOLs/CALDB
4. Suzaku/XIS analyses walk through
5. Suzaku/HXD analyses walk through
6. Hitomi/HXI analyses walk through

If you learn Hitomi analyses tools, you will be an expert for XRISM also, I hope.

1. Documents

Suzaku

ü ABC Guide (for Guest Observers)
http://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/

ü Technical Description (for Proposers)
http://www.astro.isas.jaxa.jp/suzaku/doc/suzaku_td/

ü 7 steps (by Suzaku helpdesk Japan)
http://www.astro.isas.jaxa.jp/suzaku/analysis/7step_XIS_20071025.txt
http://www.astro.isas.jaxa.jp/suzaku/analysis/7step_HXD_20120418.html

ü 1st step manual (only in Japanese)
http://cosmic.riken.jp/suzaku/help/guide/fstep_web/fstep.html

Hitomi

ü Data Reduction Guide
https://heasarc.gsfc.nasa.gov/docs/hitomi/analysis/hitomi_analysis_guide_20171214.pdf

ü Step by step guide
https://heasarc.gsfc.nasa.gov/docs/hitomi/analysis/hitomi_stepbystep_20161222d.pdf

ü Calibration descriptions
https://heasarc.gsfc.nasa.gov/docs/hitomi/calib/hitomi_caldb_docs.html

1.1 Before analyzing the data

- Whether your Observation was done or not: check observation log
  - Suzaku: http://darts.isas.jaxa.jp/astro/tables/SUZAKU_LOG.html
  - Hitomi: please check data reduction guide

- Important events in the operation
  - Suzaku spacecraft http://www.astro.isas.jaxa.jp/suzaku/log/operation/
  - XIS http://www.astro.isas.jaxa.jp/suzaku/log/xis/
  - HXD http://www.astro.isas.jaxa.jp/suzaku/log/hxd/
  - Hitomi: please check data reduction guide

- Limitation of the pipe line products / Calibration
  - check Suzaku notes in http://www.astro.isas.jaxa.jp/suzaku/process/.
  - Hitomi: please check calibration descriptions

- Announcements from detector teams
  - Suzaku: http://www.astro.isas.jaxa.jp/suzaku/analysis/xxx/ (xxx=hxd, xis, xrt)
  - Hitomi: please check data reduction guide

1.2 Download datasets

Software (*Suzaku / Hitomi*)

HEASoft (http://heasarsc.gsfc.nasa.gov/docs/software/lheasoft/)

Calibration database files

Suzaku: ISAS (http://www.astro.isas.jaxa.jp/suzaku/caldb/)
GSFC (http://heasarc.gsfc.nasa.gov/docs/heasarc/caldb/suzaku/)
Hitomi: ISAS(http://darts.isas.jaxa.jp/pub/legacy.gsfc.nasa.gov/caldb/data/hitomi/)
GSFC(https://heasarc.gsfc.nasa.gov/docs/hitomi/calib/)

Data Products

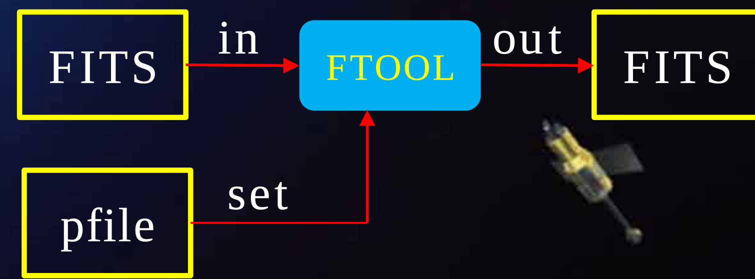
Suzaku: FTP area (ftp://darts.isas.jaxa.jp/pub/suzaku/)
DARTS @ISAS (http://www.darts.isas.jaxa.jp/astro/suzaku/)
HEASARC FTP area (ftp://legacy.gsfc.nasa.gov/)
Hitomi: FTP area (https://www.darts.isas.jaxa.jp/pub/hitomi/data/obs/1/)
DARTS @ISAS (https://www.darts.isas.jaxa.jp/astro/hitomi/)
HEASARC FTP area (ftp://legacy.gsfc.nasa.gov/hitomi/data/obs/1/)

Additional products for *Suzaku*

HXD-PIN (NXB: http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/pinnxb/)
HXD-GSO (NXB: http://www.astro.isas.jaxa.jp/suzaku/analysis/hxd/gsonxb/)

2. Concept: FTOOLS & XANADU

Data format: standard FITS
Analyses tool: FTOOLS



HEAsoft package (at NASA HEASAC)

- Mission indepedent FTOOLS
- Mission specific FTOOLS
- General software, XANADU

X-ray Event file
= List of events (signal + noise), FITS
1 event has TIME
PI (pulse height invariant)
X, Y (detector/sky coordinate)

xselect

Spectral file
(PI vs count) → xspec

Light curve file
(TIME vs count) → xronos

Image file
(X,Y vs count) → ximage

***Suzaku* and *Hitomi* follow this concept.**

Concept: Suzaku/Hitomi/XRISM products

Two-step pipeline processing before distribution

Raw Packet Telemetry → First FITS file (FFF) → (FTOOL) → Second FITS file (SFF) → (FTOOL) → Cleaned FITS

Telemetry DB

CALDB

Format Conversion Only

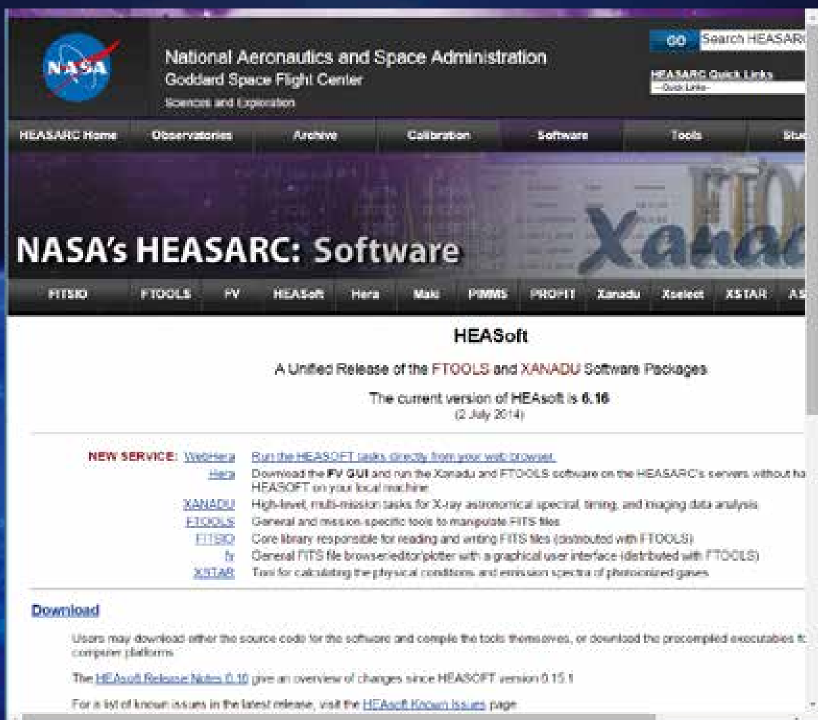
- FFF & SFF are the same format (*)
- Fill calibrated columns & screening
- GO can reprocess the data anytime with latest CALDB and/or ftools

(*) except for Hitomi HXI/SGD

***Suzaku*, *Hitomi*, (and *XRISM*) follow this concept.**

3. Install HEASoft environment

1. Download HEASoft package from http://heasarc.gsfc.nasa.gov/docs/software/lheasoft/



2. Make and install

```
% tar xpvzf heasoft-6.16src.tar.gz
% cd  heasoft-6.16/BUILD_DIR
%  ./configure –prefix=XXXX
% make
% make install
% cd XXX
% ln –s i686-pc-linux-gnu-libc2.7 linux
```

3. Setup HEASoft in your terminal

```
$ setenv HEADAS XXX/linux
$ source $HEADAS/BUILD_DIR/headas-init.csh
```

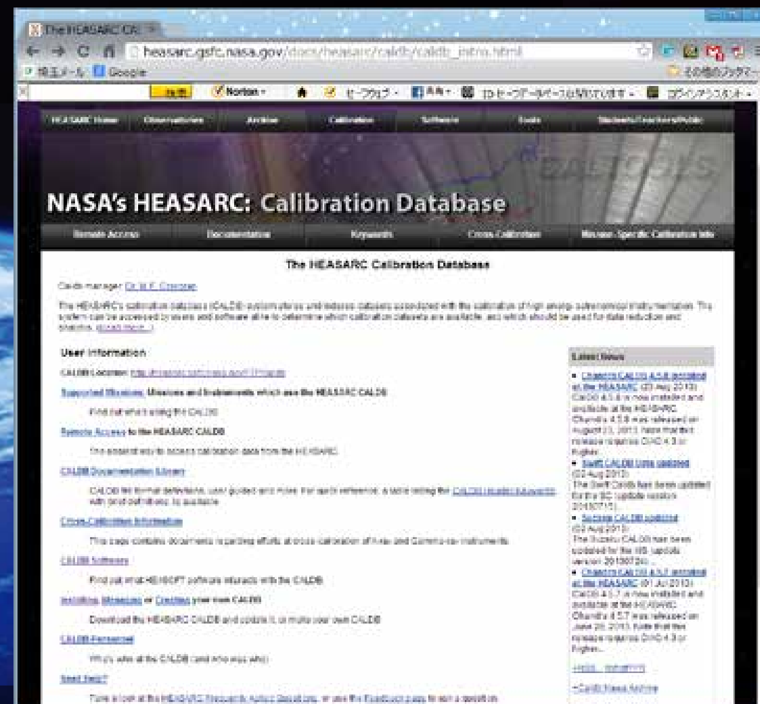
Install CALDB

1. Copy CALDB files from http://heasarc.gsfc.nasa.gov/FTP/caldb/

% ncftpget -R ftp://darts.isas.jaxa.jp/pub/legacy.gsfc.nasa.gov/caldb/

At least, the following directories are required for Suzaku/Hitomi analyses.

/caldb/software/
/caldb/data/suzaku/
/caldb/data/hitomi/



2. Set up CALDB

% cd /caldb/software/tools
% edit caldbinit.csh
(change CALDB path)

3. Setup CALDB in your terminal

$ setenv CALDB xxx
$ source $CALDB/ /caldb/software/toolscaldbinit.csh

Reprocess your data

Since the data are final, you need not to reprocess them.

Suzaku Products

% ls
405022010/ ß your data downloaded

% aepipeline indir=405022010 outdir=405022010r ¥
steminputs=ae405022010 entry_stage=1 exit_stage=2 ¥
instrument=ALL

The reprocessed data will be appeared in 405022010r/ dir.

Hitomi Products

% ls
100050020/ ß your data downloaded

% ahpipeline indir=100050020 outdir=100050020r ¥
steminputs=ah100050020 entry_stage=1 exit_stage=2 ¥
instrument=ALL ¥
stemoutputs=DEFAULT verify_input=no ¥
create_ehkmkf=yes seed=7 clobber=yes chatter=2 mode=hl

The reprocessed data will be appeared in 100050020r/ dir.

You can reprocess your products with the same manner!

List of *Suzaku* FTOOLs

General
aeaspect
aeattcor
aeattcor2
aebarycen
aecoordcalc
aemkehk
aemkpinudhk
aemkreg
aepipeline
aetimecalc
gtisynch
mkphlist
suzakuversion

XIS
xis5x5to3x3
xisarfgen
xiscontamicalc
xiscoord
xisexpmapgen
xisgtigen
xisllegtigen
xisnxbgen
xispi
xisputpixelquality
xisrmfgen
xissim
xissimarfgen
xistime
xisucode

HXD
hxdarfgen
hxddtcor
hxdgrade
hxdgtigen
hxdmkgainhist
hxdpi
hxdpi_old
hxdscltime
hxdtime
hxdxb

HXD-WAM
hxdwambstid
hxdwamgrade
hxdwampi
hxdwampipeline
hxdwamtime
hxdmkwamgainhist
hxdmkwamlc
hxdmkwamspec
hxdbstjudge
hxdbsttime
hxdmkbstlc
hxdmkbstspec

Magenta: for analyses

List of *Hitomi* FTOOLs

General
- aharfgen
- ahbackscal
- ahcalcl32ti
- ahcalctime
- ahexpmap
- ahfilecaldb
- ahfilter
- ahgainfit
- ahgetvector
- ahgtigen
- ahmkehk
- ahmkregion
- ahmktim
- ahmodhkext
- ahpipeline
- ahscreen
- ahsxtarfgen
- ahsysinfo
- ahtempcaldb
- ahtime
- ahtimeconv
- ahtrendtemp
- attplot
- hitomiversion

SXS
- sxsanticolc
- sxsanticopi
- sxsbranch
- sxsextend
- sxsflagpix
- sxsgain
- sxsmkrmf
- sxsnxbgen
- sxsperseus
- sxspha2pi
- sxspipeline
- sxspixgti
- sxsplot
- sxsregext
- sxsrmf
- sxssamcnt
- sxsseccor
- sxssecid

- mxsgti
- mxstime

SXI
- sxiflagpix
- sxigainfit
- ximodegti
- sxinxbgen
- sxiphas
- sxipi
- sxipipeline
- sxiplot
- sxirmf

HXI/SGD
- hxievtid
- hxigainfit
- hxinxbgen
- hxipipeline
- hxiplot

- sgdarfgen
- sgdevtid
- sgdgainfit

- hxirspeffimg
- hxisgddtime
- hxisgdexpand
- hxisgdmerge
- hxisgdpha
- hxisgdsff
- hxisgdshield

- cams2att
- cams2det
- camsplot
- camssim

Magenta: for analyses, Green: specific for initial data

Suzaku Helpdesk & GOF

- GSFC Suzaku Help for US GOs

  http://heasarc.gsfc.nasa.gov/cgi-bin/Feedback

  ask questions via www page

- Suzaku Help Japan (*)

  for Jp/Asian/Europa GOs

  http://cosmic.riken.jp/suzaku/help

  just fill the template and
  send E-mail to
  suzaku_help@crab.riken.jp

(*) Note: volunteer based system
no special permission to access private data

4. walk through: Suzaku XIS

- Imaging (energy band image, NXB generation, vignetting correction)
- Light curve
- X-ray spectral analyses (response generation, NXB, fitting)

XIS imaging & light curve

Event FITS → filter & extract → Image FITS

Event FITS → filter & extract → lc FITS

FTOOL: extractor
XANADU: xselect

- Start xselect

```
[terada@rouen test]$ xselect
```

- Read event

```
> Enter session name >[xsel] COSPAR
COSPAR:SUZAKU > read event
> Enter the Event file dir >[.] .
> Enter Event file list >[] ae403007010xi0_0_3x3n066a_cl.evt.gz  ae403007010xi0_0_5x5n066a_cl.evt.gz
```

- Filter by PHA

```
COSPAR:SUZAKU-XIS0-STANDARD > filter
> Enter what filter? >[] PHA_CUTOFF
> Lower cutoff for PHA >[] 0
> Upper cutoff for PHA >[] 1024
```

- Extract image, check, save

```
COSPAR:SUZAKU-XIS0-STANDARD > bin image
COSPAR:SUZAKU-XIS0-STANDARD > save image
> Give output file name >[] test
COSPAR:SUZAKU-XIS0-STANDARD > saoimage
```

- Extract light curve, check, save

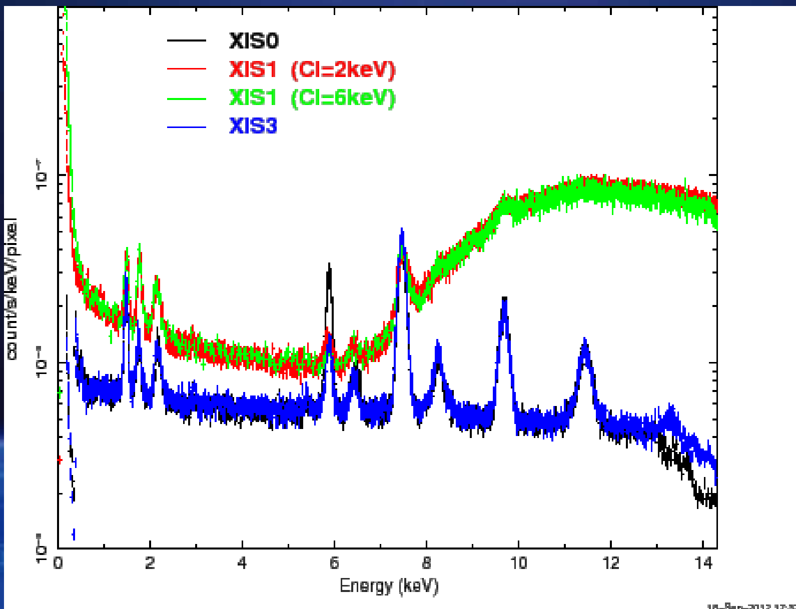
```
COSPAR:SUZAKU-XIS0-STANDARD > bin curve
COSPAR:SUZAKU-XIS0-STANDARD > plot curve
COSPAR:SUZAKU-XIS0-STANDARD > save curve
> Give output file name >[] test
```

- Exit xselect

```
COSPAR:SUZAKU-XIS0-STANDARD > exit
```

XIS NXB generation

Non X-ray background for the XIS can be calculated by the FTOOL, *xisnxbgen*



CALDB

Tawa et.al 08

NXB datasets observed during the satellite points the Earth, sorted by COR (cut-off rigidity) and HXD-PIN UD count.

Extract and scale with COR/PIN_UD of the observation

NXB PI file

(3rd extension is NXB SKY image)

```
$ xisnxbgen outfile=${OUTFILE} ¥
        phafile=${PHAFILE} ¥
        region_mode=SKYREG regfile=${REGFILE} ¥
        orbit=${ORBFILE} attitude=${ATTFILE} ¥
        time_min=-300 time_max=-150
$
```

- XIS region for calculation
- orbit, attitude files for input
- Time coverage of the database (day)

XIS vignetting corrected image

Detected Image = Response * SRC Image + NXB

XIS efficiency map × XRT absorption map × XRT Vignetting function

Exposure Map
FTOOL: *xisexpmapgen*

Ray-tracing
FTOOL: *xissim*

1. Calculate Exposure Map

```
$ xisexpmapgen outfile=ae${OBSID}xi${XISID}_exp.img ¥
  phafile=pi/ae${OBSID}xi${XISID}.pi ¥
  attitude=evt/ae${OBSID}.att.gz'
```

2. Calculate Simulated Image

```
$ xissim instrume=XIS${XISID} ¥
  photon_flux=1e+3 flux_emin=0.3 flux_emax=12.0 ¥
  enable_photongen=yes spec_mode=0 qdp_spec_file=spec/spec_${SPEC}.qdp ¥
  xis_rmffile=rmf/ae506004010xi${XISID}_bgd.rmf ¥
  image_mode=2 ra=308.41667 dec=44.05 sky_r_min=0.0 sky_r_max=15.0 ¥
  ea1=308.418459466083 ea2=45.934219709675 ea3=345.171293587340 ¥
  time_mode=0 limit_mode=0 nphoton=$NPHOTON ¥
  pointing=AUTO attitude=evt/ae506004010.att ¥
  outfile=sim_xi${XISID}_${SPEC}.fits >& log/sim_xi${XISID}_${SPEC}.log
```

3. Make total exposure map (Efficiency × Vignetting)

```
$ ftimgcalc bitpix = "D" ¥
  outfile=$OUTFIL expr="A * B / $SIMSCALE" ¥
  a='exp_img/${EXPMAP}[1]' b='sim_img/${SIMIMG}[0]'
```

à *Response part prepared.*

XIS vignetting corrected image

Detected Image = Response * SRC Image + NXB

XANADU: ximage

XIS efficiency map × XRT absorption map × XRT Vignetting function

Exposure Map

FTOOL: *xisexpmapgen*

Ray-tracing

FTOOL: *xissim*

4. Subtract NXB Image (calculated by xisnxbgen)

```
$ ftimgcalc bitpix = "D" outfile=${OUT_IMG} ¥
   expr="A - (B * $EXP_RATIO)" ¥
   a='${SRC_IMG}[0]' b='${NXB_IMG}[3]'
```

ß Detected Image - NXB

5. Calculate SRC Image

```
$ ximage
   XIMAGE> read/fits/size=400/rebin=4 sky_img5/ae506004010xi0_05_10kev_sky_bgsubt.img
   XIMAGE> read/exposure/size=400/rebin=4 expvig_img/ae506004010xi0_pl0_05_10kev_exp_vig.img
   XIMAGE> save_image
   XIMAGE> read/fits/size=400/rebin=4 sky_img5/ae506004010xi1_05_10kev_sky_bgsubt.img
   XIMAGE> read/exposure/size=400/rebin=4 expvig_img/ae506004010xi1_pl0_05_10kev_exp_vig.img
   XIMAGE> sum_image
   XIMAGE> save_image
   XIMAGE> read/fits/size=400/rebin=4 sky_img5/ae506004010xi3_05_10kev_sky_bgsubt.img
   XIMAGE> read/exposure/size=400/rebin=4 expvig_img/ae506004010xi3_pl0_05_10kev_exp_vig.img
   XIMAGE> sum_image
   XIMAGE> save_image
   XIMAGE> disp/cor
   XIMAGE> write/display_map/fits ae506004010xis_pl0_05_10kev_sky5.img
   XIMAGE> quit
```

ß / Exposure map

ß Sum 3 chip images

XIS spectra: response

From a lecture yesterday (Mission III)

E (energy)
q (direction)

Detector

Q (charge) = PH (pulse height)
x (position)

what we want to know

what we can get

E à *PHA …. Response matrix* R

$$\overrightarrow{PH} = R\,\vec{E}$$

We cannot do $\vec{E} = R^{-1}\overrightarrow{PH}$ because of large uncertainties in off-diagonal element!

Select Incident model à simulate PH distribution (using response function *R*)
à Compare simulated PH vs. observed PH
※ reduce the number of freedom

XANADU: *xspec*

http://heasarc.gsfc.nasa.gov/docs/xanadu/xspec

XIS spectra: response

Calculation of response function (rmf & arf)

FTOOLS: *xisrmfgen*, *xissimarfgen*

```
$  xisrmfgen phafile=$PHAFILE outfile=$RMFFILE
```

Ishisaki et.al 07

```
$ xissimarfgen instrume=XIS${XISID} ¥
    source_mode=SKYXY source_x=${SOURCE_POS_X} source_y=${SOURCE_POS_Y} ¥
    num_region=1 region_mode=SKYREG ¥
    regfile1=${REG_NAME_SRC} arffile1=${ARF_NAME_SRC} ¥
    limit_mode=MIXED num_photon=${SIM_MUM_PHOTON} accuracy=0.005 ¥
    phafile=${PHAFILE} ¥
    detmask=${CALDM_CALMASK} gtifile=${GTIFILE} ¥
    attitude=${ATTFILE} rmffile=${RMFFILE} estepfile=$ESTEP
```

Enjoy spectral fittings !

5. Walk through: Suzaku HXD

- X-ray spectra (PMT gain, dead time, NXB)
- Light curve / Timing analyses (dead time, bary-centric correction)

HXD light curve & spec: script

HXD is non Imaging detector, although detection mechanism is complex.
à What you can extract are spectral files & light curves.
Simple for users !

Calculate PIN PI

```
$ hxdpinxbpi ¥
  input_fname='evt/aeXXXXXhxd_0_pinno_cl.evt.gz' ¥
  pse_event_fname='@evt/aeXXXXXhxd_0_wel_uf.list' ¥
  bkg_event_fname='bgd/aeXXXXX_hxd_pinbgd.evt.gz' ¥
  outstem='TESTpin' >& hxdpinxbpi.log
```

Calculate PIN Light curve

```
$ hxdpinxblc ¥
  input_fname='evt/aeXXXXXhxd_0_pinno_cl.evt.gz' ¥
  pse_event_fname='@evt/aeXXXXXhxd_0_wel_uf.list' ¥
  bkg_event_fname='bgd/aeXXXXX_hxd_pinbgd.evt.gz' ¥
  outstem='TESTpin' >& hxdpinxblc.log
```

For GSO, use hxdgsoxbpi and hxdgsoxblc.

ß Cleaned event
ß Pseudo event for dead time correction
ß NXB event

HXD spectra: PMT gain & reprocess

※ in 2018, we have final products and you need not perform reprocessing

It takes time for determination of PMT gain, please wait for 1-2 months after the observation.
à Currently, we do NOT use gain history table observed, but use gain function, which may be valid for future observation. The gain is released in CALDB (ae_hxd_gsogpt_yyyymmdd.fits), which may be updated roughly once par year.
If the gsogpt file is latest, you do not need to reprocess your data.

Most Important thing is to use the latest GSO gain file, which is also used for NXB estimation. The version of gain file is different between NXB and OBS should be the same, otherwise, the systematics become much larger.

1. Check CALDB environment if the GSO gain file is latest
2. If needed, please reprocess your data with *aepipeline*.

HXD spectra: dead time correction

Dead time correction is already done if you use the FTOOL script *hxdXXXxbspec.*

Manually (if you extract PI file from Event), the dead time correction can be done by FTOOLS *hxddtcor*.

```
$ hxddtcor event_fname="aeXXXXhxd_0_wel_uf.evt" ¥
        pi_fname="@pi.list" chatter=0
```

ß Please do NOT use cleaned event. Use uncleaned event.

Note: aeXXXXhxd_0_wel_uf.evt contains

- PIN event à stored in pinno_cl.evt
- GSO event à stored in gsono_cl.evt
- Pseudo event, generated by electronics à pse_cl.evt
- Noise (anti coincidence out), not in event_cl/

Pseudo event is generated periodically (4 Hz) on board, but discarded if the instrument is busy for acquisition (i.e., the dead time).
à Number of Pseudo event presents REAL time.

HXD spectra: NXB event files

Extract NXB PI file is already done if you use the FTOOL script *hxdXXXxbspec*.

Fukazawa et.al 10

If you want to extract NXB manually, please use *xselect*.

Note that

- The GTI should be exactly the same between observation and NXB.
- The NXB event file is already dead-time corrected.
  Please do NOT run hxddtcor agin.
- The number of counts is 10 times larger for PIN NXB to reduce statistical error in the procedure. For GSO NXB, the counts is not multiplied.

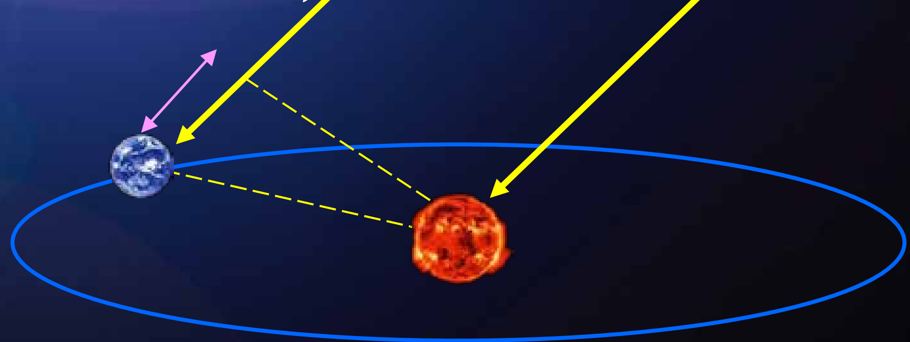
When you write a paper, please note the version of NXB in the paper.
The version can be checked in the FITS keyword

```
METHOD  = 'LCFITDT (bgd_d)'    / background modeling method
METHODV = '2.0ver0804'         / processing version
```

Timing analyses

The TIME assigned in the event files is time second since 2000-01-01 measured on the spacecraft for Suzaku, 2014-01-01 for Hitomi.

Terada et.al 08 (suzaku)
Terada et al 18 (hitomi)



In searching for coherent pulses from neutron star pulsars, for example, you have to apply the bary-centric correction by the FTOOLs *aebarycen*.(Suzaku), or *barycen* (Hitomi/XRISM)

```
$ aebarycen ¥
  filelist=aeXXXXX.evt orbit=aeXXXXX.orb.gz ¥
  ra=$RA dec=$DEC
```

```
$ lcurve        ß plot light curve
$ powspec       ß make power spectrum
$ efsearch      ß Period search
$ efold         ß make folded light curve
```

http://heasarc.gsfc.nasa.gov/docs/xanadu/xronos/xronos.html

6. Walk through: Hitomi HXI

On ither Instruments of Hitomi,
please refer “Step-by-step guide”.

G21.5-0.9 (100050010~100050040)

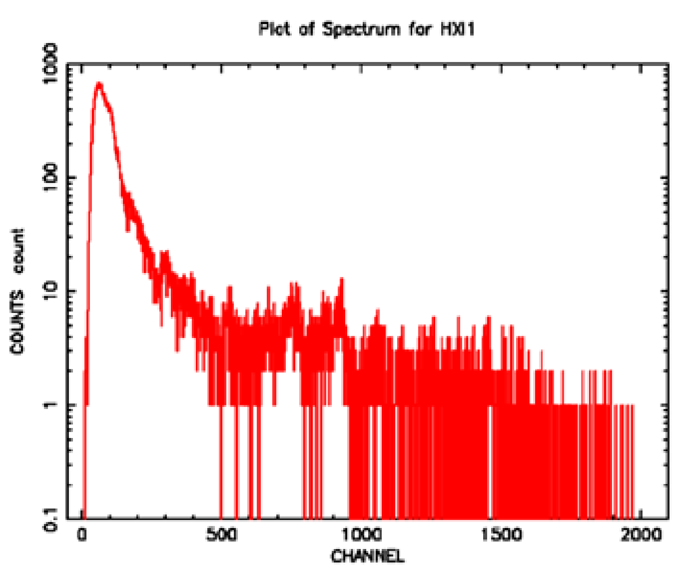
Reprocessing

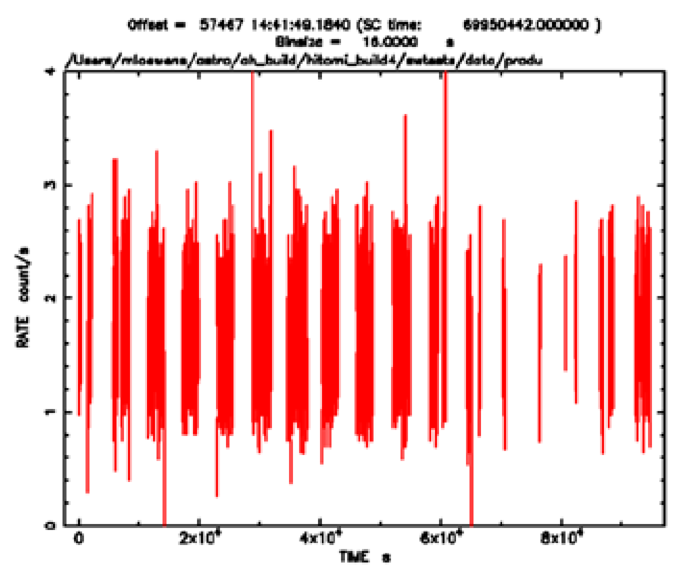
Basically, you do not need to reprocess the data.

Extract Spectra & Light curve

Same procedure as Suzaku XIS.

```
$ xselect
xsel:SUZAKU > read events
../100050020/hxi/event_cl/ah100050020hx1_p0camrec_cl.evt.gz
xsel:HITOMI-HXI1-CAMERA_NORMAL1 > filter region
../../regions/region_HXI_100050012340.reg
xsel:HITOMI-HXI1-CAMERA_NORMAL1 > extract spectrum
xsel:HITOMI-HXI1-CAMERA_NORMAL1 > save spectrum ah100050020hx1_p0camrec_cl.pi
xsel:HITOMI-HXI1-CAMERA_NORMAL1 > plot spectrum
xsel:HITOMI-HXI1-CAMERA_NORMAL1 > extract curve
xsel:HITOMI-HXI1-CAMERA_NORMAL1 > save curve ah100050020hx1_p0camrec_cl.lc
xsel:HITOMI-HXI1-CAMERA_NORMAL1 > plot curve
```





Dead time correction of Spectra & LC

Same procedure as Suzaku HXD, but new.

```
$ hxisgddtime \
        infile=data/100050020/hxi/event_cl/ah100050020hx1_p0camrecpse_cl.evt.gz
        inlcfile=data/products_hxi/ah100050020hx1_p0camrec_cl.lc
        inspecfile=data/products_hxi/ah100050020hx1_p0camrec_cl.pi
        outlcfile=data/products_hxi/ah100050020hx1_p0camrec_dtime.lc
        outfile=data/products_hxi/ah100050020hx1_p0camrec_dtime.pi
        gtifile=data/100050020/hxi/event_cl/ah100050020hx1_p0camrec_cl.evt.gz chatter=2 clobber=yes
```

You will get deadtime-corrected spectral file and/or lc file.

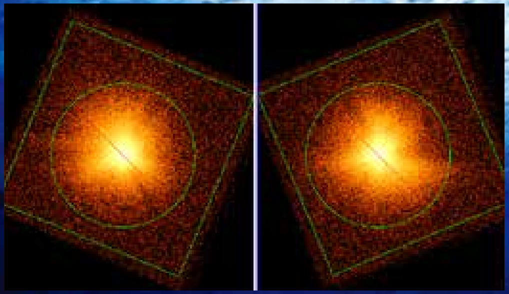
Dead time corrected NXB spectra

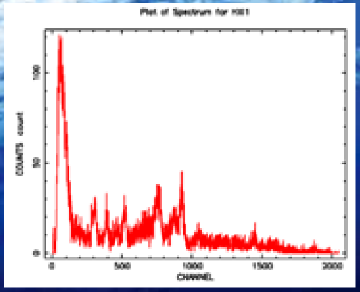
Same procedure as Suzaku XIS.

If you use the standard screening criteria, you can use the “cleaned” NXB database, ah_hx1[2]_nxbevtcl2_20140101v001.evt (for NXB) and ah_hx1[2]_nxbpsecl_20140101v001.evt (for dead time correction).
The tool *hxinxbgen* will generate the dead-time corrected NXB spectrum for your specific SKY region.

If you use specific screening criteria, please refer the step-by-step guide.

```
$ hxinxbgen \
        infile=data/100050020/hxi/event_cl/ah100050020hx1_p0camrec_cl.evt.gz
        ehkfile==../100050020/auxil/ah100050020.ehk.gz
        innxbfile=ah_hx1_nxbevtcl2_20140101v001.evt
        inpsefile=ah_hx1_nxbpsecl_20140101v001.evt
        innxbehk=ah_gen_nxbehk_20140101v002.fits outpifile=ah100050020hx1nxb_cl.pi
        regmode=SKY regfile=region_HXI_100050012340_sky.reg cleanup=yes chatter=3
        clobber=yes mode=hl logfile=ah100050020hx1nxb_cl.log sortbin=0,6,7,8,9,10,11,12,13,99
```





Then, you can enjoy imaging spectroscopy in the hard X-ray band.

Did you enjoy?
This presentation will be on the conference page.
Please refer it on your analyses, and use *Suzaku*, *Hitomi*, and *XRISM* in the future.

End