Improvement of charge-transfer efficiency of XRISM/Xtend CCDs due to un unintentional warming

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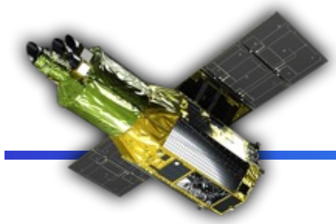
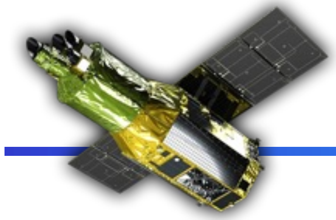
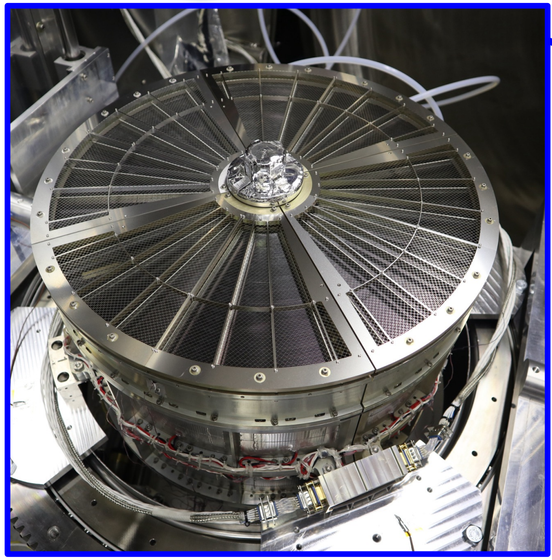


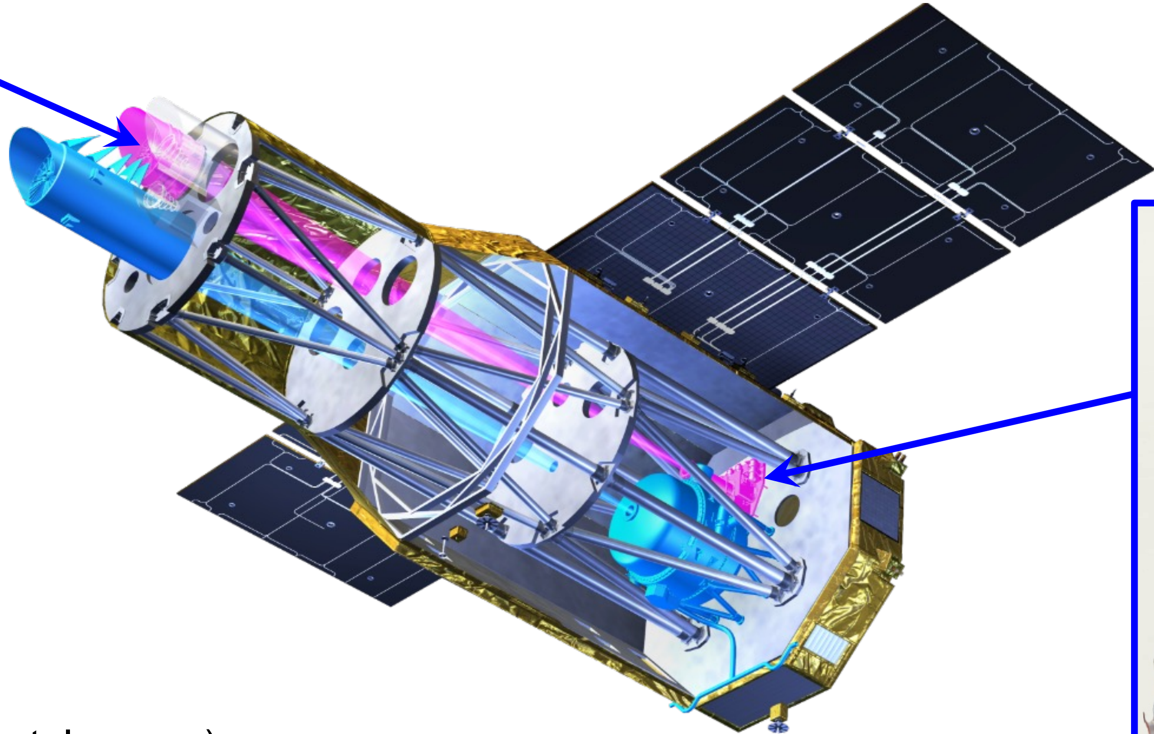
Abstract

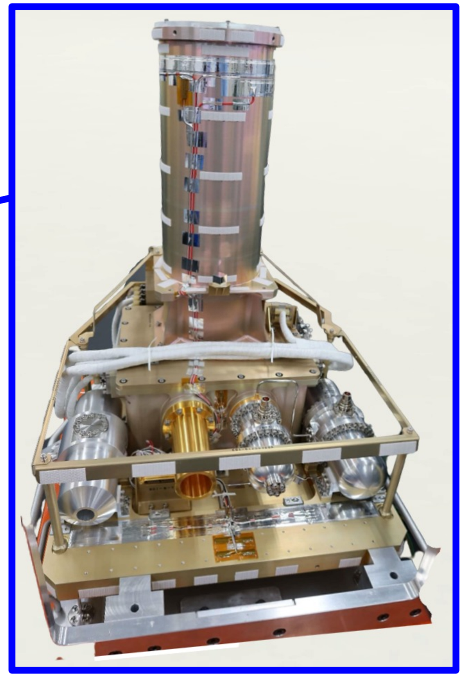
- In November 2024, we encountered an unexpected malfunction of the FPGA in the on-board electronics installed in XRISM/Xtend, likely due to a single event effect
- After the recovery, we recognized a discontinuous rise in the time history of ^{55}Fe spectrum peak. We conclude that this rise is due to the improvement of charge-transfer efficiency.
- During the recovery operation, we stopped the cooler so that the temperatures of CCDs increased up to 0 ℃ from the operation temperature of −110 ℃. Although the time period during which the CCDs were not at the nominal operation temperature was relatively short (~a day), it is likely that the unintentional warming of CCDs worked as an annealing in the right direction.



Xtend on XRISM

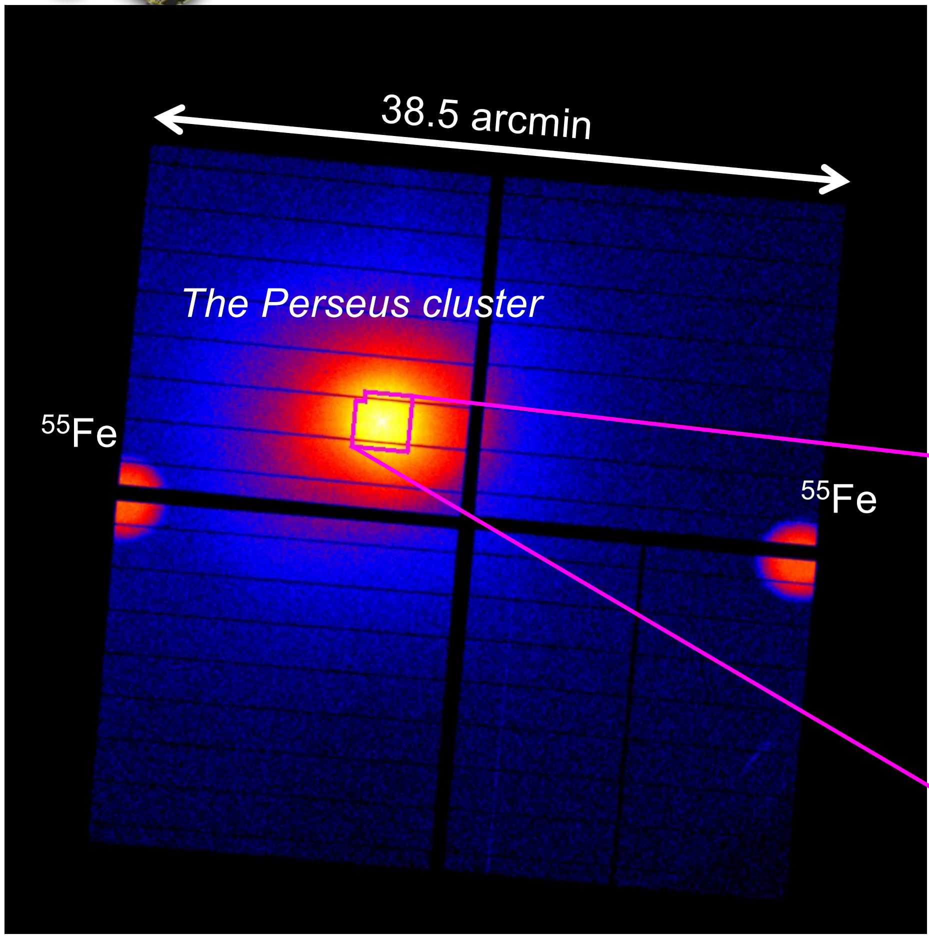




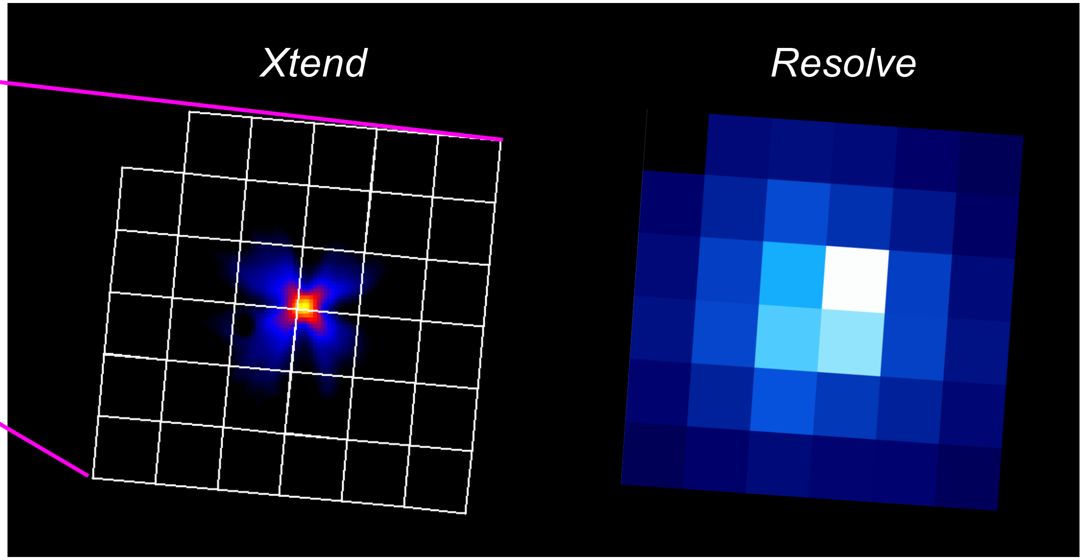


- Xtend (soft X-ray imaging telescope)
  = XMA (X-ray Mirror Assembly) + SXI (Soft X-ray Imager; CCD camera)
- XMA is an Aluminum thin-foil-nested conically approximated Wolter-I optics. Both Xtend and Resolve have an XMA with identical design.
- Xtend and Resolve observe the same sky direction and covering almost the same energy band

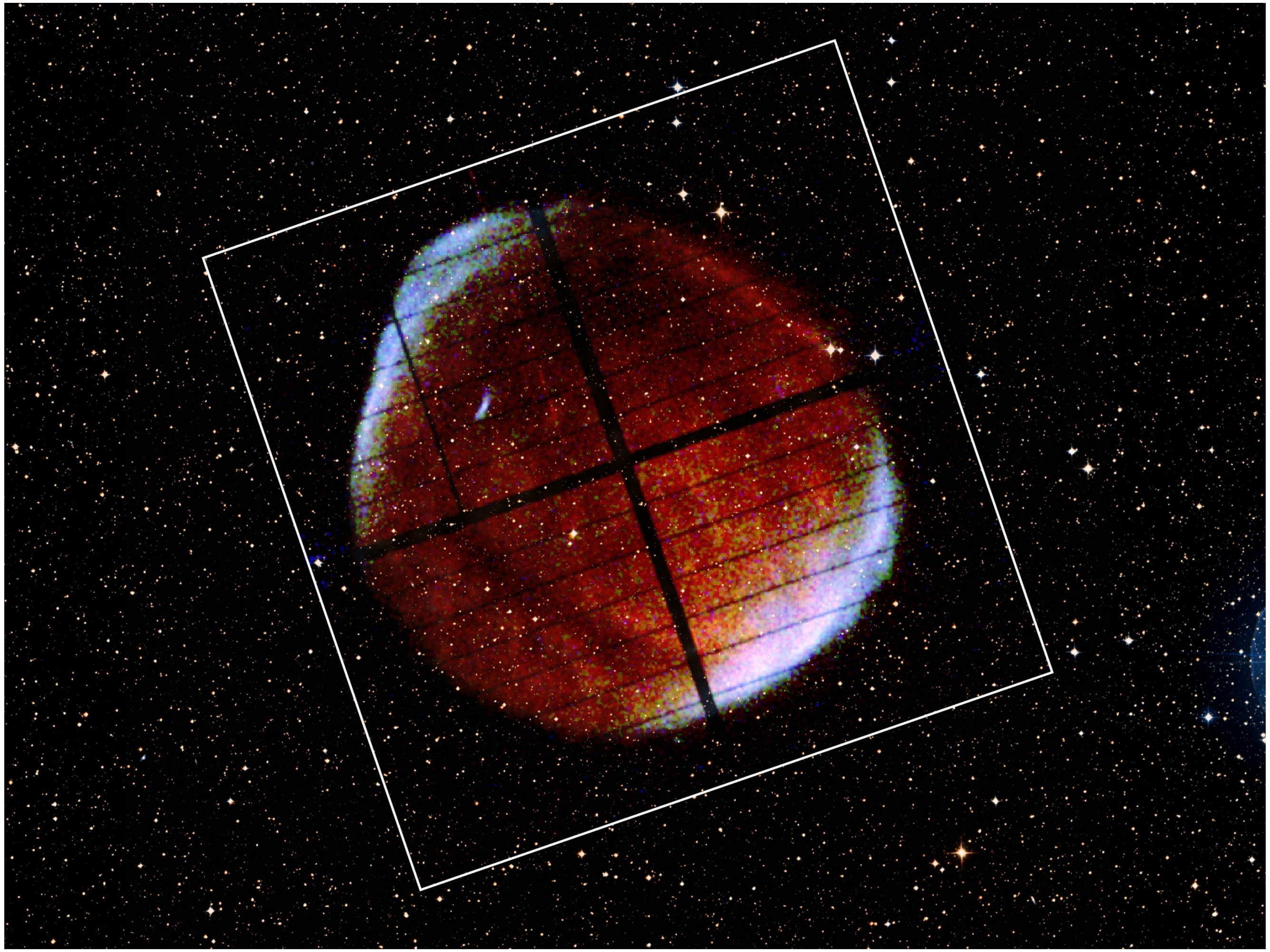
Characteristics of Xtend

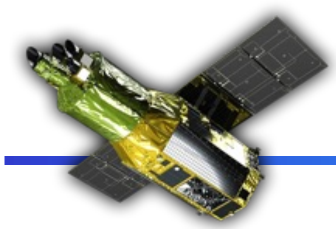


- Large FoV of 38’5 × 38’5 encompasses the 3’x3’ FoV of Resolve in its center, and the finer pixel size of 1.74” (cf. 30” in Resolve) well over-samples the PSF of XMA
- Xtend and Resolve have their own characteristics in imaging and spectroscopy, respectively, and play complementary roles in XRISM.

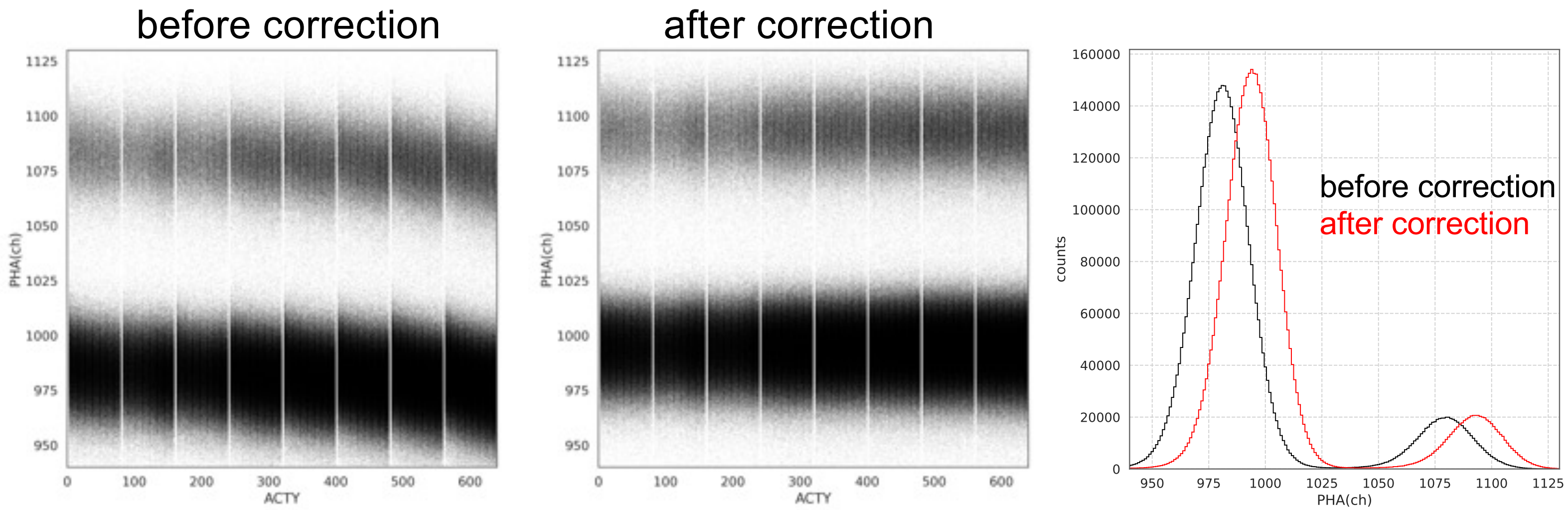


Another example of Xtend image



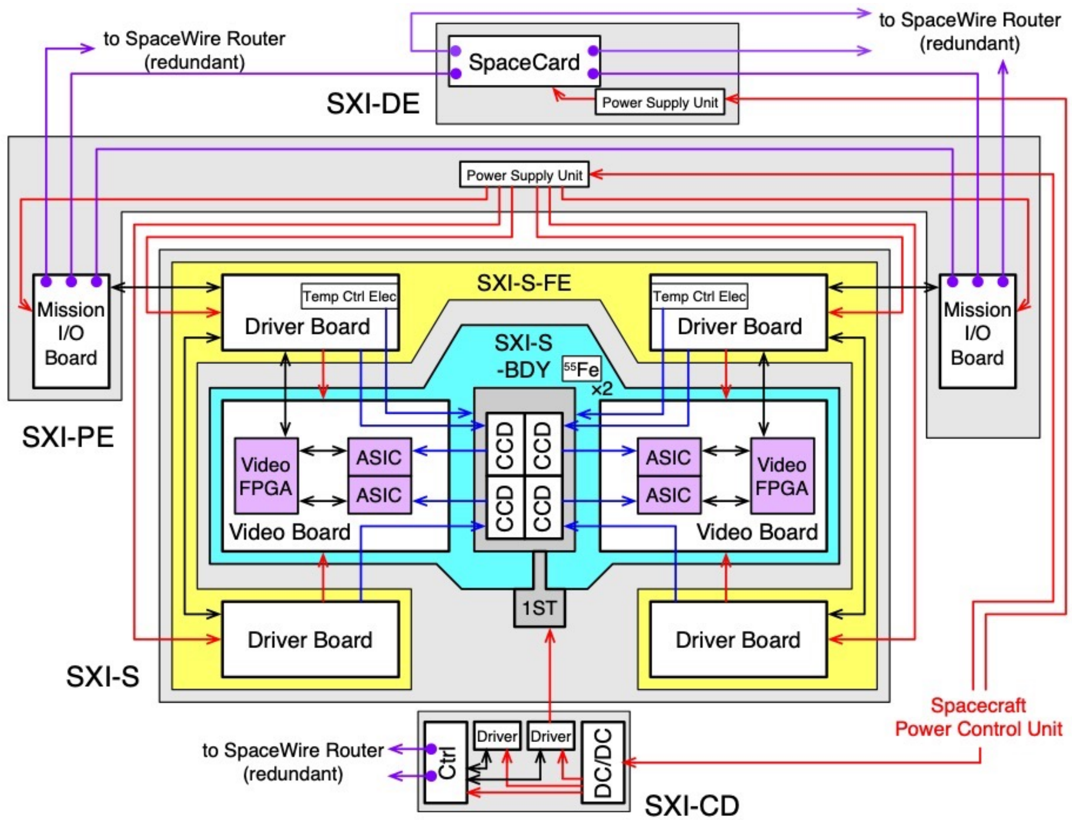


Spaced charge injection



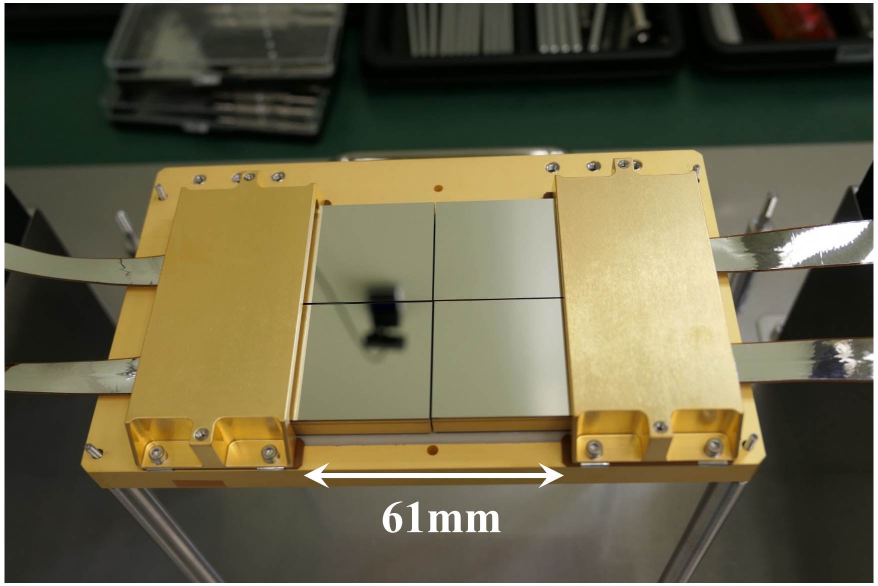
- ``Spaced charge injection'' technique is applied to compensate the charge loss due to CTI
- Left and middle figures show ``pulse-height vs row number plot'' made with the data taken in ground where where CCD area was irradiated with an ^{55}Fe source
- Because of the SCI technique, the so-called saw-tooth shape appears before the CTI correction and is gone after the CTI correction 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.

Xtend/SXI configuration



- 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 Xtend



Specifications and nominal operation parameters of the SXI CCD

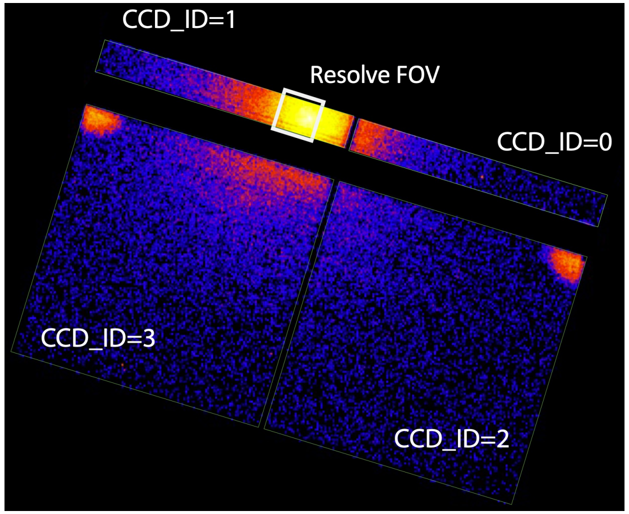
CCD Specification	Architecture	Frame transfer
	Imaging area size	30.720 mm × 30.720 mm
	Pixel format (physical/logical)	1280 × 1280 / 640 × 640
	Pixel size (physical/logical)	$24\mu m \times 24\mu m$ / $48\mu m \times 48\mu m$
	Depletion layer thickness	200 μm
	Incident surface layer (back side)	100 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

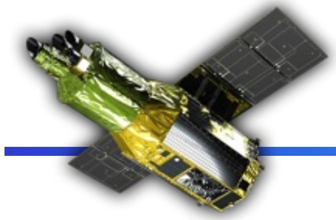
Observation modes

Mode	Area	Exposure time	Exposure per frame	Live time fraction*	Purpose
Full window	1	3.96 sec	1	0.99	General
1/8 window	1/8	0.46 sec	8	0.93	Bright point source
1/8 window + burst	1/8	0.06 sec	8	0.12	Bright point sources
Full window burst	1	0.06 sec	1	0.015	Crab mode, not for users

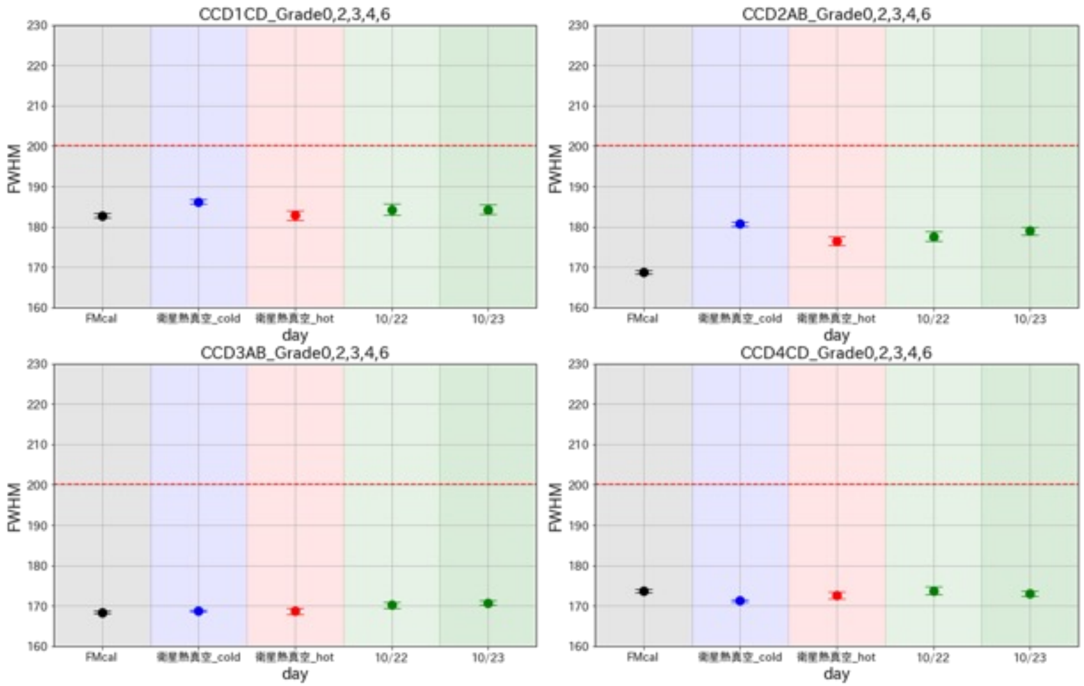
*excluding charge transfer time, during which photons detected are recorded as trailing events

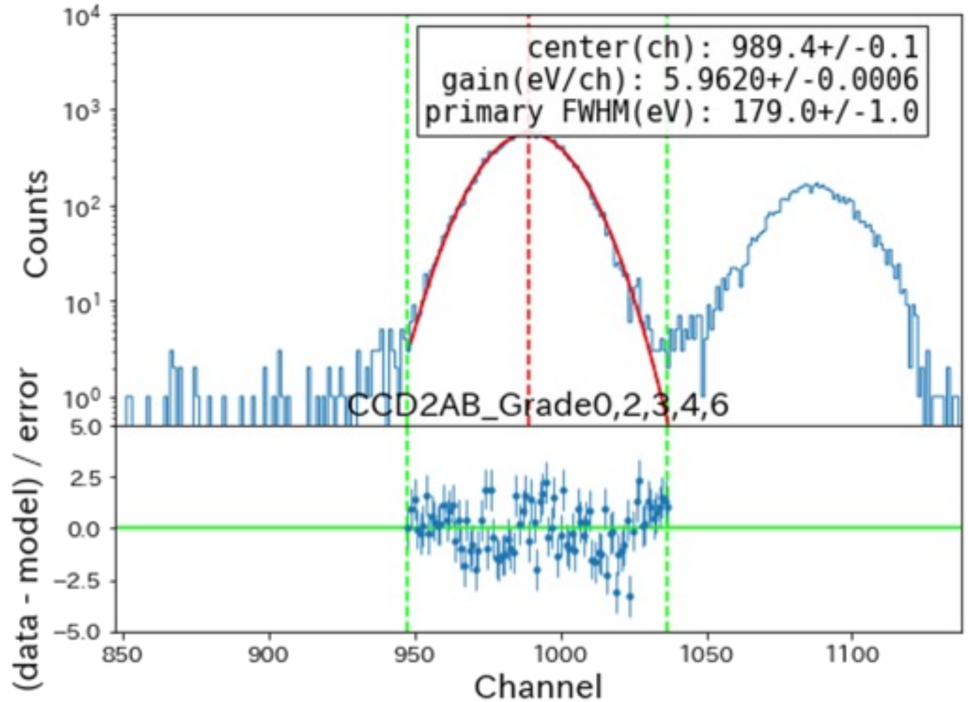


- Frame cycle is regulated by SXI-PE to be 4 sec/frame.
- We prepare window option (1/8 of the chip is readout = 8 exposures per frame) and burst option (shortened exposure time) to decrease the risk of pile-up for bright sources and improve time resolution.
- Top three modes in the table are open for 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

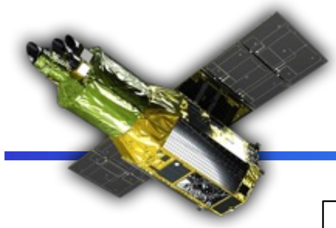


Spectroscopic performance just after the launch





- Fully consistent with ground tests
- The energy resolutions measured at 6 keV were 170-185 eV and satisfied mission requirement (better than 200 eV at 6 keV)
- These values are obtained from good grade events with all the corrections (e.g., CTI) applied



Unexpected malfunction of the FPGA

2024/11/11 09:22 - 11-23 23:40

Comment:

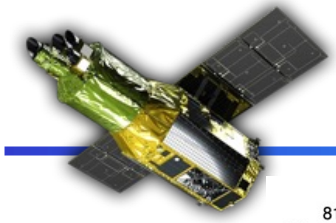
- The XRISM mission operation team detected an issue in Xtend's data readout system starting from 2024/11/11 at 09:22. Due to this issue, CCD3 and CCD4 (not aim-point chip) data are now unavailable. A cause investigation and development of a recovery plan are underway.
- This issue causes no effect on the Resolve data.
- (ps. on Dec 20) The readout system of CCD3 and CCD4 was reset from 11/22 to 11/23, and recovered at 2024/11/23 23:40.
- (ps. on Dec 20) During the affected time (11/11-11/23), timing of SAA-related commands to CCD1, CCD2 were also affected and hence some anomalous events detected for CCD1, CCD2 and their spectroscopic performances may be affected.

Observation(s) related to this note:

- 201048010 / NGC4395 (not entire but part of the observation is affected)
- 201132010 / MRK509
- 201049010 / ABELL1413
- 201103010 / PI_AQR
- 201131010 / VELA_X-1
- 201015010 / ABELL754_MAIN
- 201107010 / WR140 (not entire but part of the observation is affected)

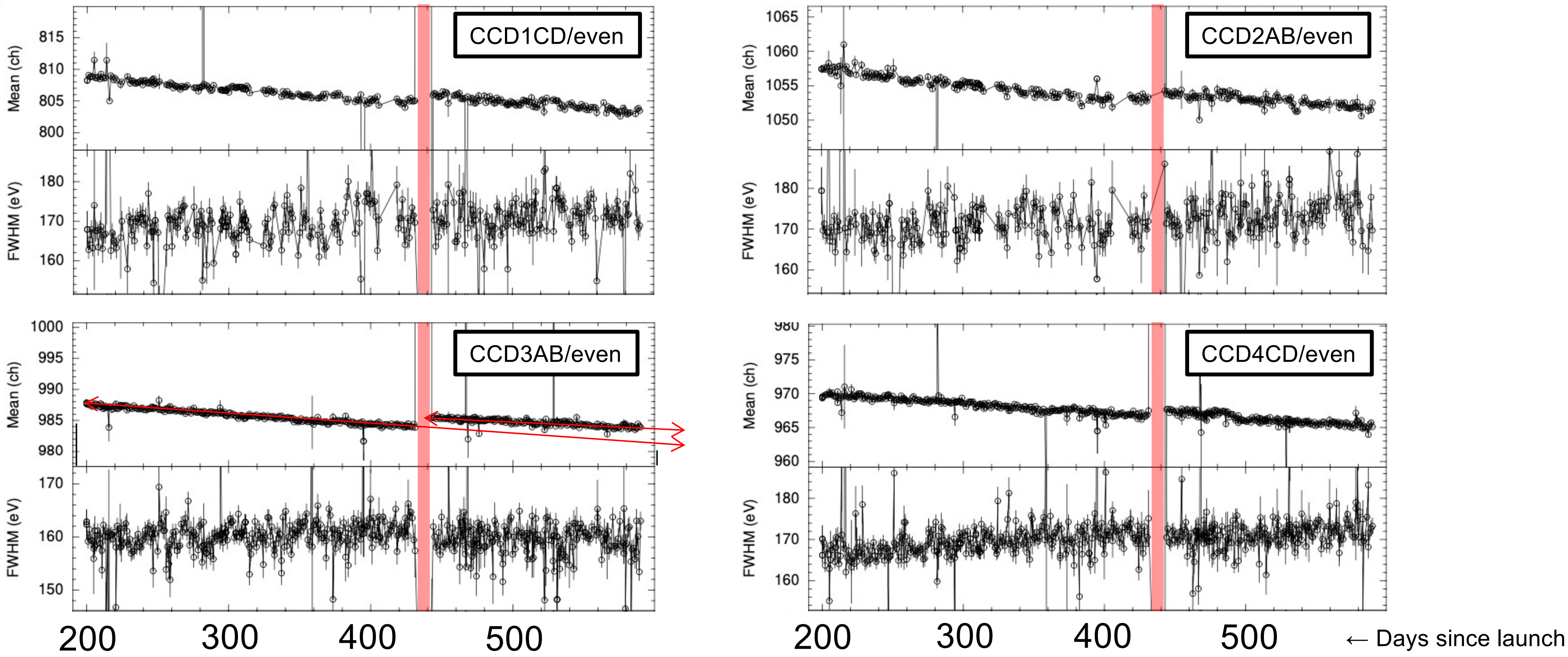
- Xtend operation log
  - open to community to summarize our special operation and/or data requiring special attention for analysis
  - https://xrism.isas.jaxa.jp/research/observers/operation_log/Xtend/index.html

- It took about two weeks from the time this issue was recognized until the return to the normal operation
  - HK data analysis, cause investigation with electronics maker, operation planning, mock test with a test bench, and recovery operation

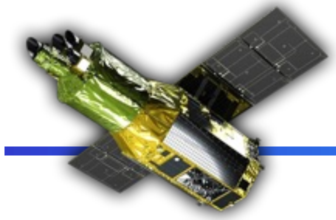


Time history of ^{55}Fe peak and width

Red bars indicate the period during which the data were not available due to the FPGA issue

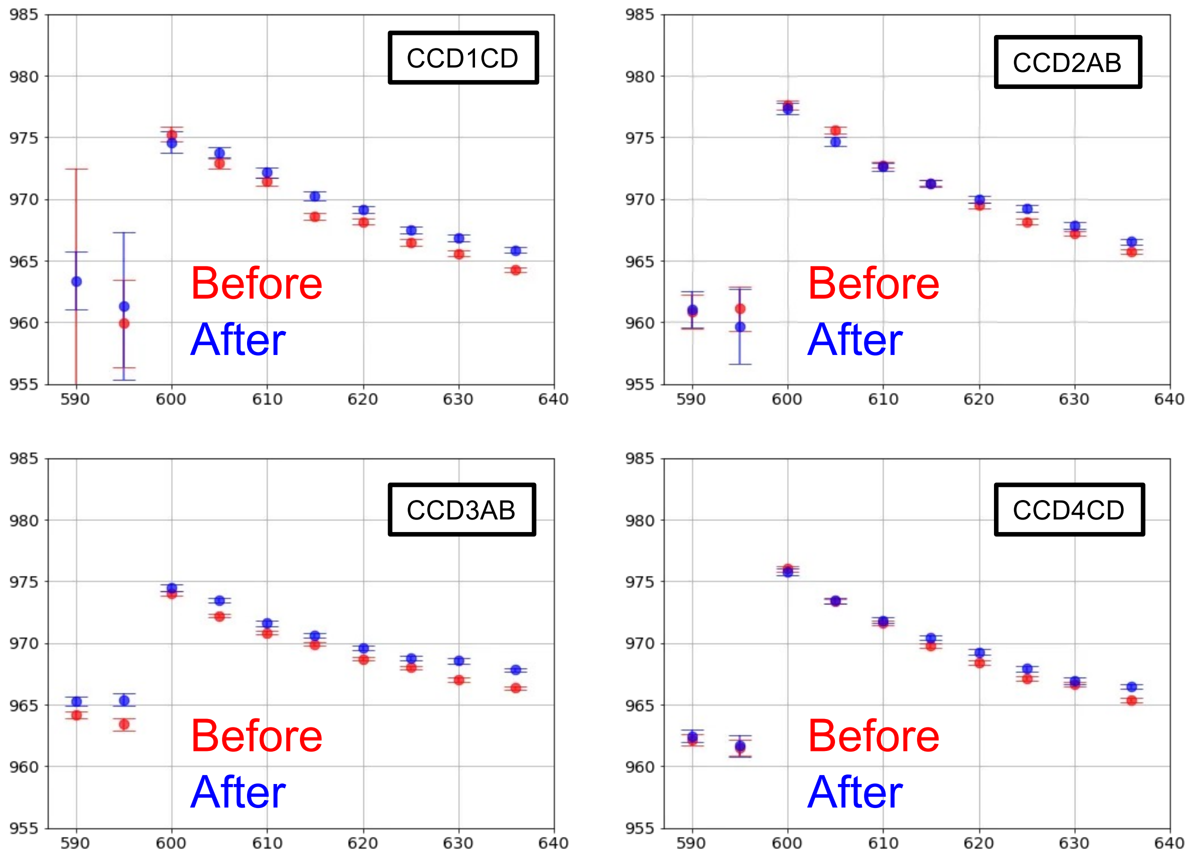


- These values are obtained from Grade 0 events without any correction (from even columns)
- After the recovery operation, we recognized a discontinuous rise in the ^{55}Fe peak trend
  - Now we can see a discontinuous fall in the ^{55}Fe width trend

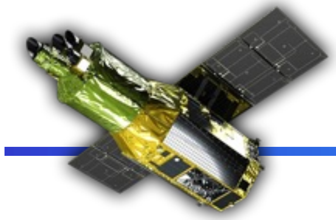


Gain shift or improvement of CTI

No CTI correction applied



- In the ground tests, an abrupt gain shift was sometimes observed after resetting the system, which was first suspected to be the case for this event
- ``pulse-height vs row number plot'' indicates, however, that the cause of this event is not a gain shift but the the improvement of CTI.
  - The effective CTI value at given pixel is greater as the distance from the nearest preceding CI row to the pixel is longer
  - Longer distant pixels show larger rise in pulse-height



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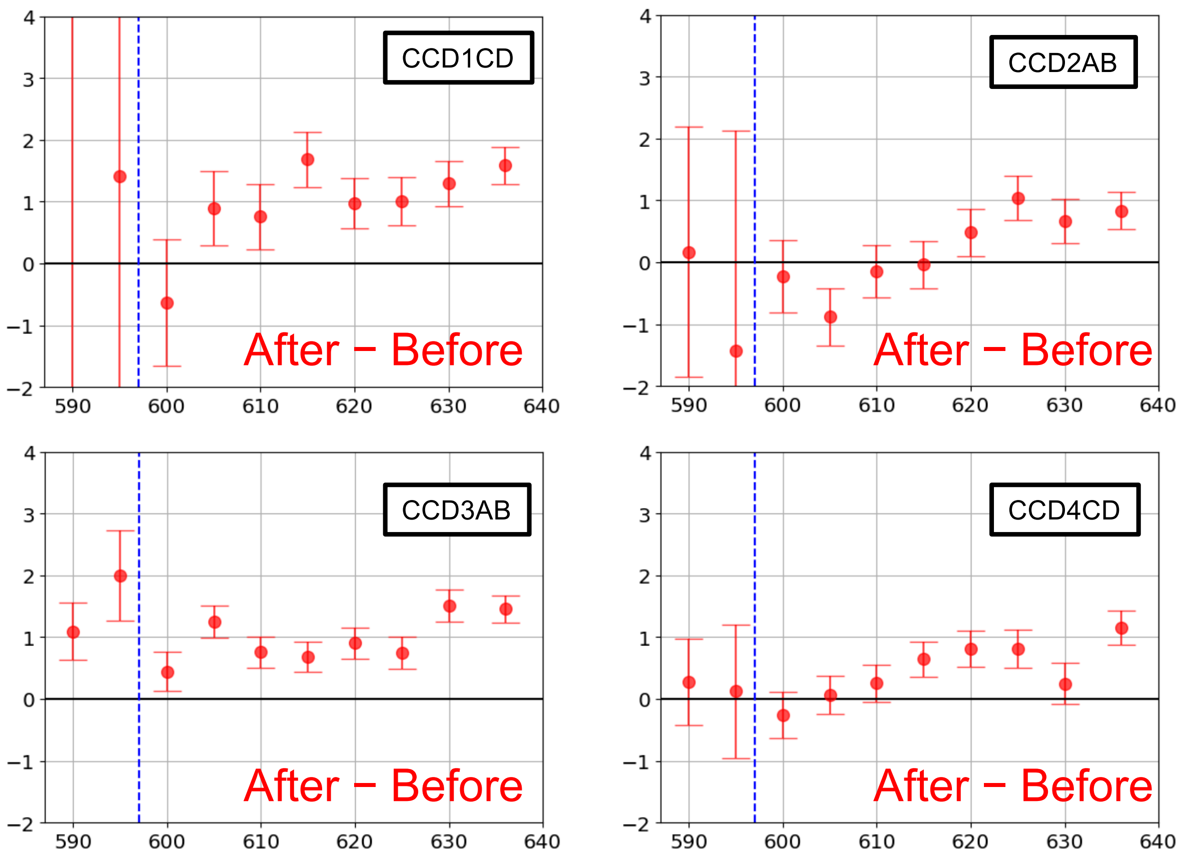

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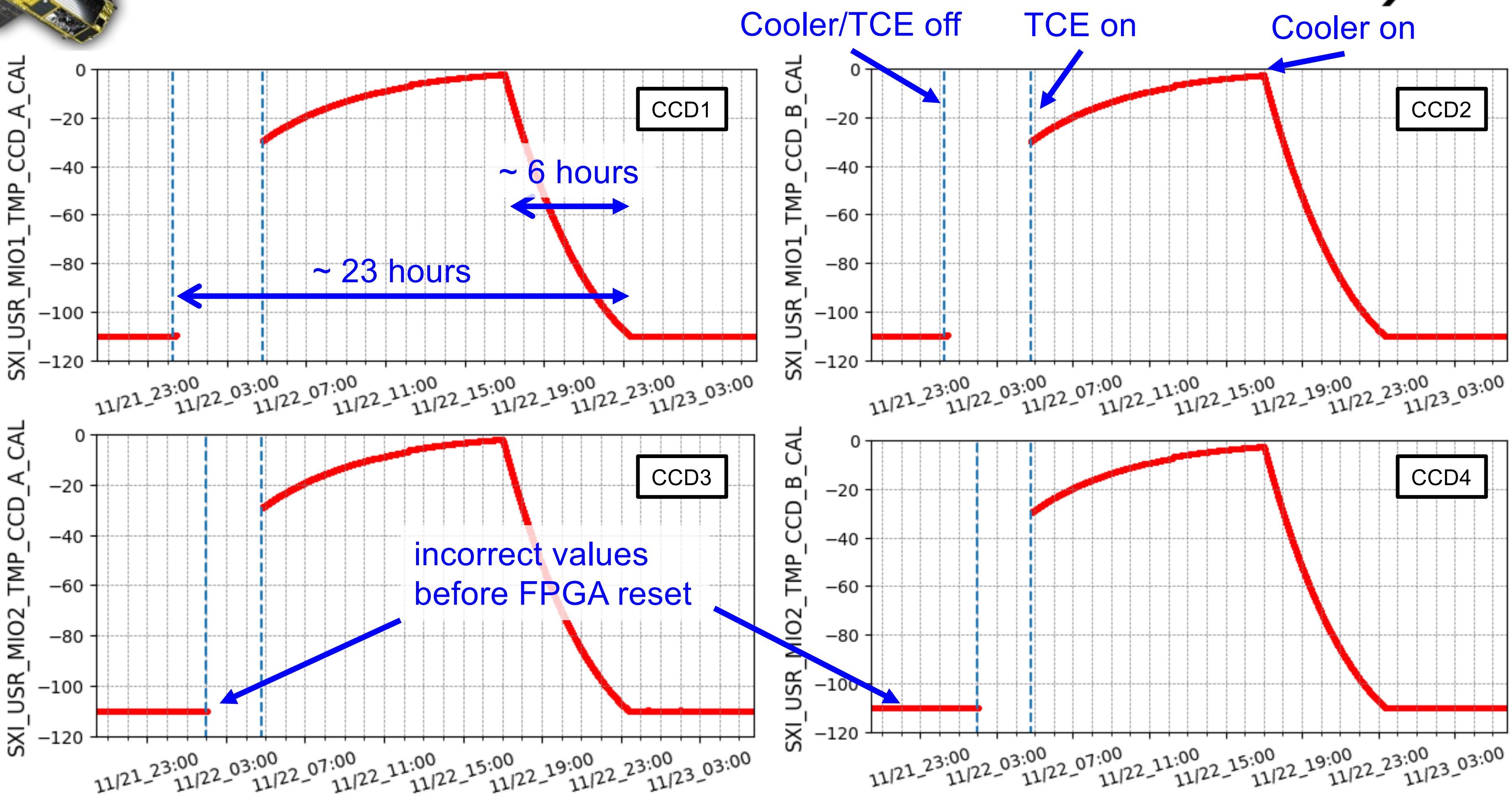
- Roughly speaking, because of this event, CTI improved by ~1×10^{-6} (<10%)

Time history of CCD temperature



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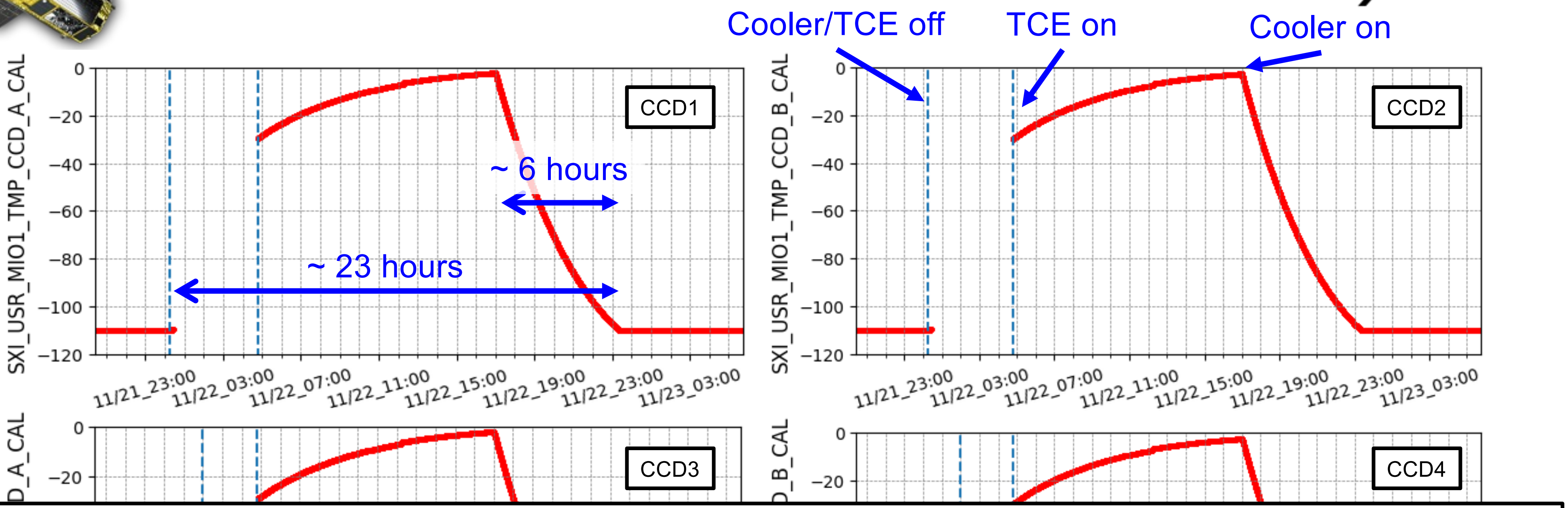
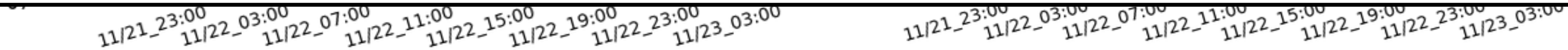
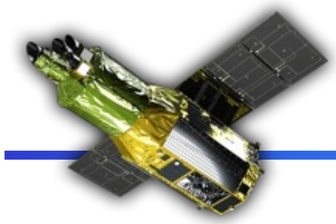


- During the recovery operation, we stopped the cooler so that the temperatures of CCDs increased up to 0 ℃ from the operation temperature of −110 ℃.
- Although the time period during which the CCDs were not at the nominal operation temperature was relatively short (~a day), it is likely that the unintentional warming of CCDs worked as an annealing in the right direction.





Discussion

- It is generally-known positive practice to warm damaged CCD devices to anneal at least some radiation defects since the HST era
- In the case of Chandra ACIS, however, CTI reversely increased by about 35% after their CCD warming
  - Soon after the damage occurred, the focal plane temperature was elevated to +20–30 ℃ for 8 hours and then the CCDs were cooled back down to the normal operating temperature, −100℃ at that point in the mission (Bautz et al. 2005)
- Any experiences of this kind of ``baking'' for other CCD missions in space, whether intentional or not?