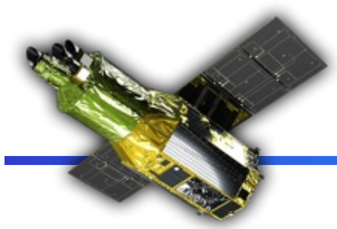
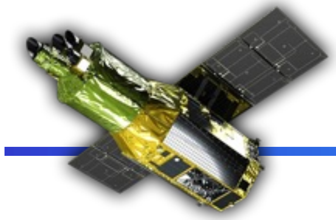


Overview of Xtend for XRISM

Koji Mori (University of Miyazaki, Japan)
on behalf of the XRISM/Xtend team
mori@astro.miyazaki-u.ac.jp



XRISM SXI team members

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H.Noda[5], H. Uchida[6], K. Hagino[7], S. B. Kobayashi[8], K.K. Nobukawa[9],
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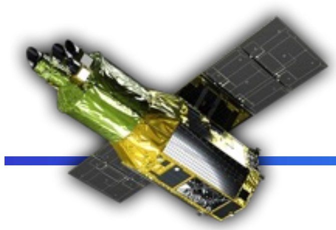
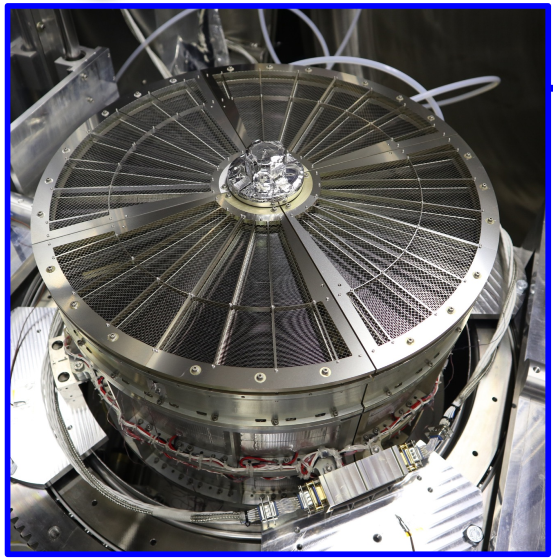
7: Univ. of Tokyo, 8:Tokyo Univ. of Science, 9: Kindai Univ., 10: Konan Univ., 11: Tohoku Gakuin Univ.,
12: Shizuoka Univ., 13: Nara Univ. of Education, 14: Chuo Univ., 15: Nagoya Univ., 16: NAOJ



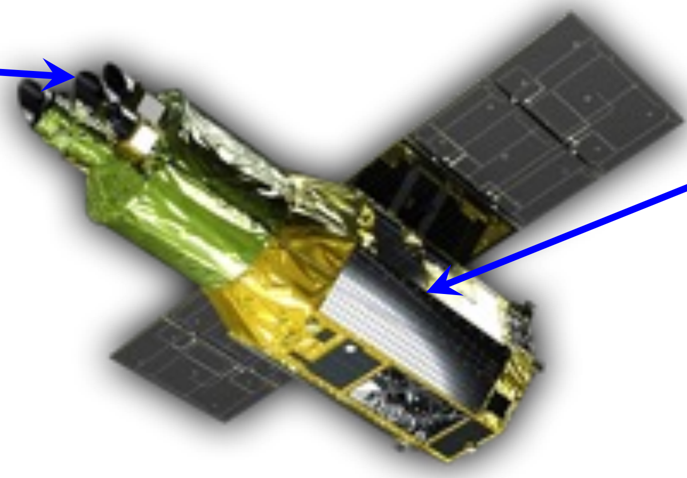
Contents

- Introduction of Xtend/SXI
- Anomalous charge issue
- Status of Xtend/SXI

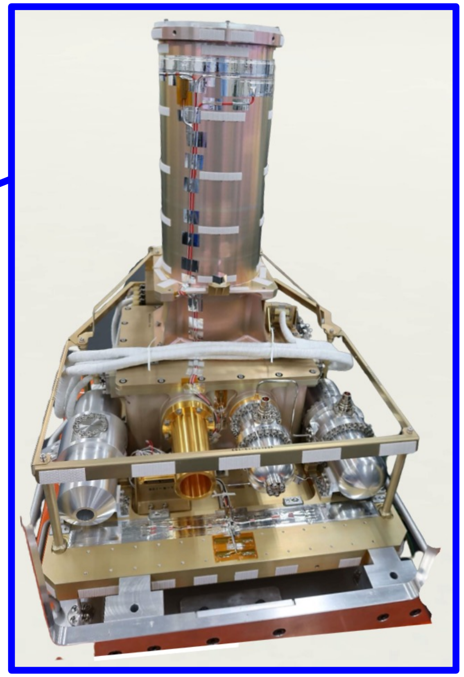
Xtend on XRISM



XMA (X-ray Mirror Assembly)

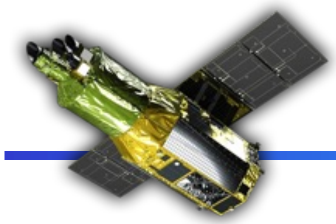


XRISM

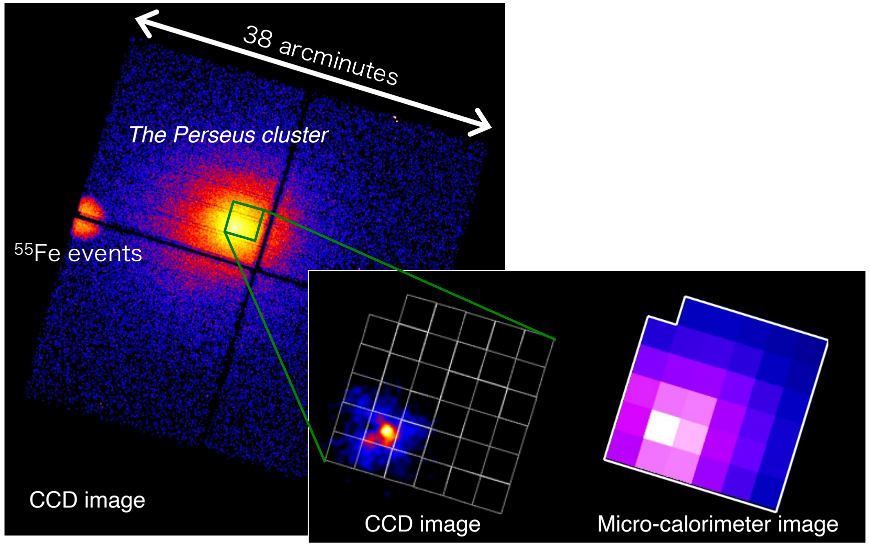


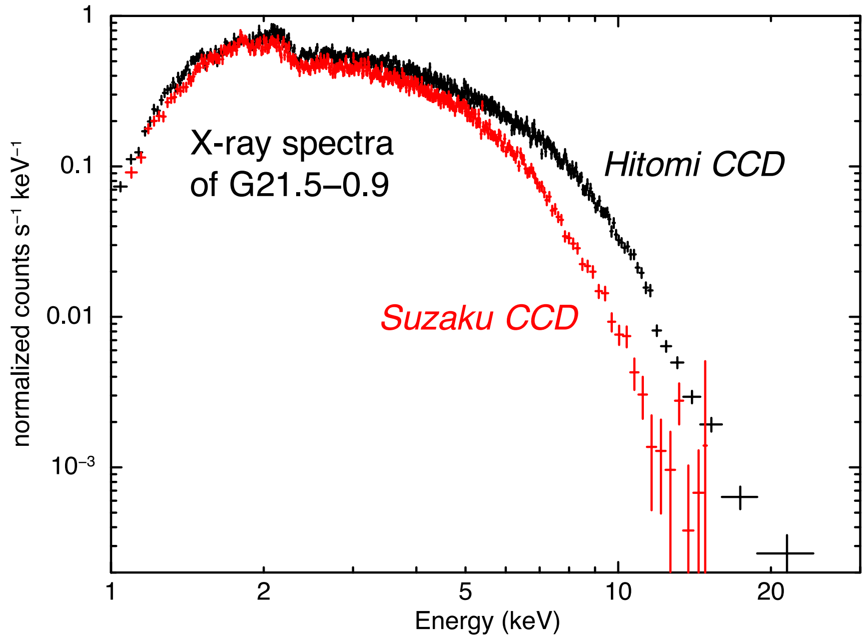
SXI (Soft X-ray Imager, CCD camera)

- Xtend (soft X-ray imaging telescope)
  = XMA (X-ray Mirror Assembly) + SXI (Soft X-ray Imager; CCD camera)
- Focal length of 5.6m, angular resolution of ≦ 1.7 arcmin (HPD requirement) and energy range of 0.4−13keV.
- We have completed the fabrication of the flight models of both SXI and XMA as shown above



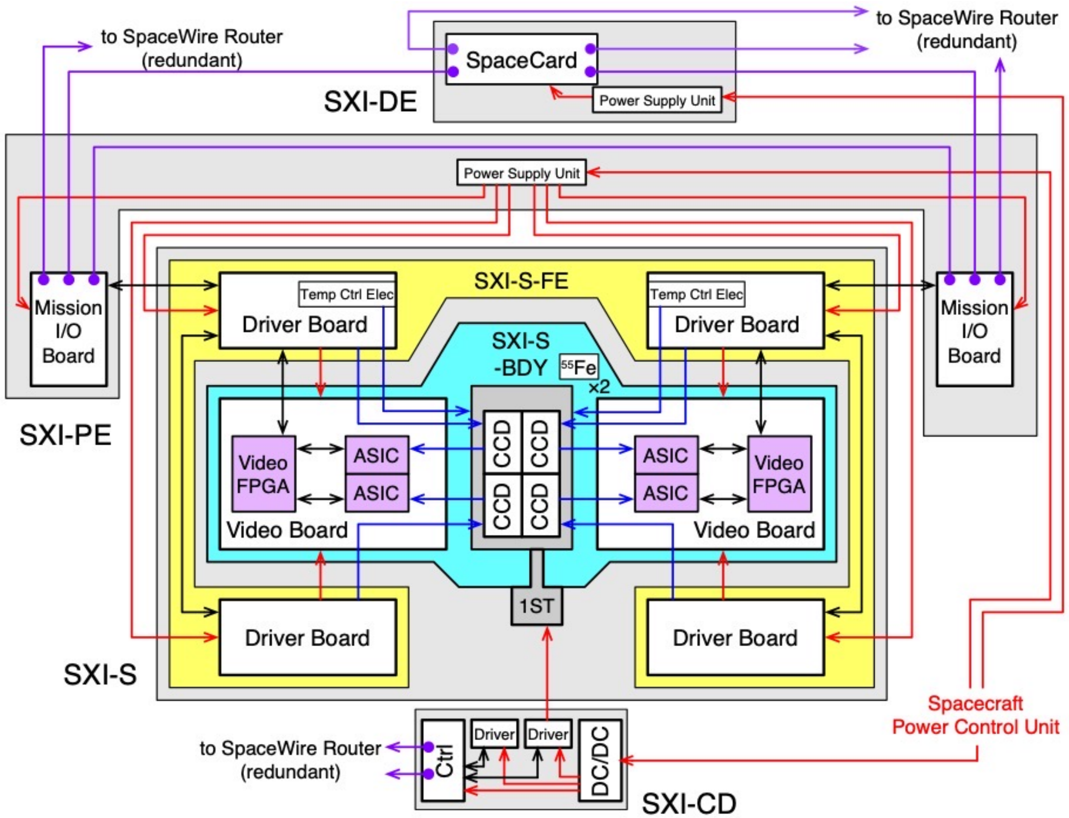
Characteristics of Xtend



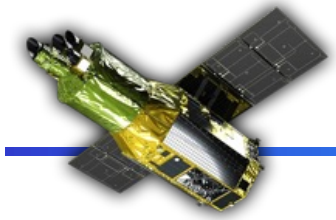


- Large FoV of 38’ × 38’ encompasses the 3’x3’ FoV of Resolve in its center, and the finer pixel size of 1.74” (cf. 30” in Resolve) well over-samples the PSF of XMA
- Thicker depletion layer (200μm) compared to the Suzaku CCD (40μm) enhances the QE and reduces Non X-ray background in higher energy band
- Xtend and Resolve have their own characteristics in imaging and spectroscopy, respectively, and play complementary roles in XRISM.

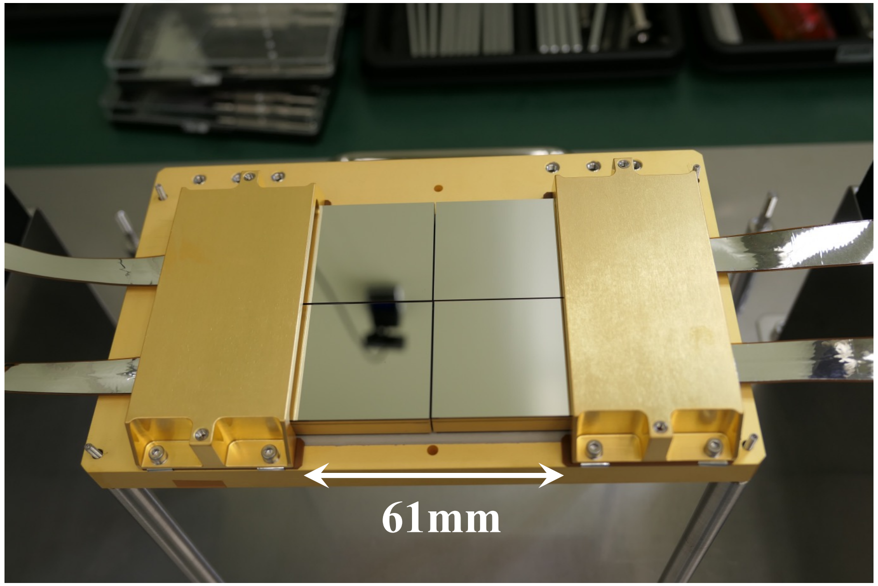
SXI Hardware



- The CCDs can be cooled down to −120℃ using the first-stage Stirling cooler.
- Driving clocks are produced in the Driver Boards and the output signal from CCDs are processed in ASICs inside the Video Boards.
- Extraction of X-ray events from images are performed in the mission I/O Boards (SXI-PE) and SpaceCard (SXI-DE).
- SXI-DE also controls the entire SXI system except for the Stirling cooler, which is operated by the cooler driver, SXI-CD.



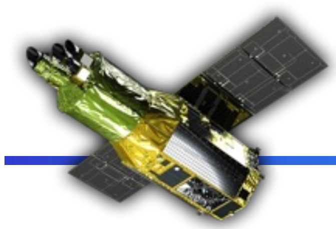
CCDs for SXI



Specifications and nominal operation parameters of the SXI CCD

CCD Specification	Architecture	Frame transfer
	Imaging area size	30.720 mm × 30.720 mm
	Pixel format (physical/logical)	1280 × 1280 / 640 × 640
	Pixel size (physical/logical)	24μm × 24μm / 48μm × 48μm
	Depletion layer thickness	200 μm
	Incident surface layer (back side)	100 nm + 100 nm thick Aluminum coat
	Readout nodes (equipped/used)	4 / 2
Operation parameters	Frame cycle	4 seconds
	On-chip binning	2×2
	Charge injection	every 160 physical rows

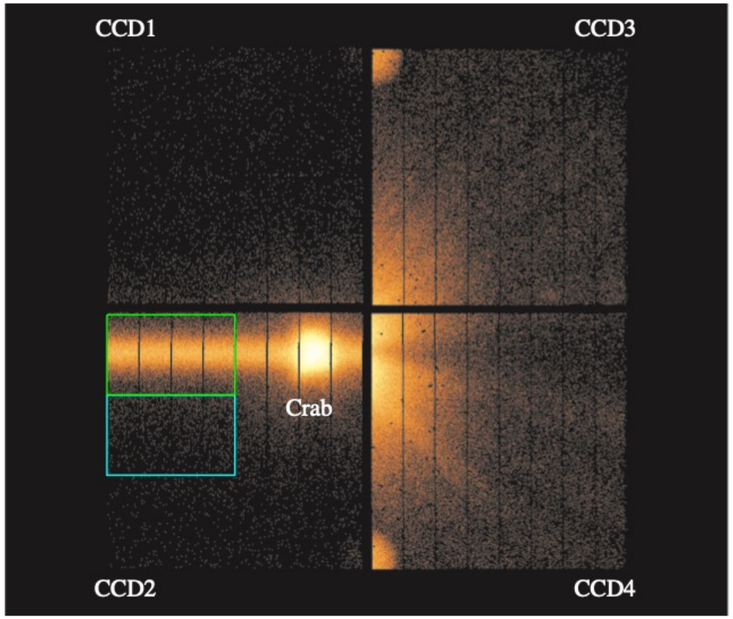
- We have developed large-size back side illumination type CCD with Hamamatsu Photonics. K.K.
- Four CCDs abutted in 2 × 2 array form an effective imaging area of 61mm square.
- Two important updates from ASTRO-H CCDs
  - Adoption of a notch implant in the charge transfer path as a measure against the increase of the CTI in orbit
  - Doubling aluminum layers (100nm + 100nm) on the incident surface to reduce the number of pinholes found in ASTRO-H CCD and introducing an extra aluminum layer above the depletion layer to decrease the flux of light leaks from the physical edges



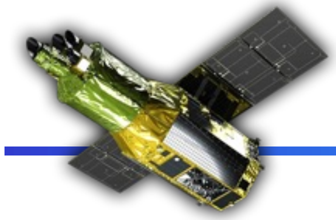
Observation modes

Mode	Area	Exposure time	Exposure per frame	Live time fraction*	Purpose
Full window	1	3.96 sec	1	1	General
1/8 window	1/8	0.46 sec	8	0.94	Bright point source
1/8 window + 0.1-s burst	1/8	0.06 sec	8	0.13	Bright point sources
0.1-s burst	1	0.06 sec	1	0.024	Crab mode, not for users

*including an entire or a part of transfer time during which photons detected are recorded as trailing events

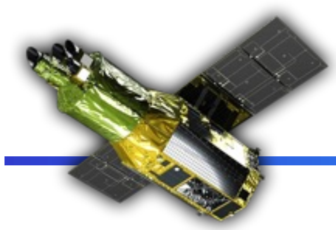


- Frame cycle is regulated by SXI-PE to be 4 sec/frame.
- We prepare window option (1/8 of the chip is readout = 8 exposures per frame) and burst option (shortened exposure time) to decrease the risk of pile-up for bright sources and improve time resolution.
- Top three modes in the table are open for users
- These modes are for the pair of CCD1 and CCD2. Regardless of the mode for CCD1/2, CCD3/4 is operated with full window mode



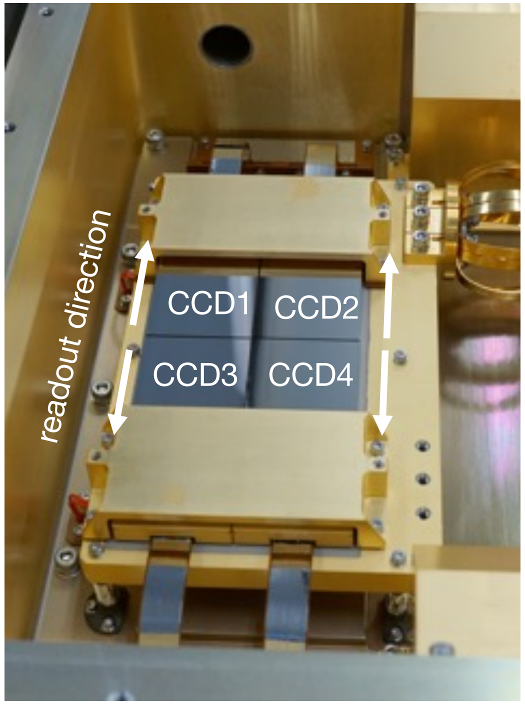
Contents

- Introduction of Xtend/SXI
- Anomalous charge issue
- Status of Xtend/SXI

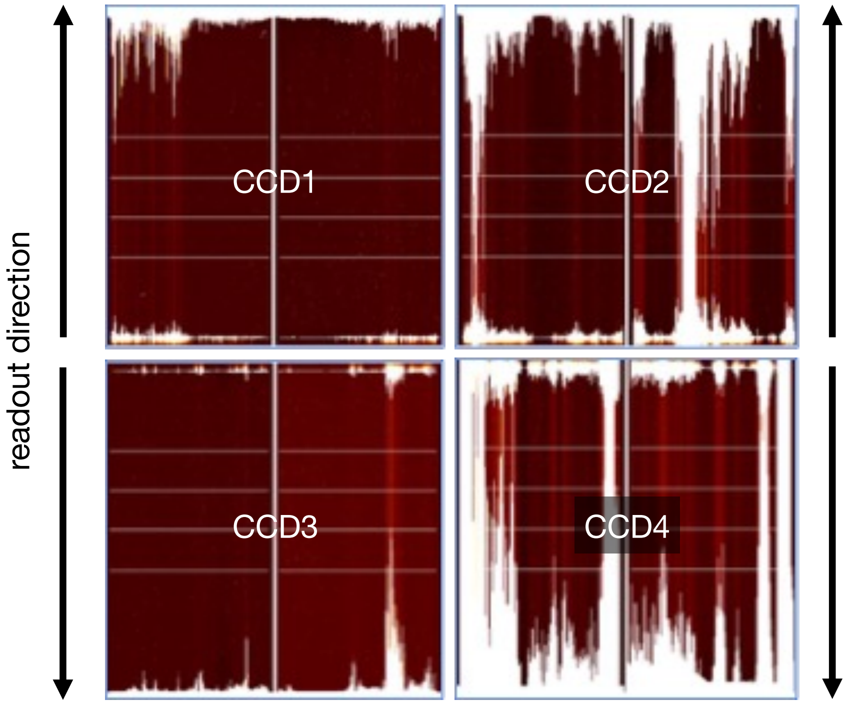


Anomalous charge issue

XRISM
X-Ray Imaging and Spectroscopy Mission



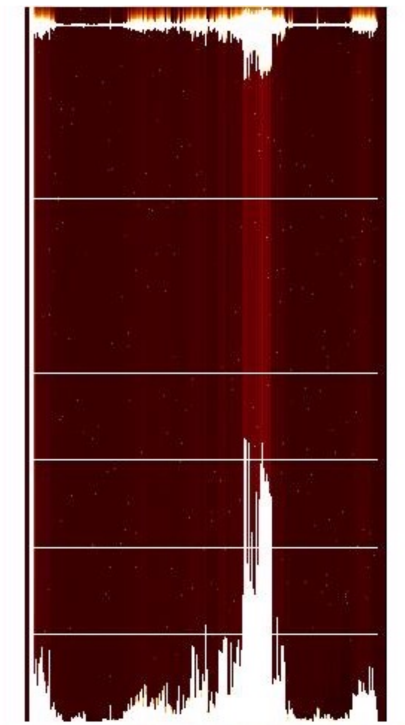
Picture of CCD1,2,3,4 installed in the camera body



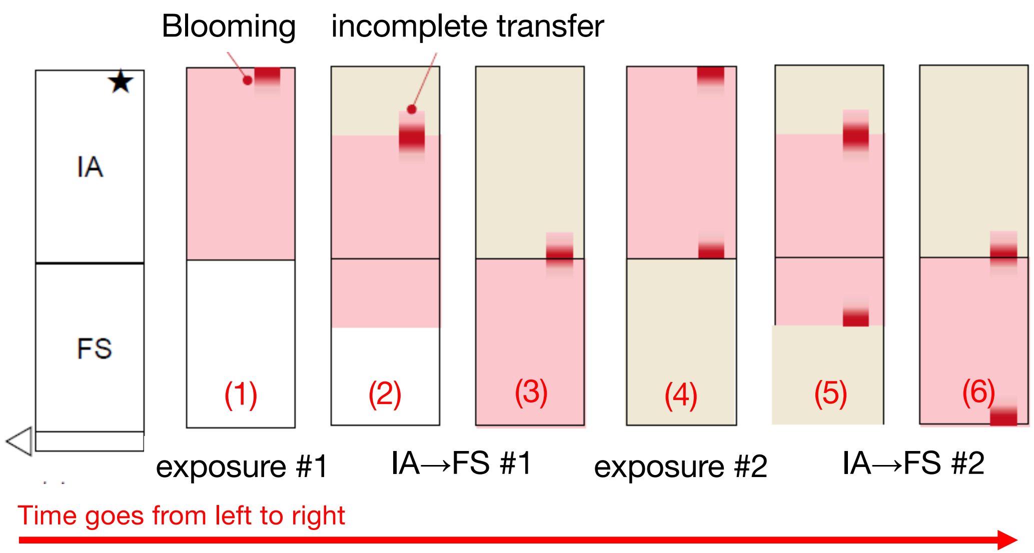
rframe data of CCD1,2,3,4 taken in the 4th test

- A large amount of anomalous charge was observed in the frame data (white colored pixels were all saturated)
- This issue was first identified in the 2nd sub-system integration test
- Pixels that are not affected by the anomalous change can detect X-ray photons and show the same spectroscopic performance

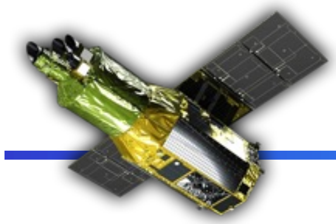
Where the charge comes from



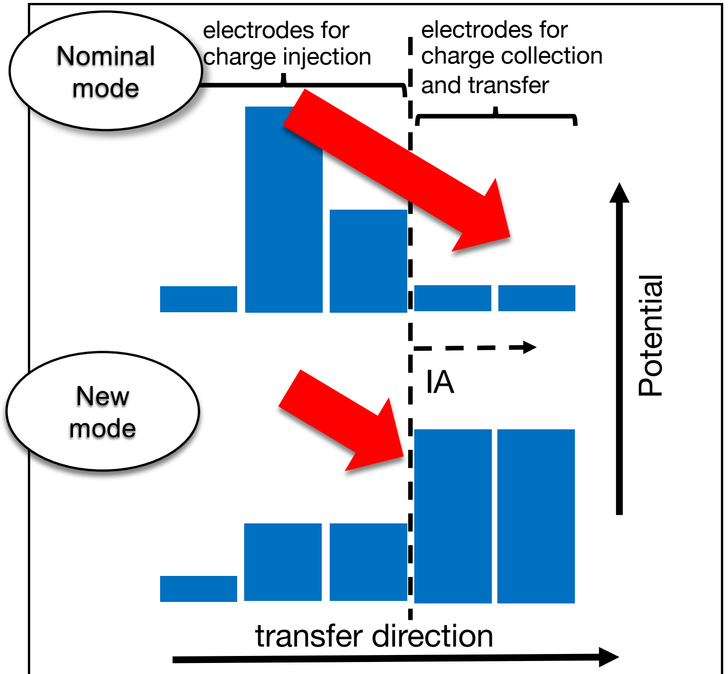
rframe data of CCD2AB



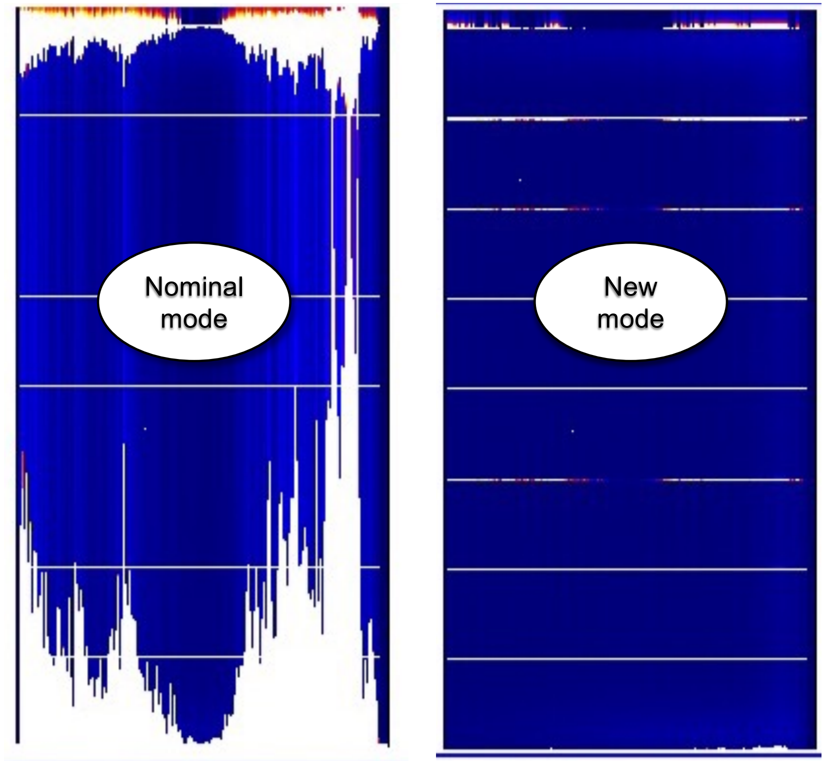
- Although anomalous charge regions are seen at the top and bottom of the imaging area (IA), anomalous charges come from the upper area of the top of the IA
  - During an exposure, blooming occurs at the top of the IA (1)
  - Such a large amount of charge can not be fully transferred, resulting in trailing charges that are left behind in the IA (2,3)
  - The left-behind charges are transferred to the frame store (FS) region and read out in the next frame (4,5,6)



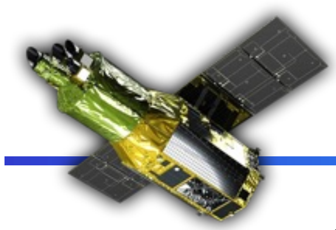
Countermeasure clocking mode



Schematic drawing of the relationship of electrode potential at the top of IA during exposure

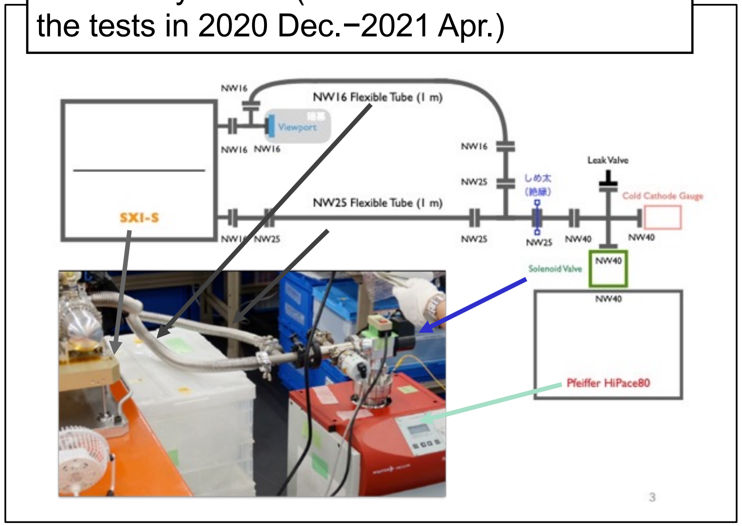


- We developed a new clocking mode with a new electrode potential setup, in which the potentials of the electrodes at the top boundary of the IA and for charge injection are increased and decreased respectively, in order to block the anomalous charges from flowing into the IA (left figure)
- The new mode did work, but not completely (right figure). This result verifies that our understanding is correct.

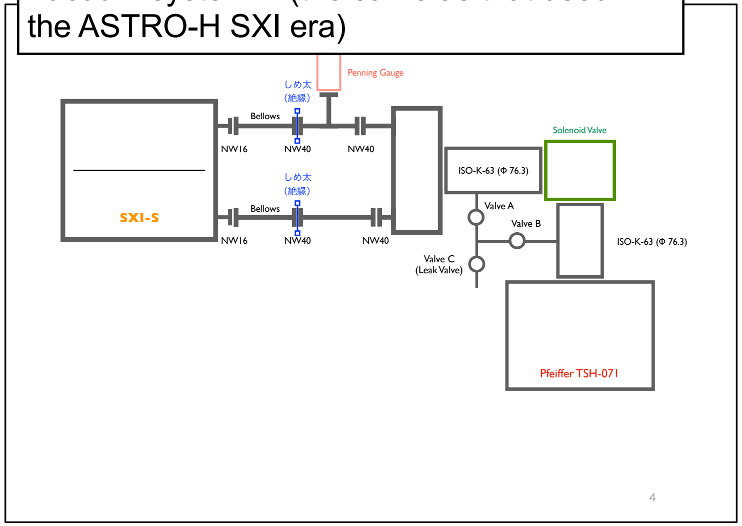


How we proceed to next step

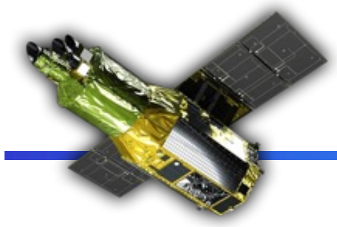
Vacuum system A (the same as that used in the tests in 2020 Dec.−2021 Apr.)



Vacuum system B (the same as that used in the ASTRO-H SXI era)



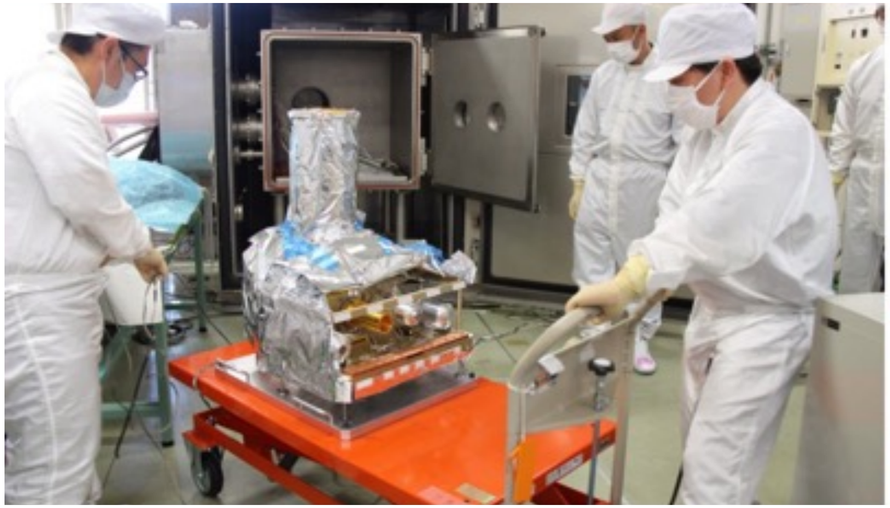
- We performed cause investigation tests of the anomalous charge issue using the FM camera with EM CCDs
- The anomalous charge issue could be reproduced using different CCDs at the difference experimental site with the vacuum system A (left fig.; the same as that used in the tests in 2020 Dec.−2021 Apr.)
- We found the anomalous charge issue did not occur with the vacuum system B (right fig.), which was used in the ASTRO-H SXI era
- Although the cause had not been identified, it was clear that what triggers this issue resides in the vacuum system A. Nevertheless, we replaced FM CCDs that experienced this issue with FM spare CCDs
- We did not observe this issue in our following FM tests, including those after integration

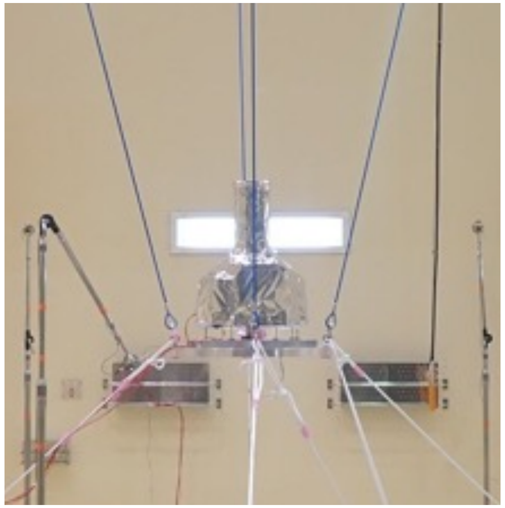


Contents

- Introduction of Xtend/SXI
- Anomalous charge issue
- Status of Xtend/SXI

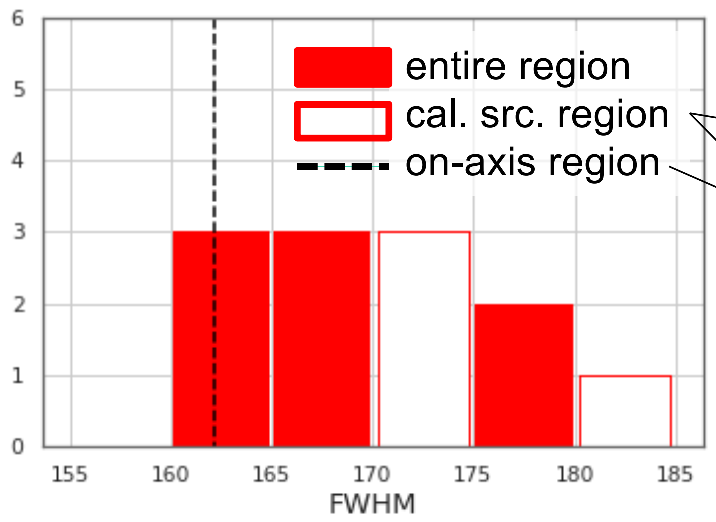
SXI sub-system tests

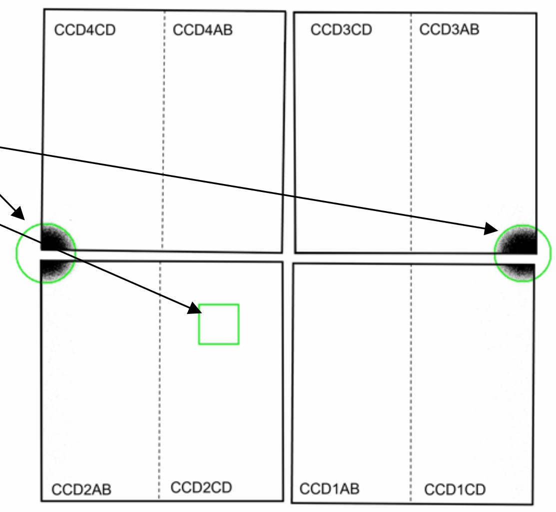




- From Jan. 2021 to Aug. 2021, we spent most of our time for tackling the anomalous charge issue. During this period, we replaced FM CCDs.
- In Sep. 2021, we performed an FM calibration test with a vacuum-tight, non-flight item bonnet.
- From Sep. 2021 to Jan. 2022, we successfully conducted a series of performance verification tests in sub-system level, including the thermal vacuum, vibration, and acoustic tests

SXI energy resolution @ 6 keV



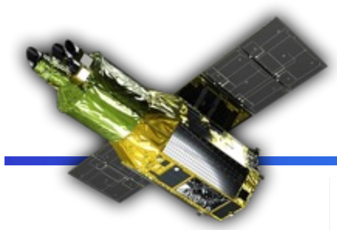


segment	entire region	cal. source region	on-axis region
CCD1AB	178.9±0.1		
CCD1CD	176.9±0.1	182.6±0.5	
CCD2AB	163.4±0.1	163.8±0.4	
CCD2CD	162.5±0.1		161.9±0.2
CCD3AB	166.0±0.1	168.1±0.3	
CCD3CD	168.4±0.1		
CCD4AB	164.5±0.1		
CCD4CD	168.9±0.1	173.2±0.4	

- The histogram and table summarize the energy resolution of the CTI-corrected spectra from various regions.
- At a given segment, the energy resolution of the cal. src. region is always worse compared to that of the entire region because the cal. src. region is located at the farthest point from the read-out nodes
- The best value is obtained at the on-axis region, which is as we intended when we determined their positions
- The mission requirement in the value of the energy resolution at the beginning of life is 200 eV or less. All the values are well below 200 eV with sufficient margin and we confirmed that our flight CCDs satisfy the mission requirement

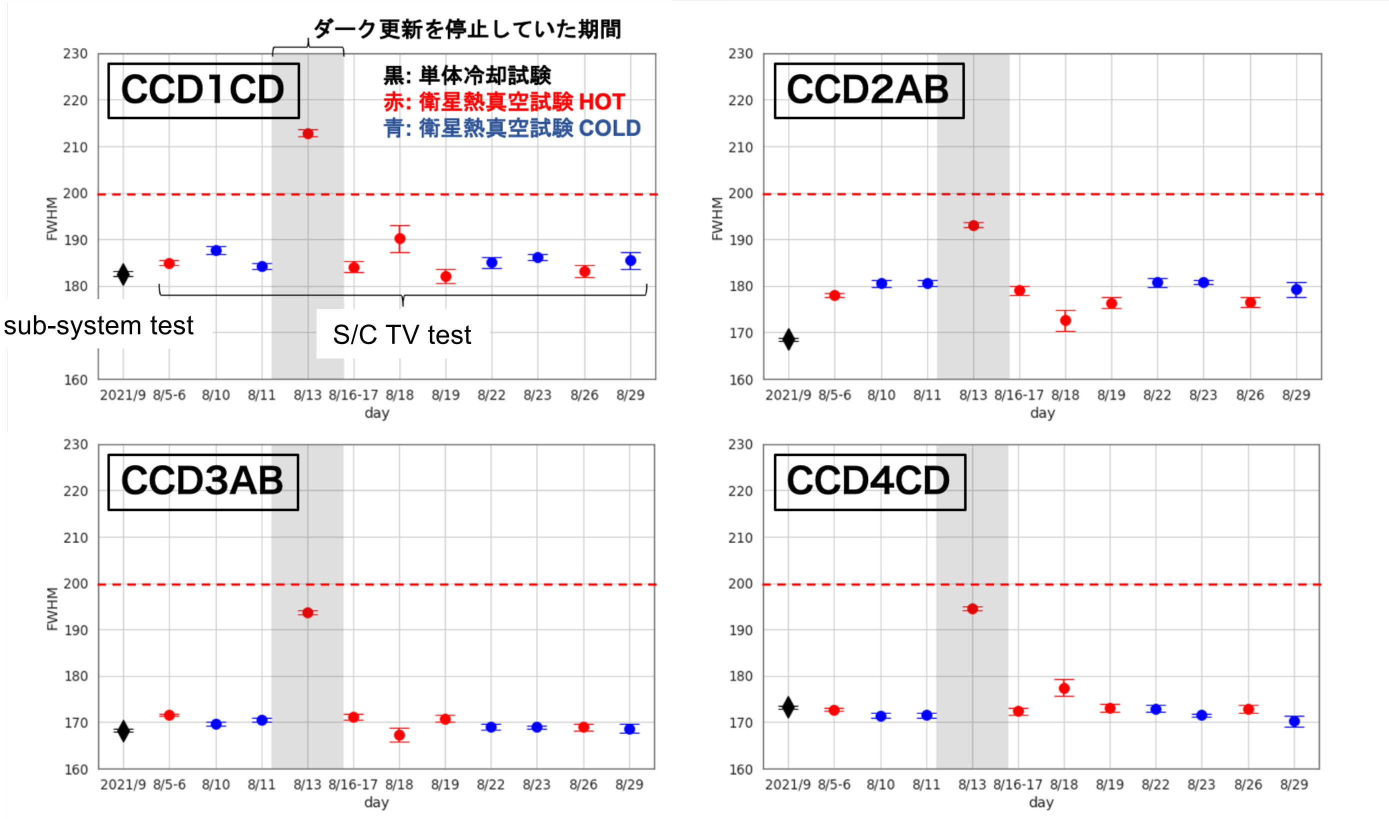
SXI in S/C thermal vac. test

- In Aug. 2022, we performed the S/C TVT, in which we repeat hot/cold modes operating sub-systems

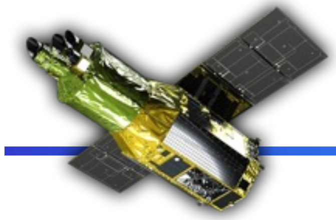


SXI energy resolution @ 6 keV

X-Ray Imaging and Spectroscopy Mission

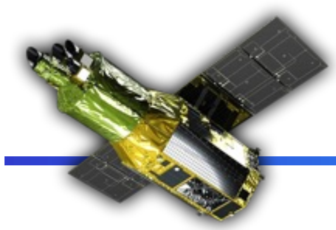


➢ The energy resolution is stable no matter what thermal condition the S/C is and consistent with that obtained in the sub-system test



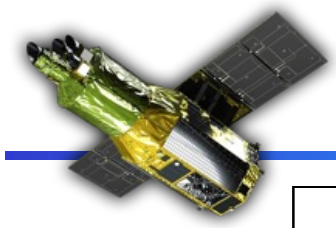
Summary

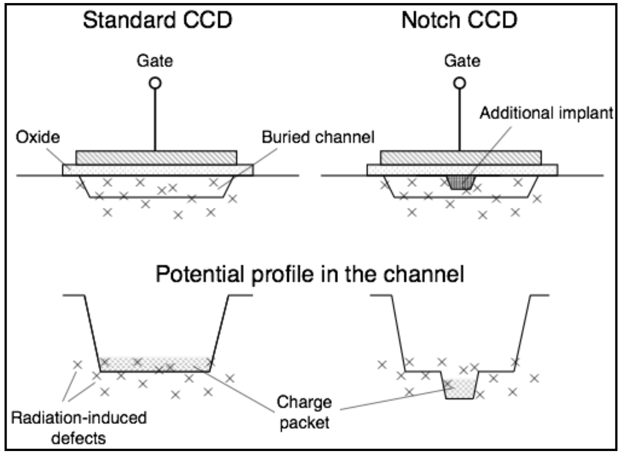
- Xtend is a soft X-ray imaging telescope developed for XRISM, consisting of of the Soft X-ray Imager (SXI), an X-ray CCD camera, and the X-ray Mirror Assembly (XMA), a thin-foil-nested conically approximated Wolter-I optics.
- Combining the SXI and XMA with a focal length of 5.6m, a field of view of 38′×38′ over the energy range from 0.4 to 13 keV is realized.
- The anomalous charge issue was an unexpected event, but we learned a lot of things from this event. We are still working on it.
- The performance verification has been successfully conducted through a series of sub-system and system level tests
- The on-ground calibration were carried out and the data analysis is ongoing
- As of Aug. 2023, Xtend is installed into the spacecraft body and awaits to be launched at Tanegashima

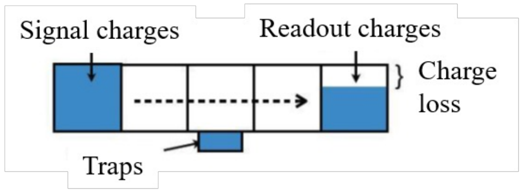


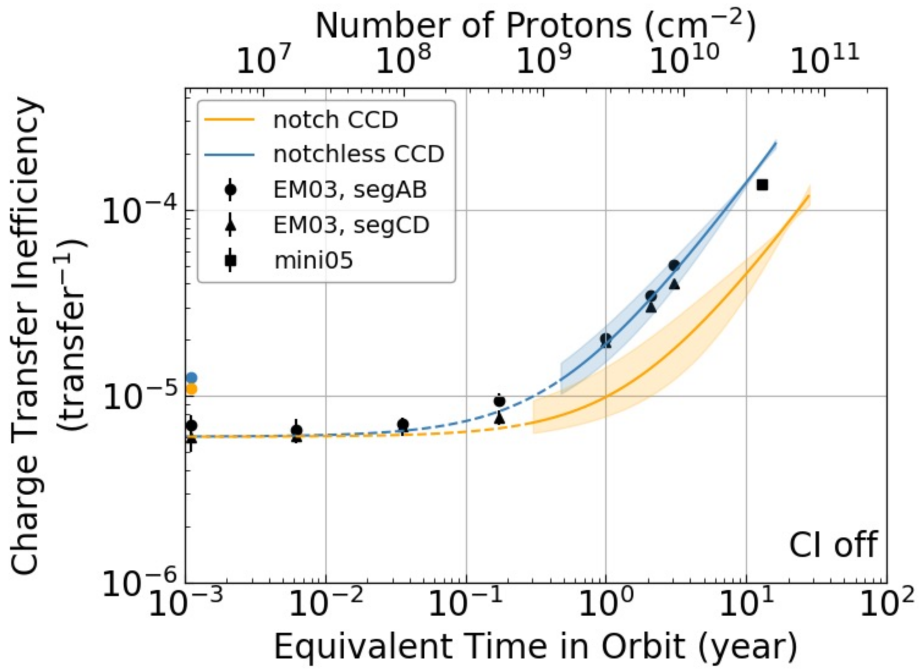
BACKUP

Updates of CCDs from Hitomi (1)



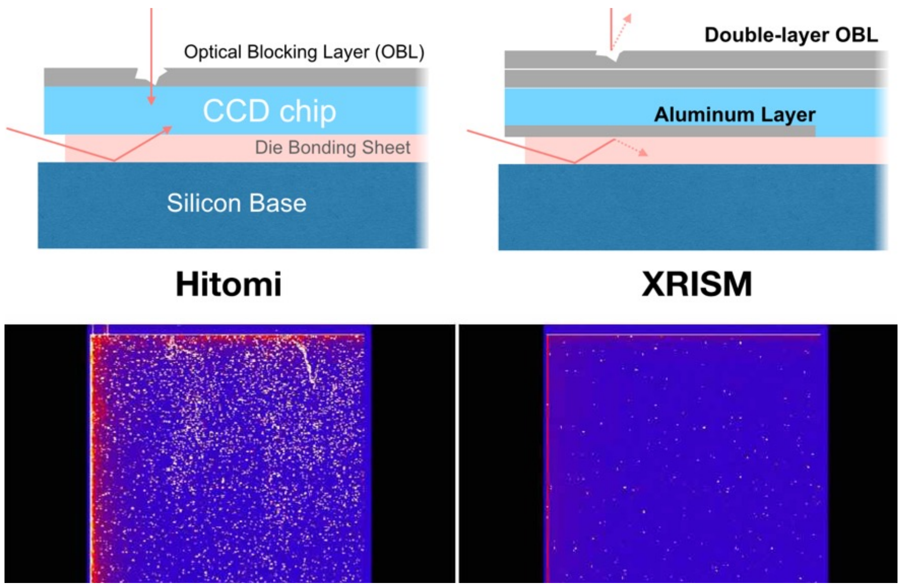


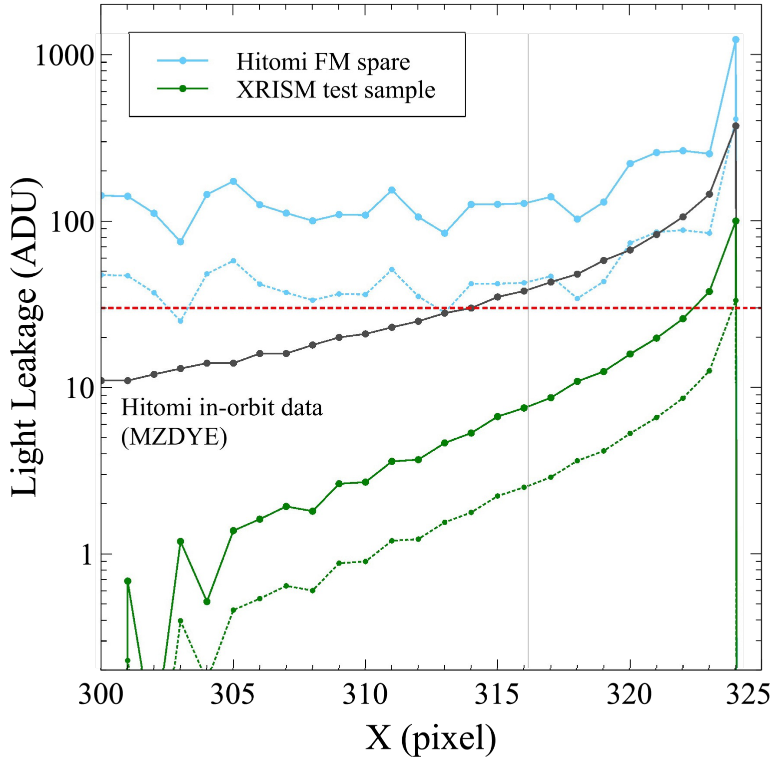




- We adopt a notch implant in the charge transfer path as a measure against the increase of the CTI (Charge Transfer Inefficiency) in orbit.
- Notch CCD exhibited better charge transfer performance compared with notchless CCD (Kanemaru+2019)

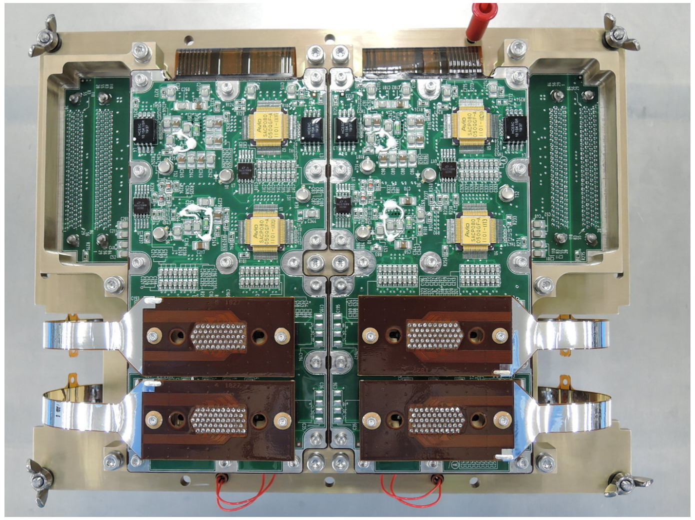
Updates of CCDs from Hitomi (2)



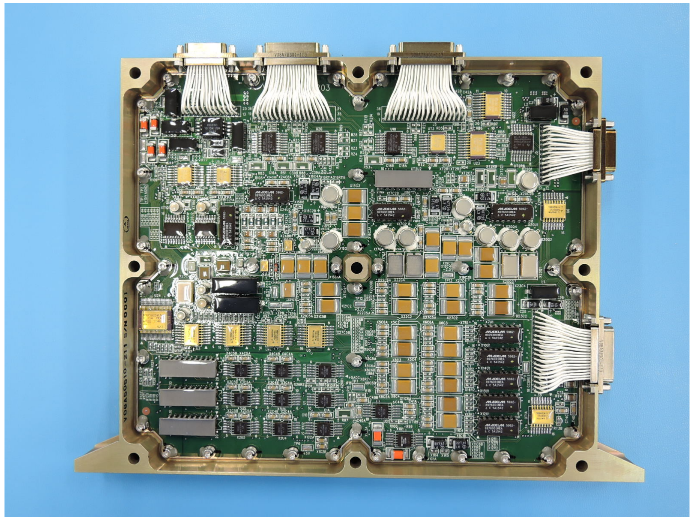


- We adopted double aluminum layers (100nm + 100nm) to reduce the number of pinholes found in Hitomi CCD.
- An extra aluminum layer above the depletion layer is introduced to decrease the flux of light leaks from the physical edges.
- Both measures have been found effective with test CCDs (Uchida+2020).

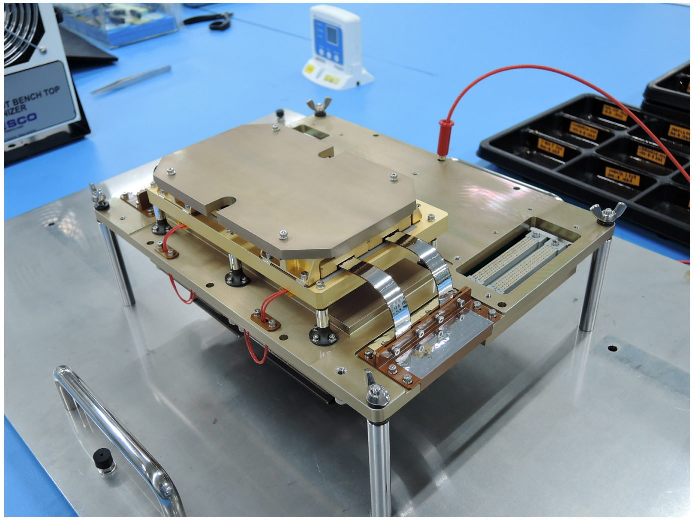
Assembling FM parts



Video Boards including ASIC and FPGA

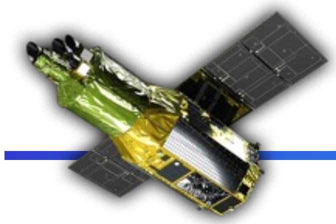


Driver Boards in SXI-S-FE



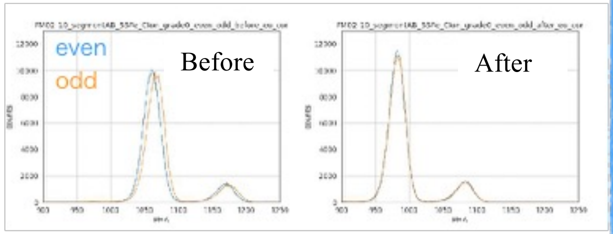
Focal plane assembly
(w/ non-flight CCD cover)

- FM analog circuit boards (Video Boards and Driver Boards) have been completed and their functions/performance have been confirmed with no problem.
- Focal plane assembly (CCDs on the cold plate + Video Boards) has been assembled.

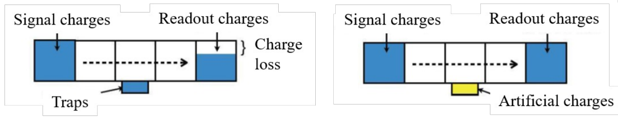


Event Process

Correct peak difference between pixels processed with different ADCs (even/odd)



Correct charge lost during transfer that depends on transfer speed and the number of transfer (Kanemaru+2020)

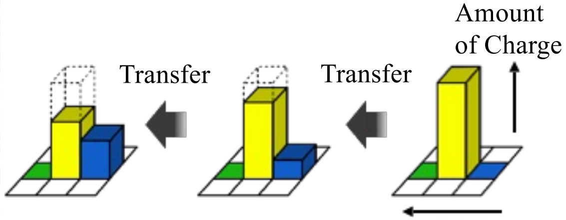


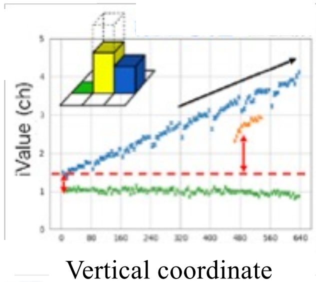
full window

- PHA(x) = PHA0×(1-cti$_{si}$×(2×(Y-640))×(1-cti$_{ss}$×(2×640))

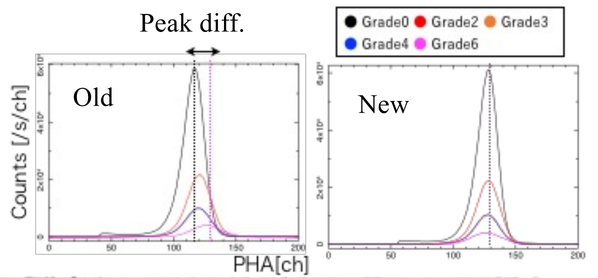
initial PHA → Even/Odd correction → Trail correction → CTI correction → Goffset correction → Gain correction → final Pulse Invariant

Correct trailed charge due to the transfer



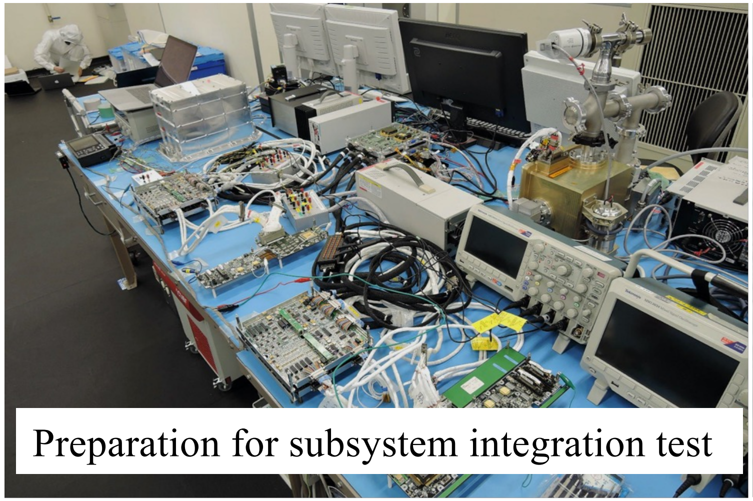


CTI dependence among Grade (pixel pattern)

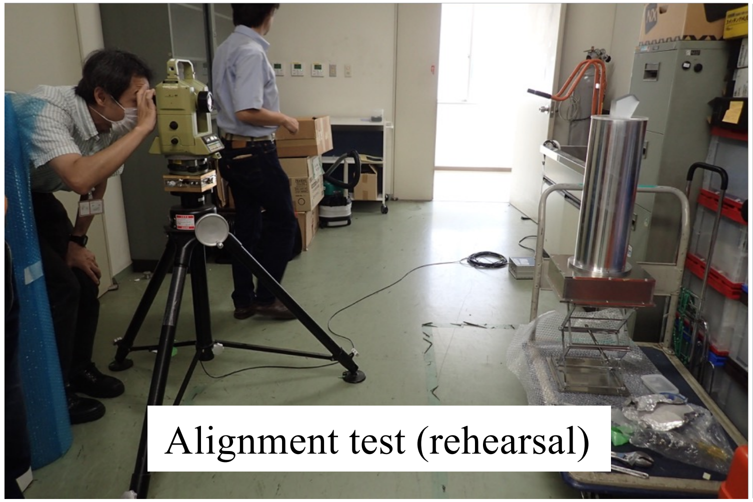


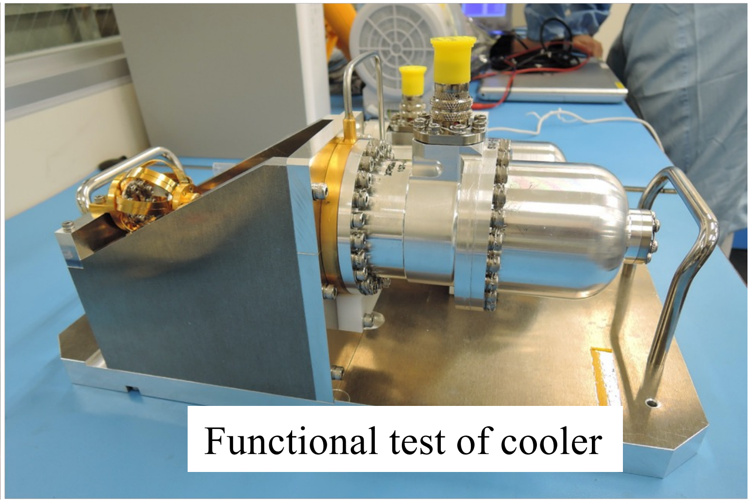
- ➢ CALDB parameters are being determined (but finalized after all FM tests)

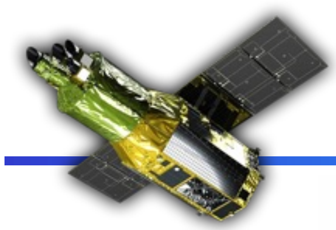
Preparing for FM tests


Preparation for subsystem integration test

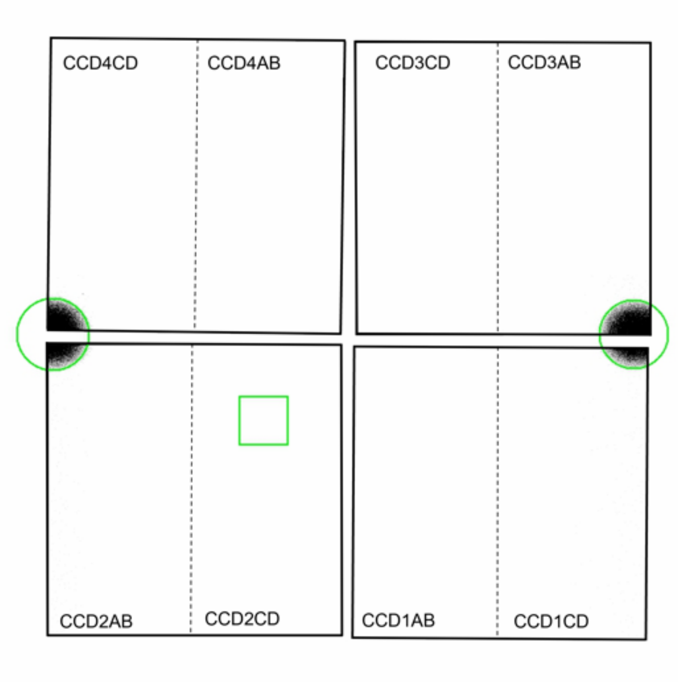

Thermal vacuum test (rehearsal)

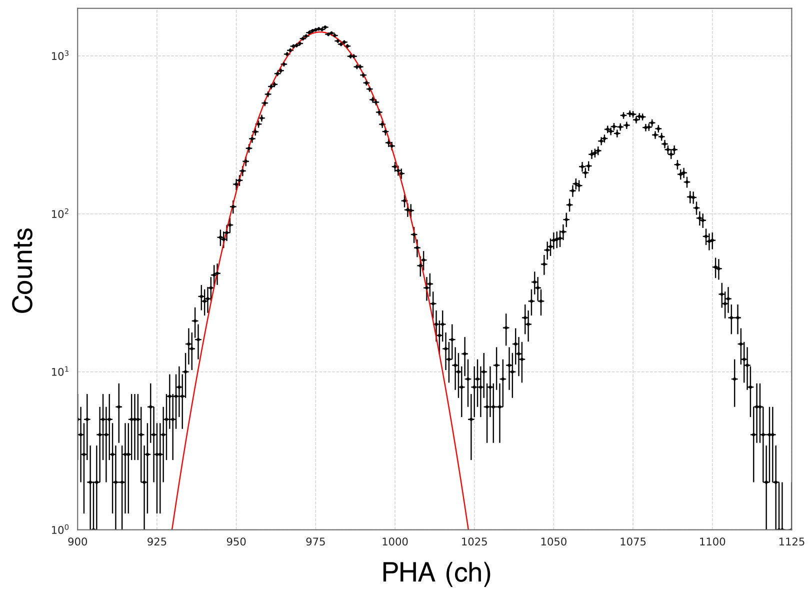

Alignment test (rehearsal)


Functional test of cooler

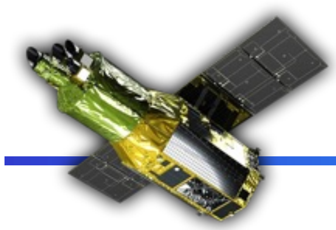


SXI thermal vacuum test (1)

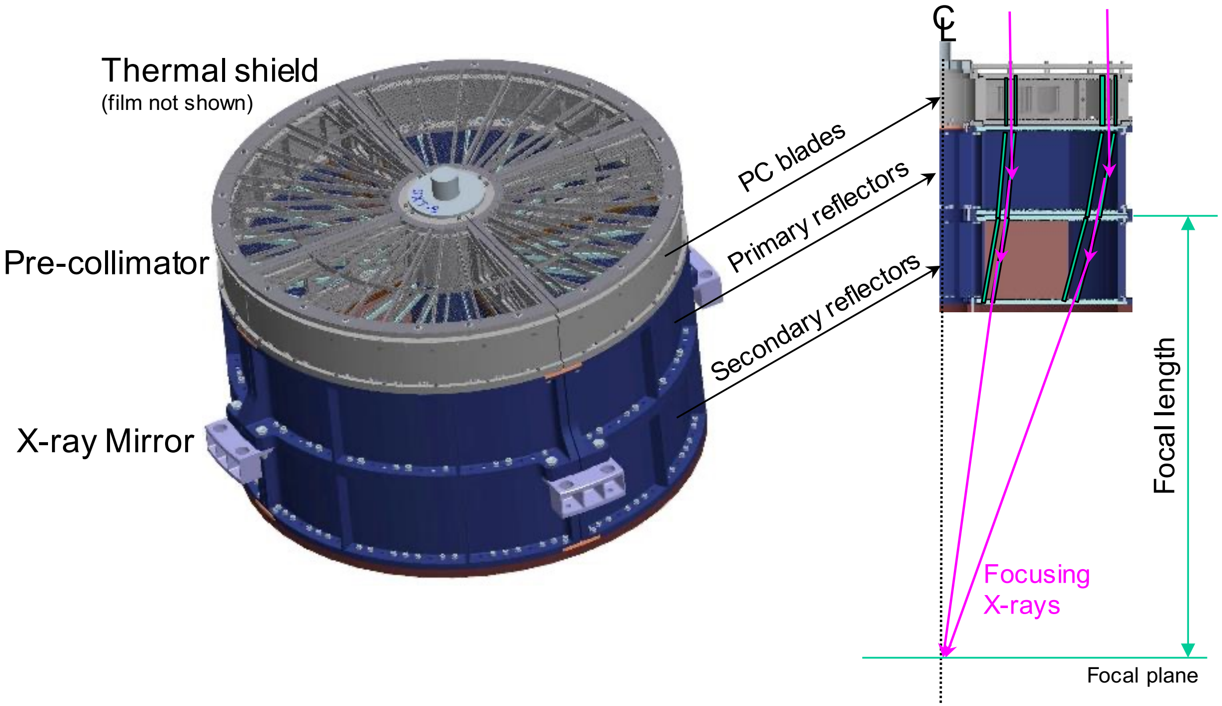




- A count map and spectrum of X-ray events from the ^{55}Fe calibration source taken in the thermal vacuum test
- From the count map, we confirmed that the count rate, irradiated location, and region size are as designed
- From X-ray spectra taken in this test, we confirmed that energy resolution is as expected from on-ground calibration discussed in later. The spectrum shown above is taken in the segment CCD2AB, is not CTI-corrected, and has an energy resolution of 177.5±0.6 eV in FWHM.

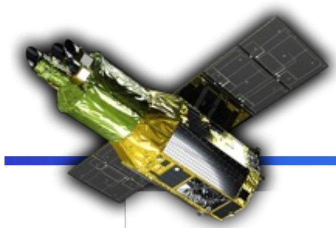


XMA configuration

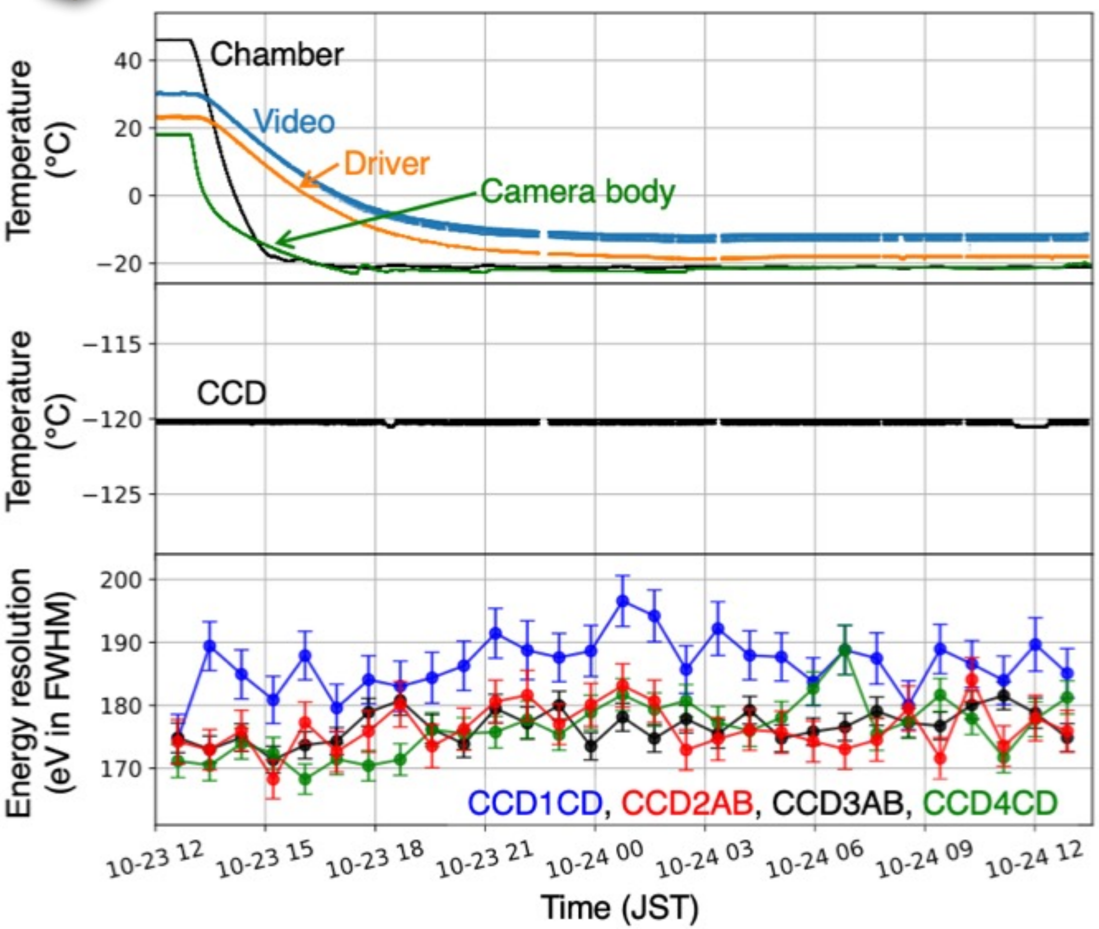


- Conically approximated nested Wolter I grazing incidence optics (203 nested shells).
- Shell height 4+4=8 inches.
- Epoxy replicated aluminum foil reflector shells (0.15-0.3 mm thick substrates, ~0.012 mm thick epoxy).
- Segmented (quadrant) configuration (203 x 4 x 2 = 1,624 foils).
- Gold surface coating for X-ray reflection.

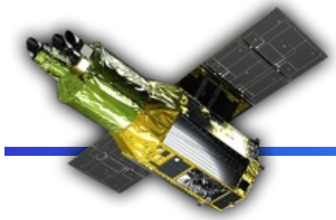
Please refer to presentations following this talk about XMA calibration status



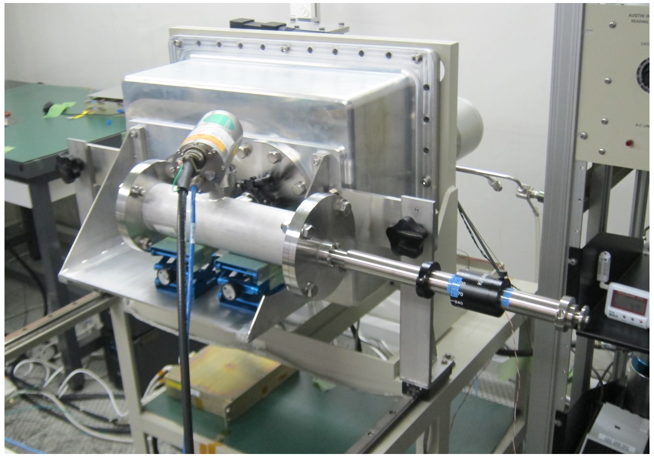
SXI thermal vacuum test (2)

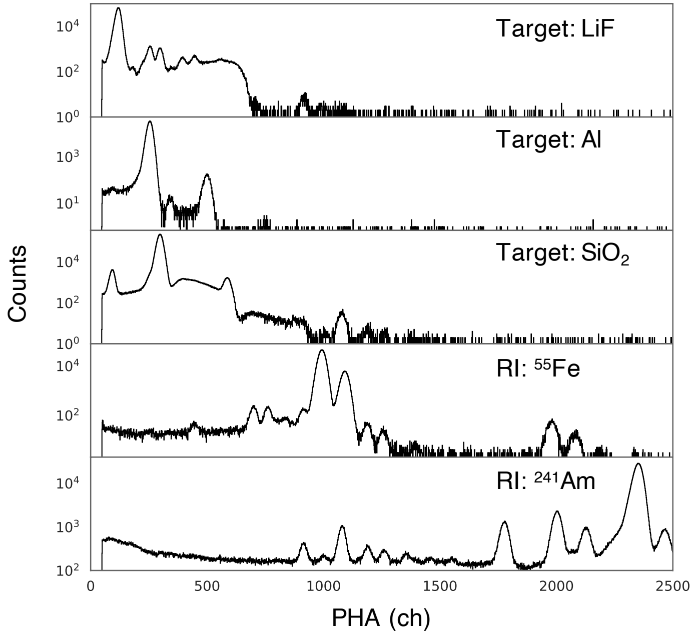


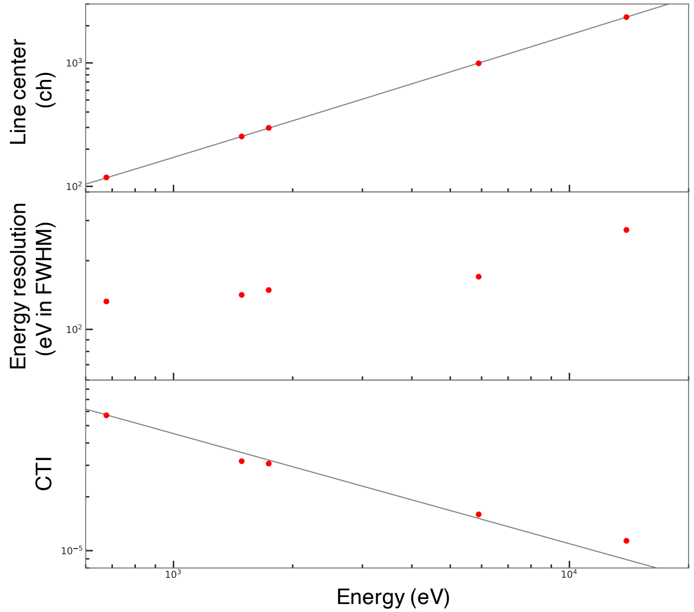
- Time history of energy resolutions measured in the four segments irradiated with X-rays from the calibration sources as well as that of temperatures of the chamber, camera body, video, driver boards, and CCD
- In this thermal vacuum test, the temperature of the camera body was forced to swing from the hottest case (+17 ◦C) to the coldest case (−20 ◦C) defined by the system, during which the SXI system successfully kept the CCD temperature constant at −120 ◦C.
- It was verified that the energy resolutions of the CCDs are stable within the statistical uncertainties and insensitive to external thermal environment variations



SXI on-ground calibration (1)

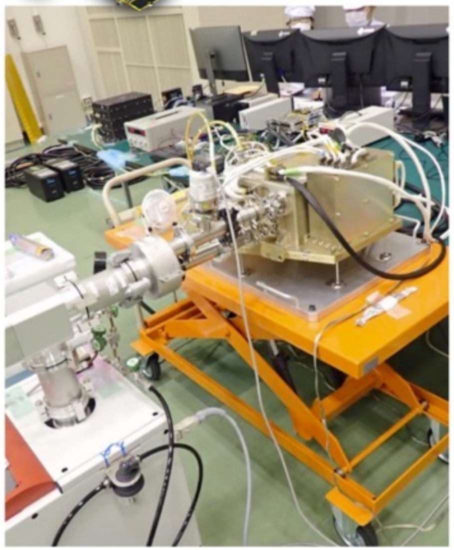


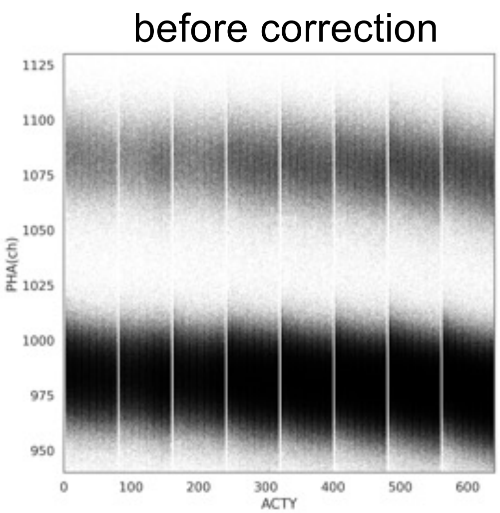


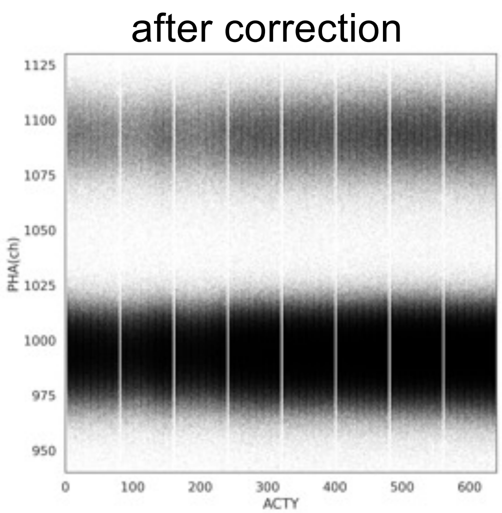


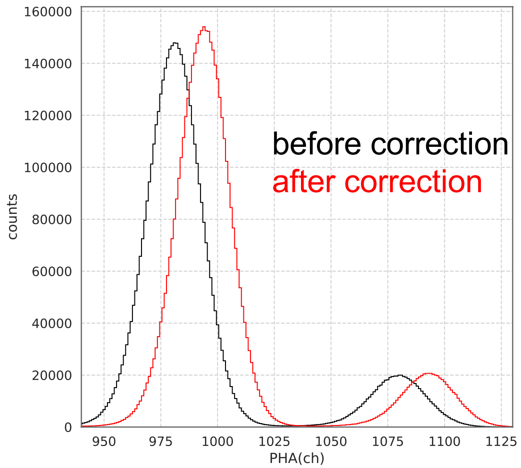
- The on-ground calibration was performed with the CCD temperature of −110 ◦C, which is the initial operating temperature in orbit.
- We conducted the SXI on-ground calibration in two stages. In the first stage, the spectroscopic performances of the flight CCDs were measured in a camera system with multi-color X-ray generator built in our laboratory
- In this system, the secondary targets (LiF, Al, SiO_2) as well as radioisotopes (^{55}Fe, ^{241}Am) can be changed without breaking vacuum
- The energy dependence of the line center, energy resolution, and CTI are measured in this stage

SXI on-ground calibration (2)



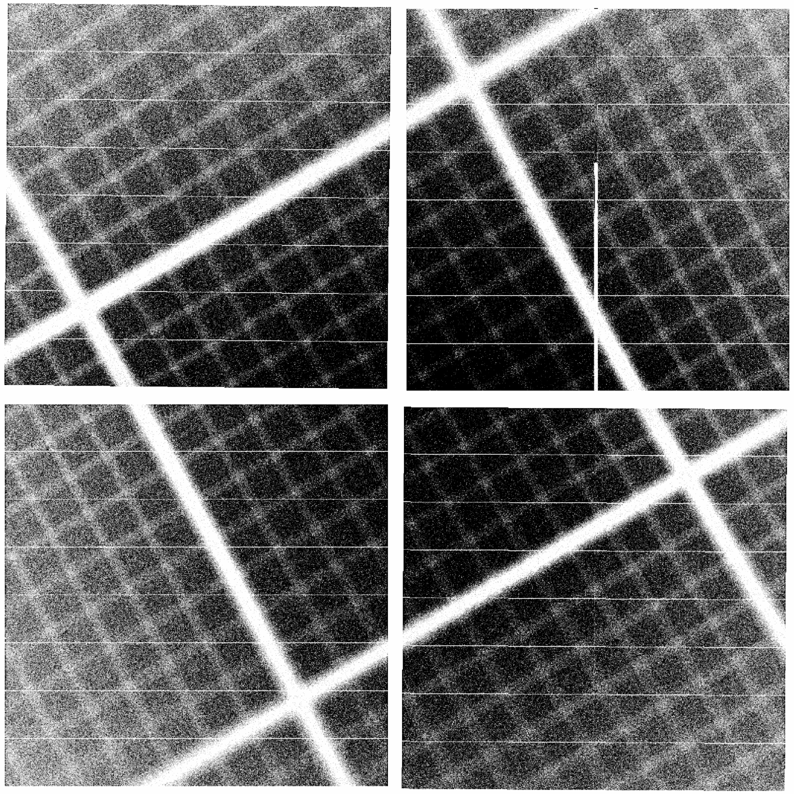


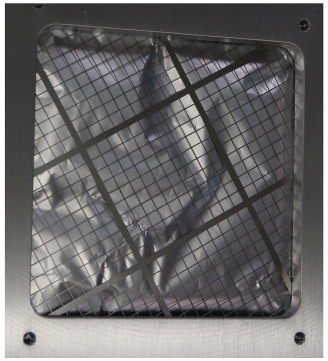




- In the second stage, the calibration was performed in the full flight configuration except for replacement of the camera bonnet in order to make it vacuum-tight. An 55Fe source was attached in the non-flight vacuum-tight bonnet and the entire areas of the four CCDs were irradiated with X-rays from the source.
- After the CTI correction, the saw-tooth shape disappears in the “pulse-height vs row number plot” and the pulse height does not depend on the row number as is expected in the case without charge loss during transfer
- It is also clear that the CTI correction makes the peak and width of the spectrum higher and narrower, respectively.

CCD orientation measurement





- In the second stage of on-ground calibration, a non-flight mesh frame was placed just above the CCD.
- The mesh was removed when the vacuum- tight bonnet was replaced with the flight bonnet before the installation of the SXI to the spacecraft body.

- We determined the relative orientation of the CCDs aligning the shadows of the mesh bars
- Gaps between active pixel regions are then obtained to be 45″–60″.