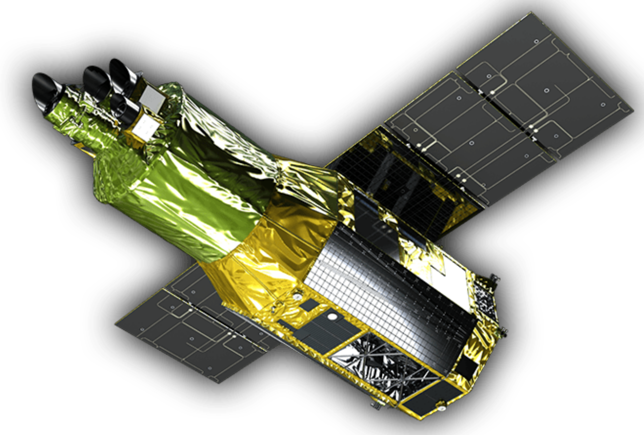


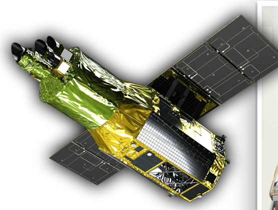
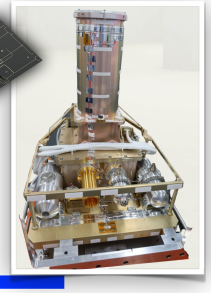
On-ground calibration of Xtend for XRISM

Hiromasa Suzuki
(Konan-U, JP)
on behalf of the XRISM/Xtend team

This work was supported by JSPS Core-to-Core Program (grant number:JPJSCCA20220002).

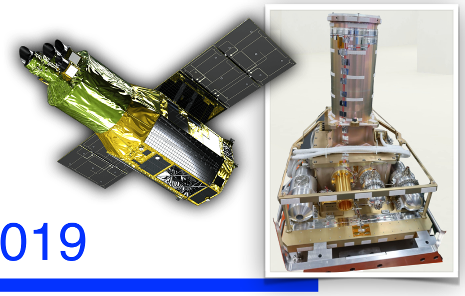
XRISM
X-Ray Imaging and Spectroscopy Mission

Talk plan

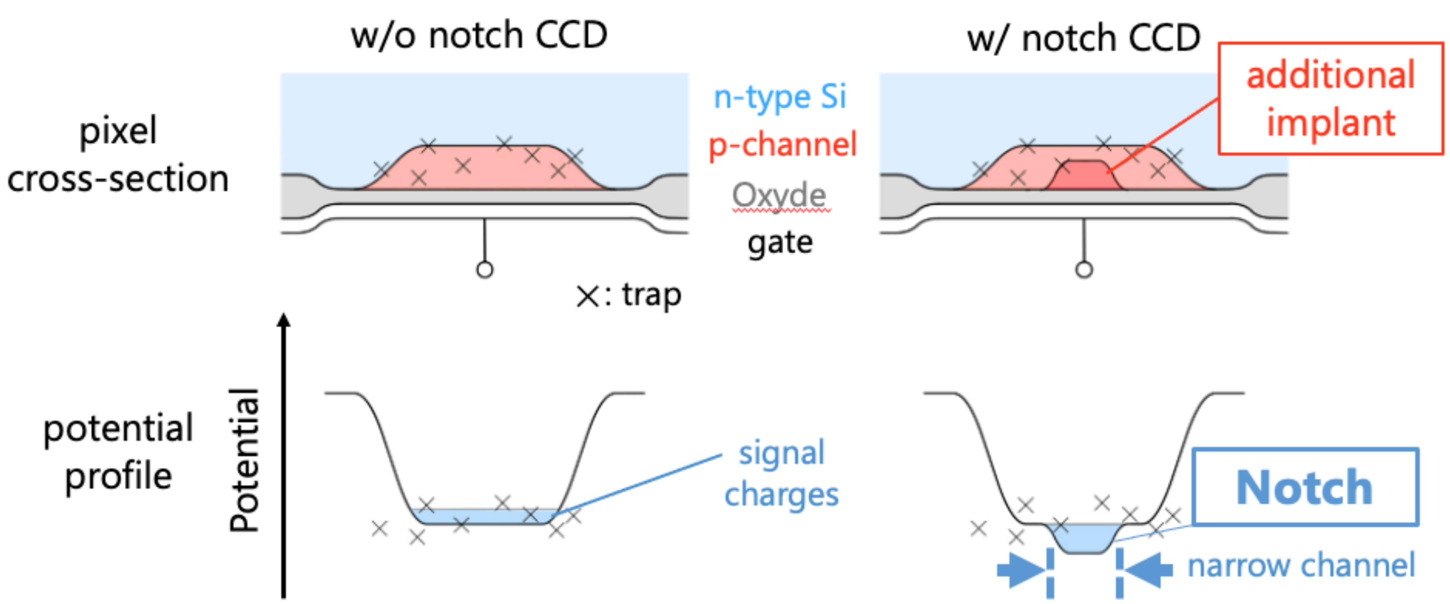



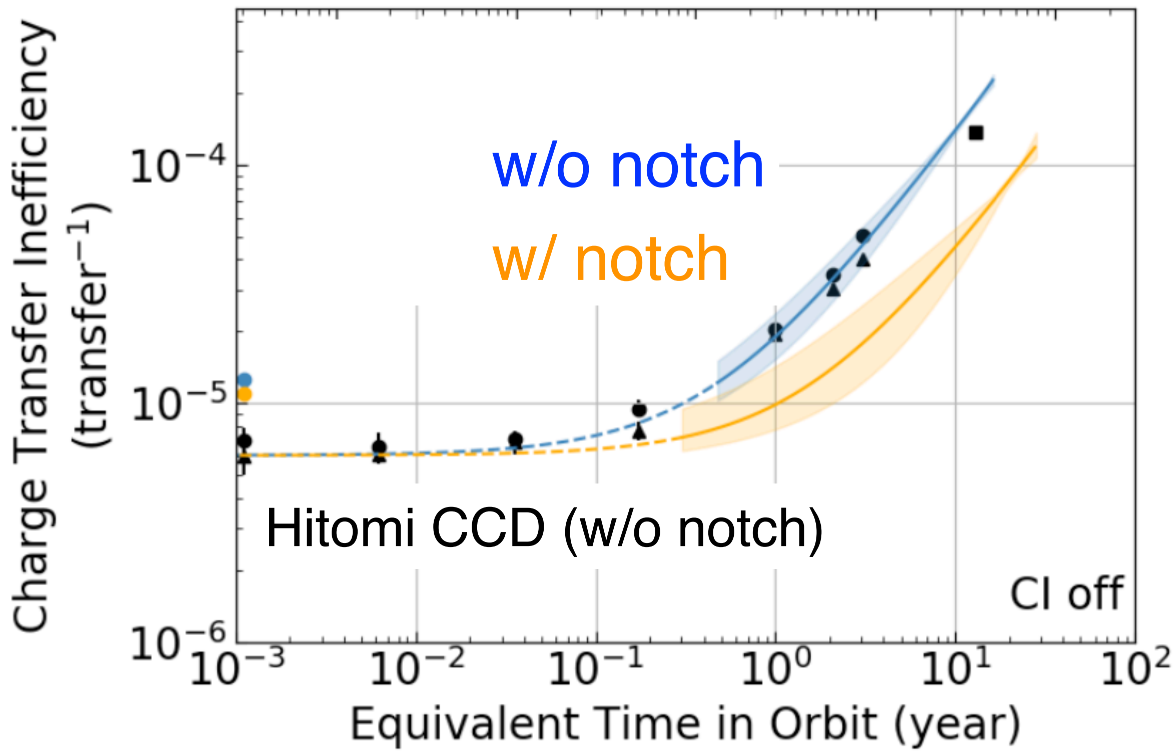
- Radiation tolerance
- CTI correction
- Optical blocking performance
- Quantum efficiency
- Performance verification and parameter optimization in thermal-vacuum test
    - cooler & heater health check
    - spectral performance
    - charge injection
    - RI verification
    - nominal operation rehearsal
- Effective area
- CCD arrangement
- CCD response

Radiation tolerance



2018–2019

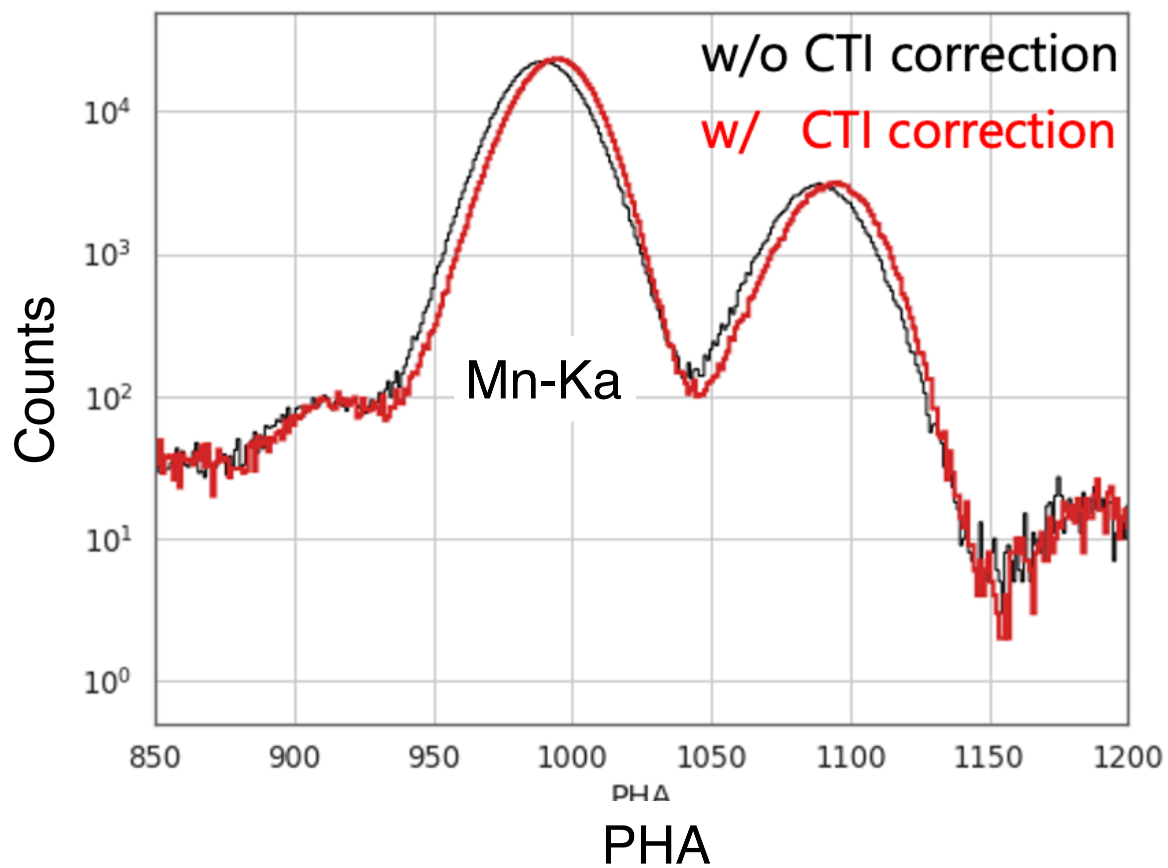


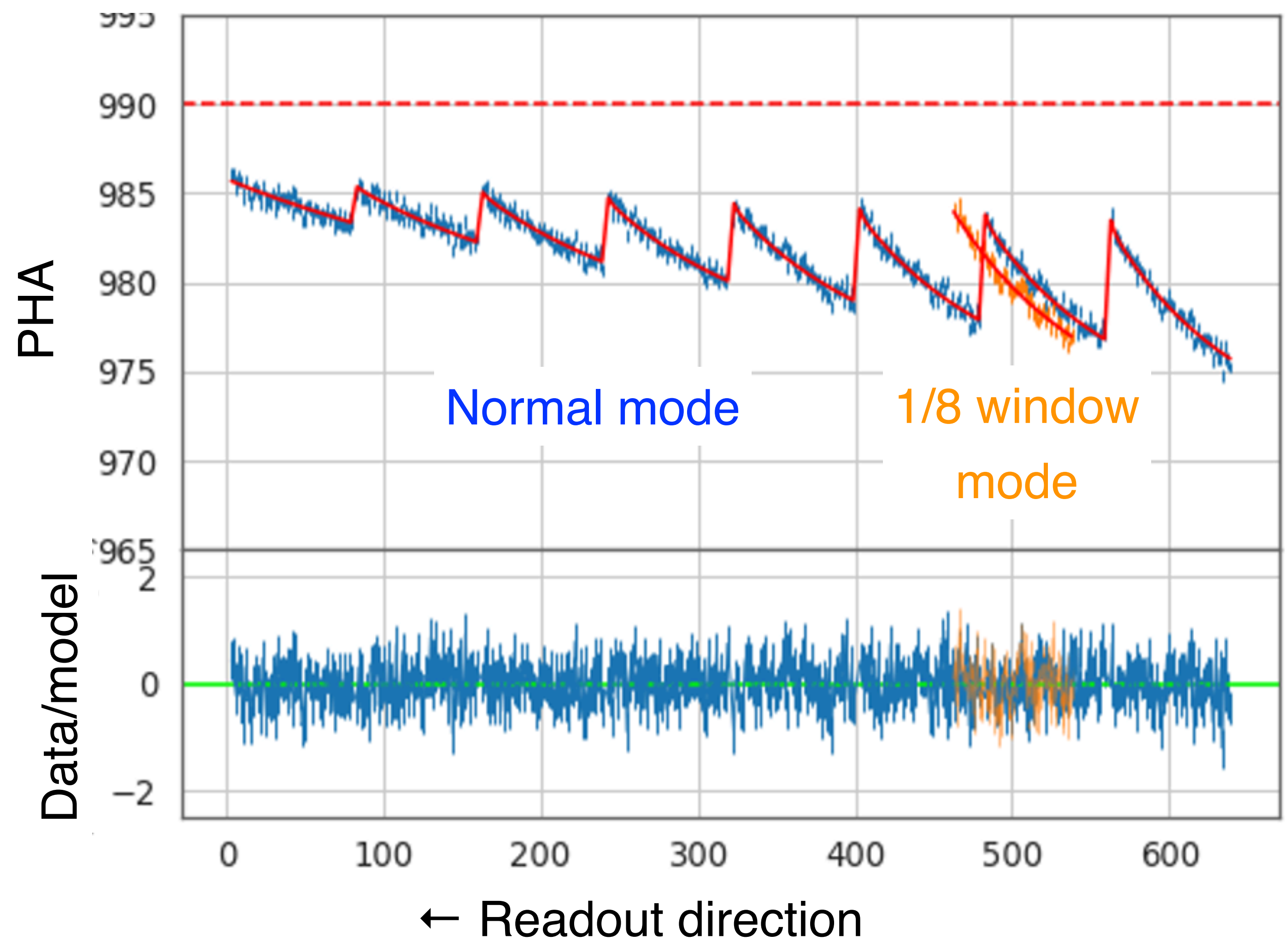


- Notch structure → suppress charge trap
→ improve CTI (charge transfer inefficiency) & radiation tolerance
- 2–3x improvement in tolerance confirmed with proton irradiation experiment

CTI correction

2019–2020



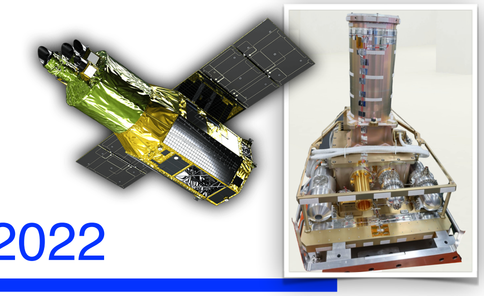


(Kanemaru et al. 2020)

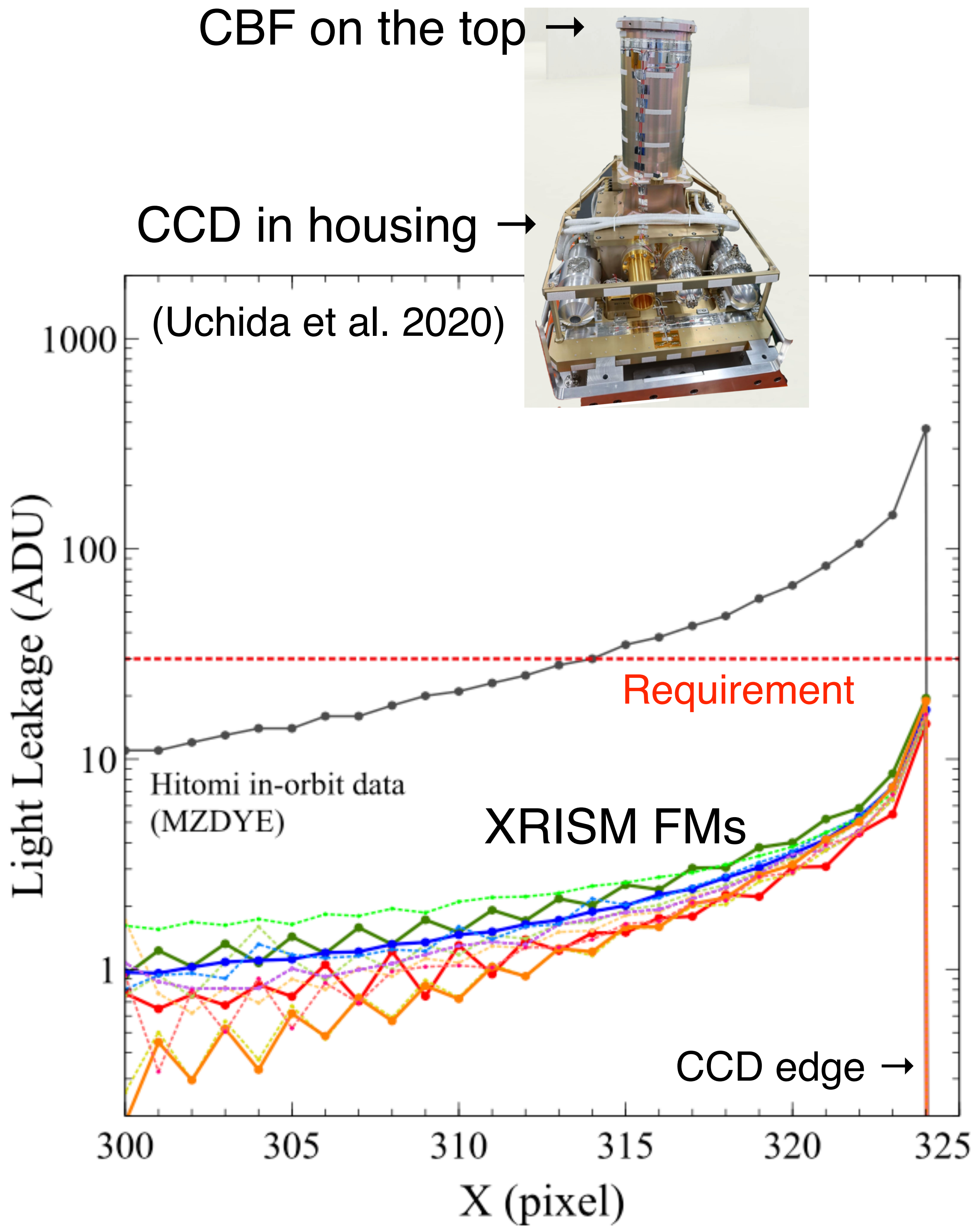
- CTI depends on positions
- Constructed a model to explain spatially dependent CTI
- CTI also depends on incoming X-ray flux,
  but it is negligible when CI (charge injection) is ON

Optical blocking performance

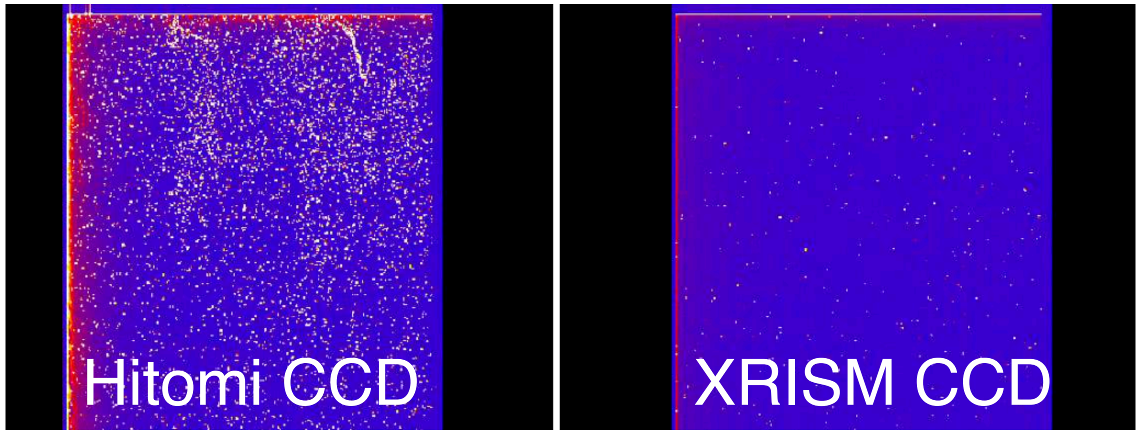
2019–2022



- Optical light irradiation to CCDs
  → $< 10^{-4}$ transmission at OBLs (optical blocking layers) on CCDs
- Optical light irradiation to CBF (contamination blocking filter)
  → $< 10^{-3}$ transmission
- Leak check at thermal-vacuum test
  → confirmed sufficiently small number of pinholes

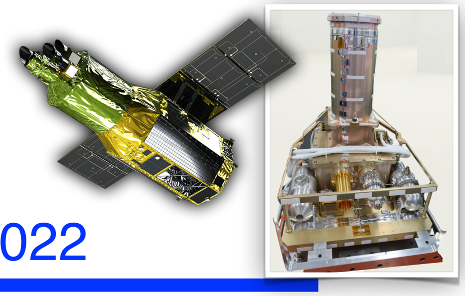


Optical light irradiation

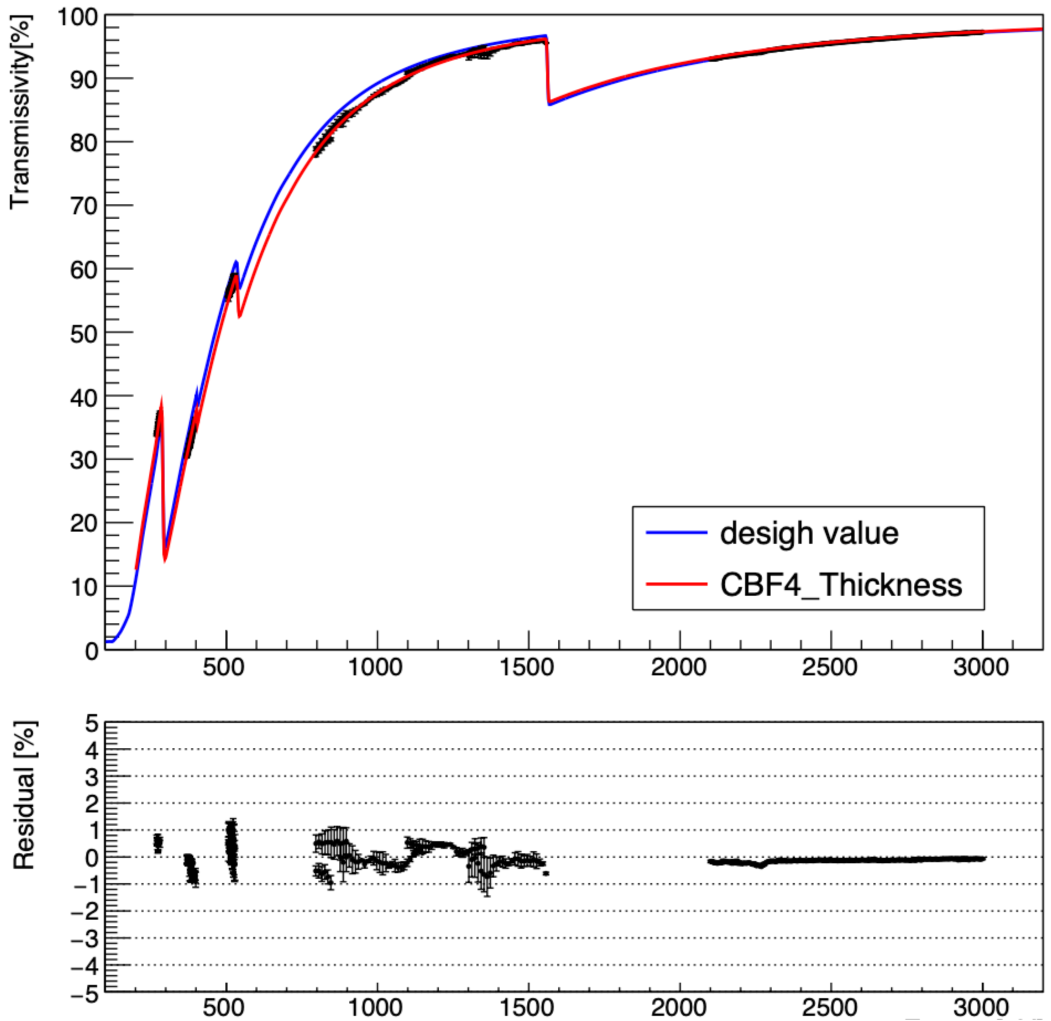


CBF (contam. blocking filter), OBL (optical blocking layer)

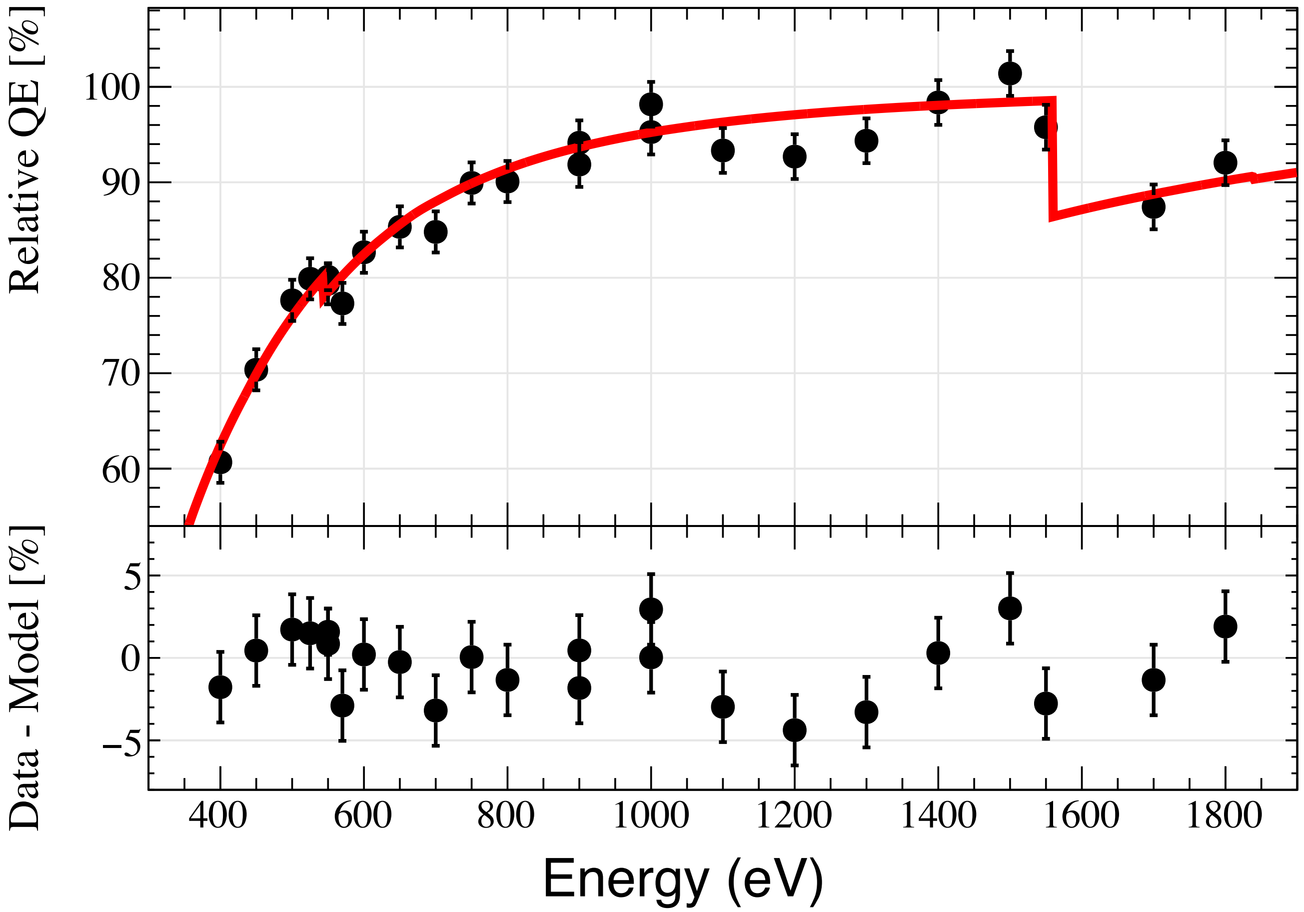
2020–2022



CBF transmissivity vs. energy

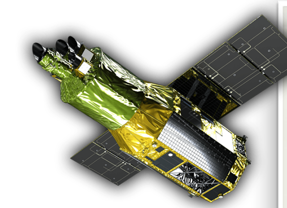


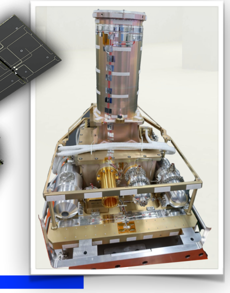
OBL transmissivity vs. energy



- X-ray beam irradiation to determine CBF & OBL thicknesses
- OBL: Al 228±8 nm (~2x Hitomi, as designed)
- CBF: Al 109.8±0.7 nm + Polyimide 238.2±0.5 nm

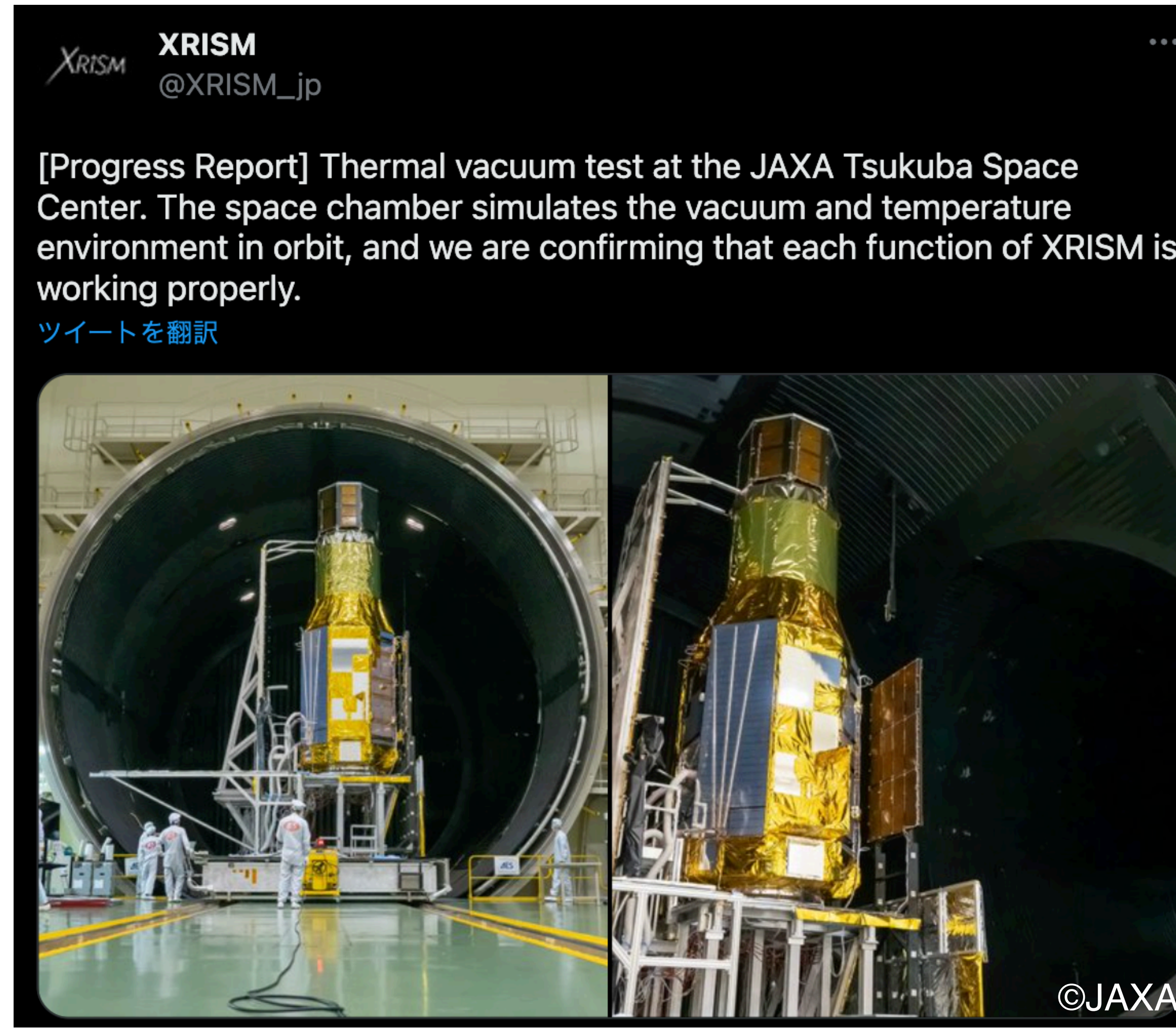
Thermal-vacuum test





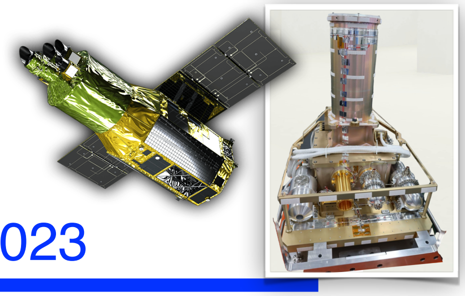
2022–2023

- 2022.08 at Tsukuba Space Center
- Goals of Xtend team
    - Confirm cooling performance
    - Confirm spectroscopic performance
    - Confirm optical blocking performance
    - Optimize charge injection amounts & obs. parameters
    - Nominal operation rehearsal

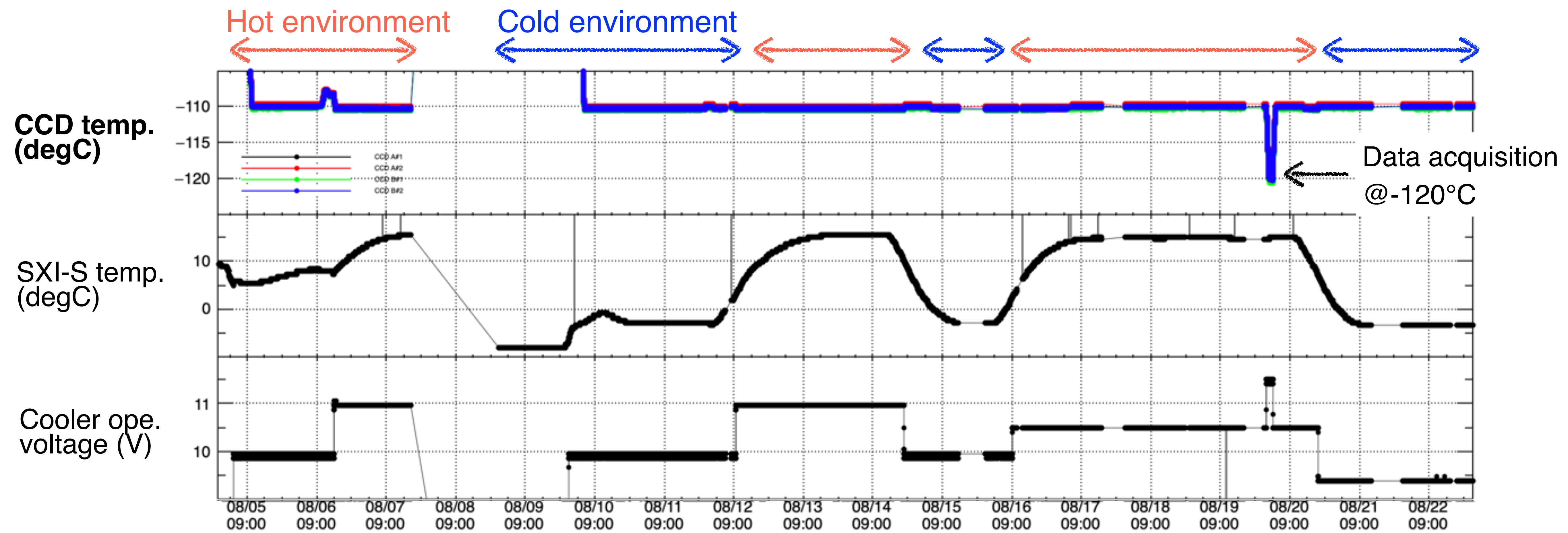


XRISM
X-Ray Imaging and Spectroscopy Mission

Thermal-vacuum test



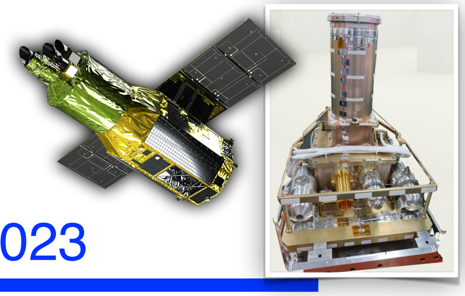
2022–2023

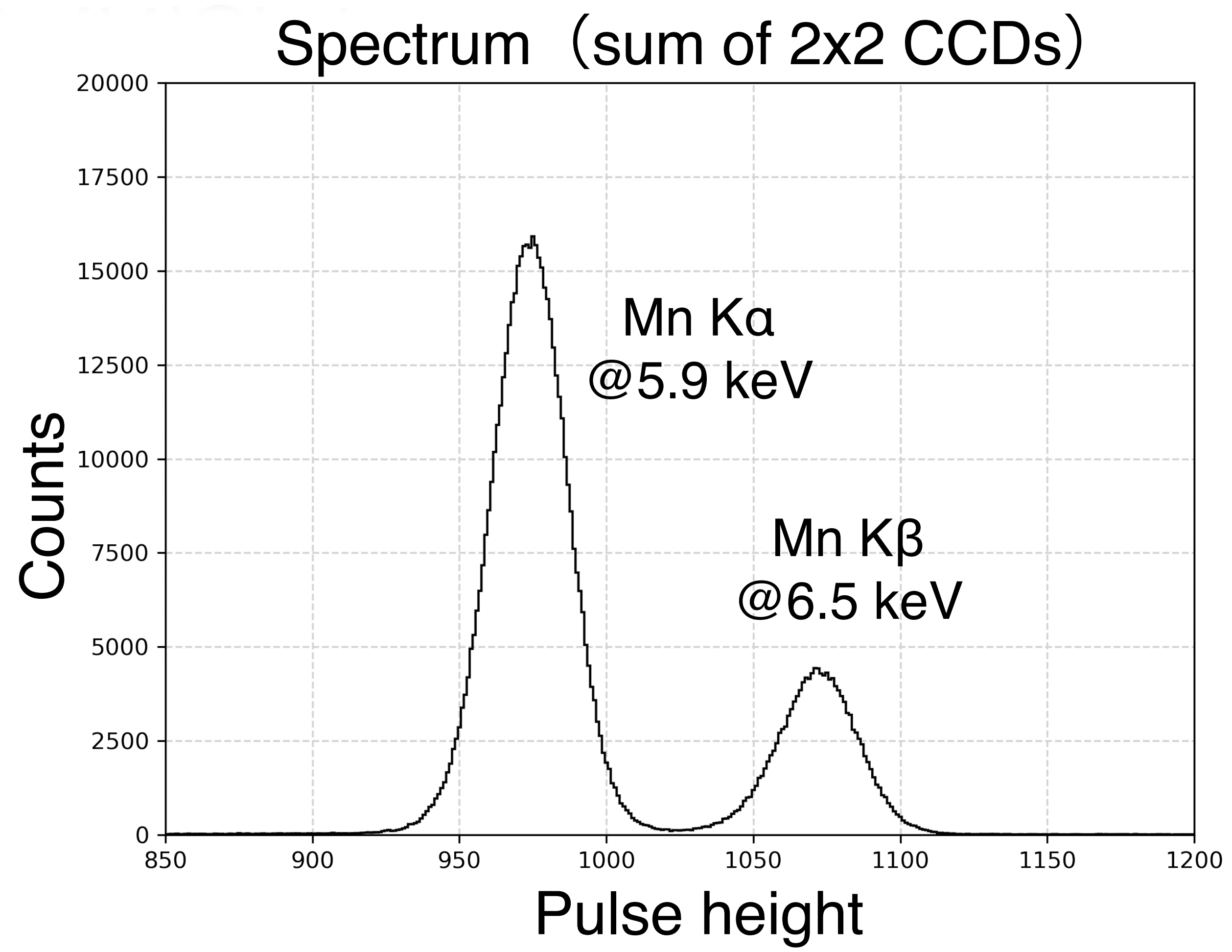


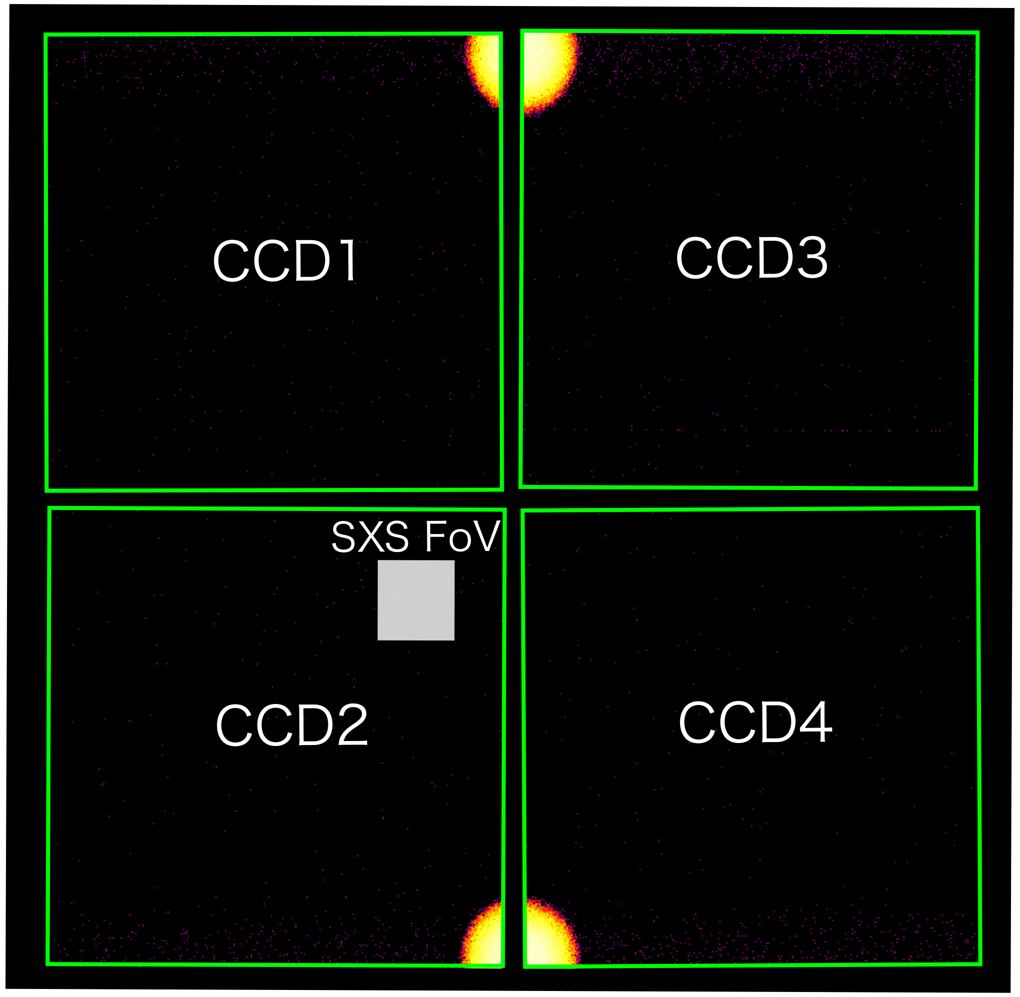
- Confirmed cooling performance
    - cooler & heater
- CCDs can be kept at -110 degC

Thermal-vacuum test

2022–2023



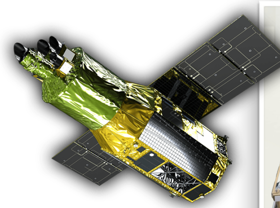
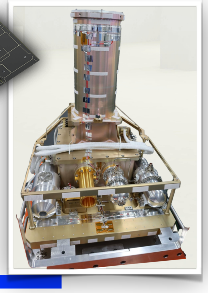




Cal. source ^{55}Fe

- Confirmed spectral performance
- Confirmed RIs' positions & intensities
- Optimized charge injection amounts, event selection parameters
- Performance of 1/8-window mode & 1/8-window+burst also verified

Effective area

X-ray mirror assembly's effective areas

	1.5 keV	6 keV (estimate)	6.4 keV
Measured effective area	590 cm^2	431 cm^2	428 cm^2
Thermal shield transmission	0.906	0.933	0.933
Net effective area	535 cm^2	402 cm^2	399 cm^2

※ values will be slightly updated

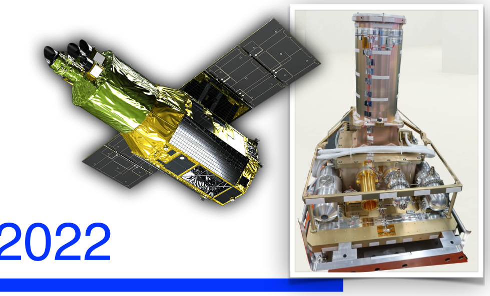
↓ 404 cm^2 (if QE considered)

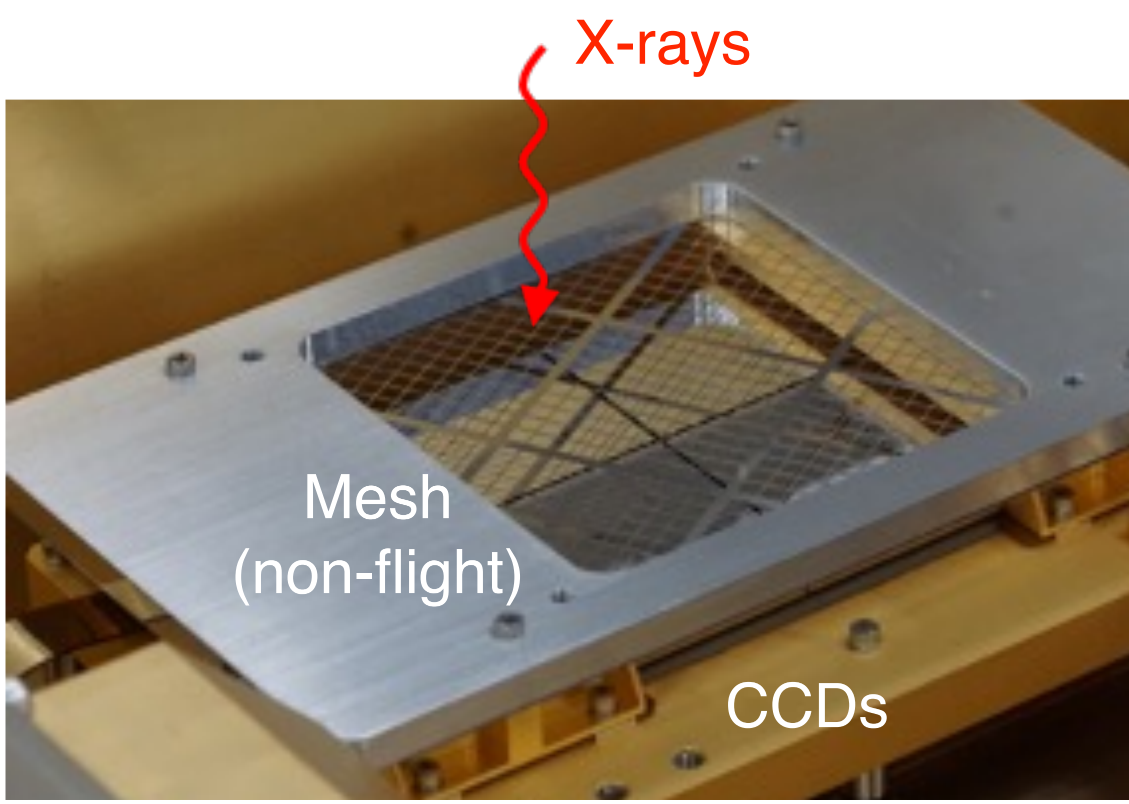
↓ 321 cm^2 (if QE considered)

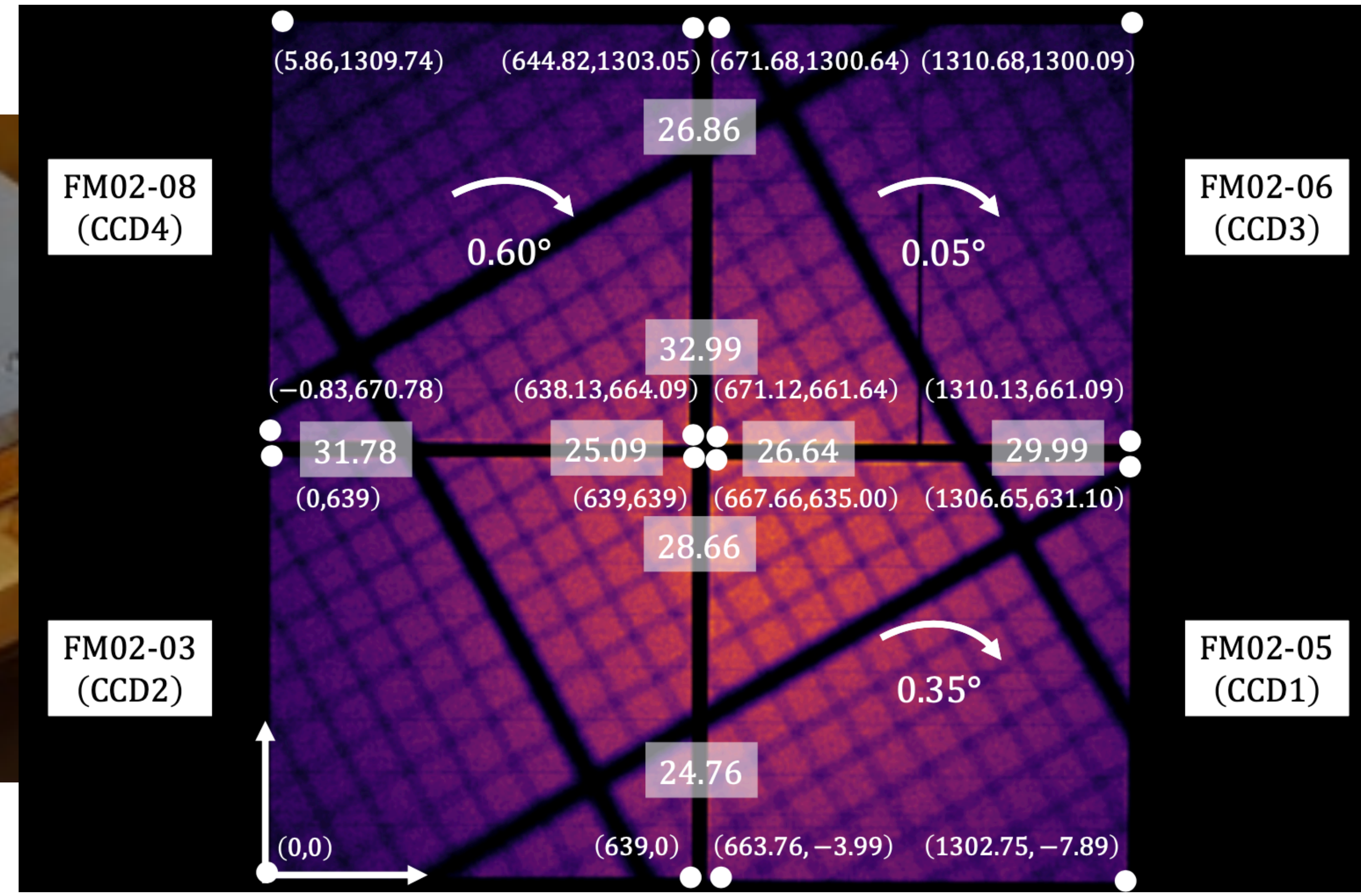
- Satisfy requirements
- Next Hayashi-san's talk

CCD arrangement

2021–2022

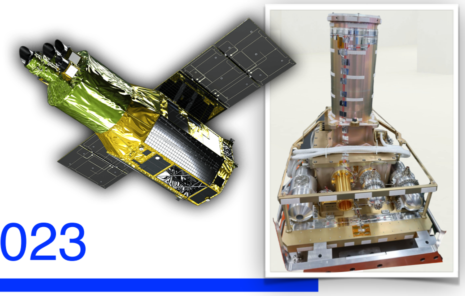


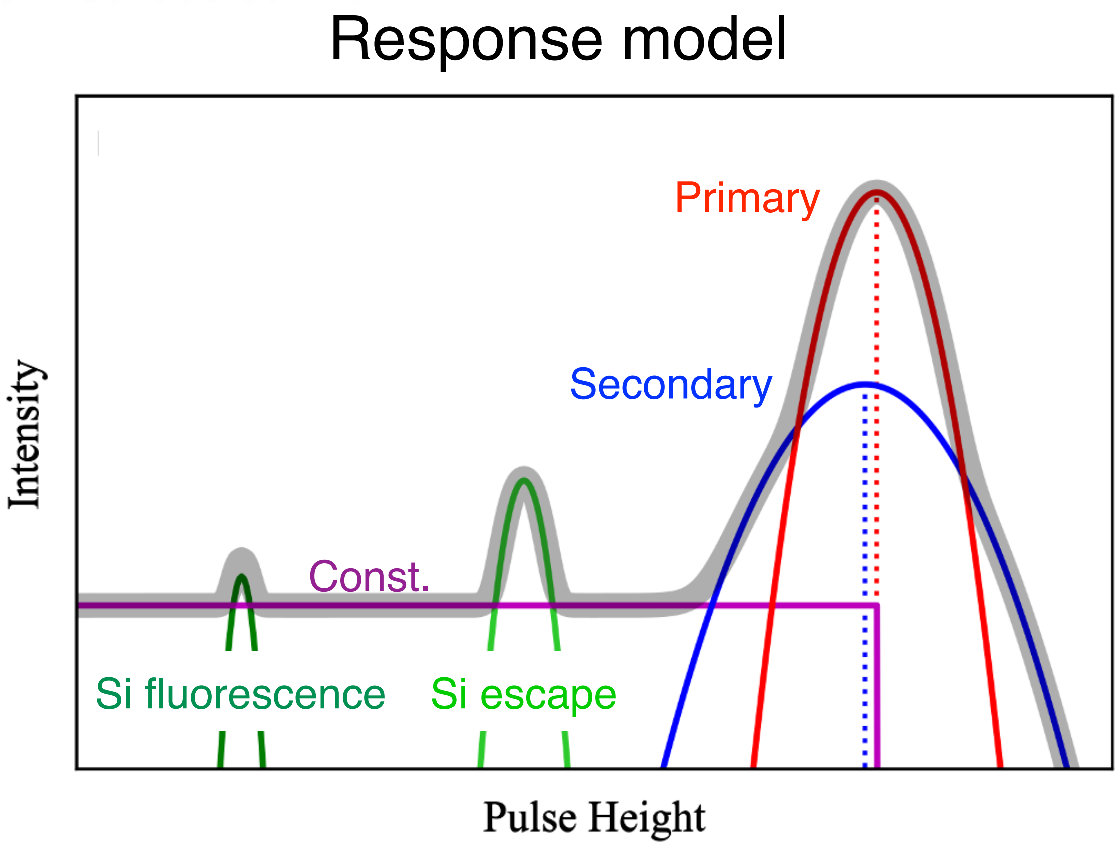


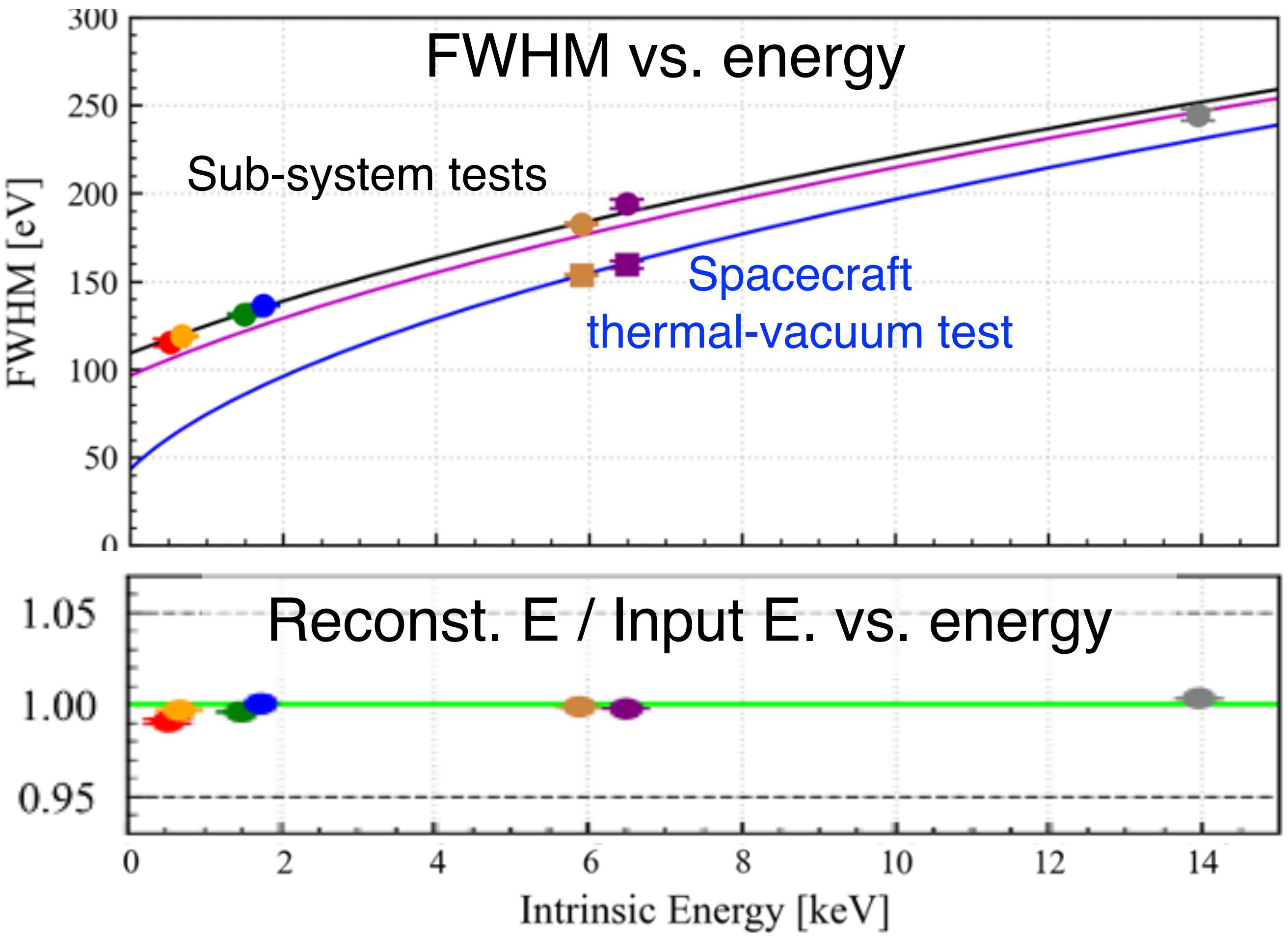


- Relative positions of 2x2 CCDs are measured using non-flight mesh frame
- CCD gaps are 45–60”

CCD response



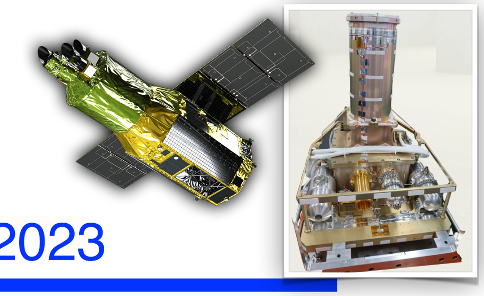




- X-ray line irradiation in 0.5–14 keV
- Response model was constructed based on data from sub-system tests
- and was verified in spacecraft thermal-vacuum test

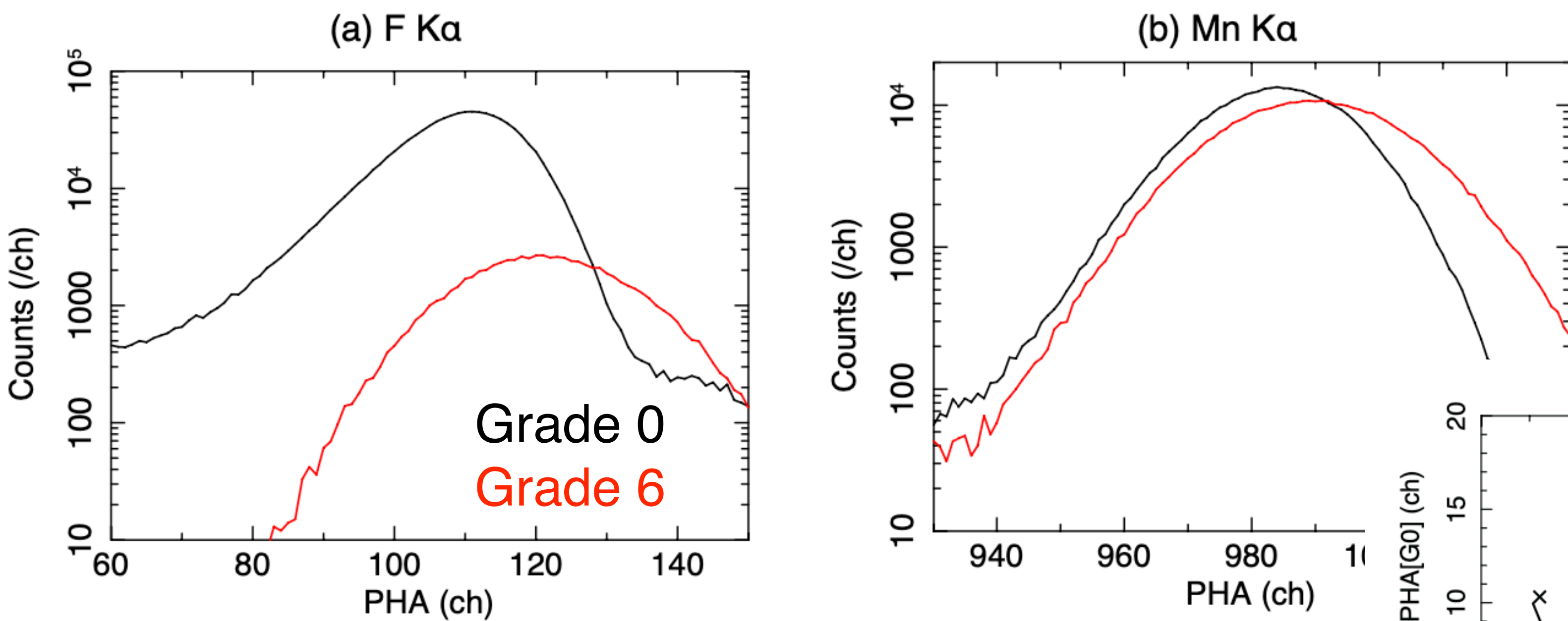
Line	E (keV)
O-Kα	0.5249
F-Kα	0.6768
Al-Kα	1.4866
Si-Kα	1.7398
Mn-Kα	5.89505
Mn-Kβ	6.4904
Np-Lα	13.95

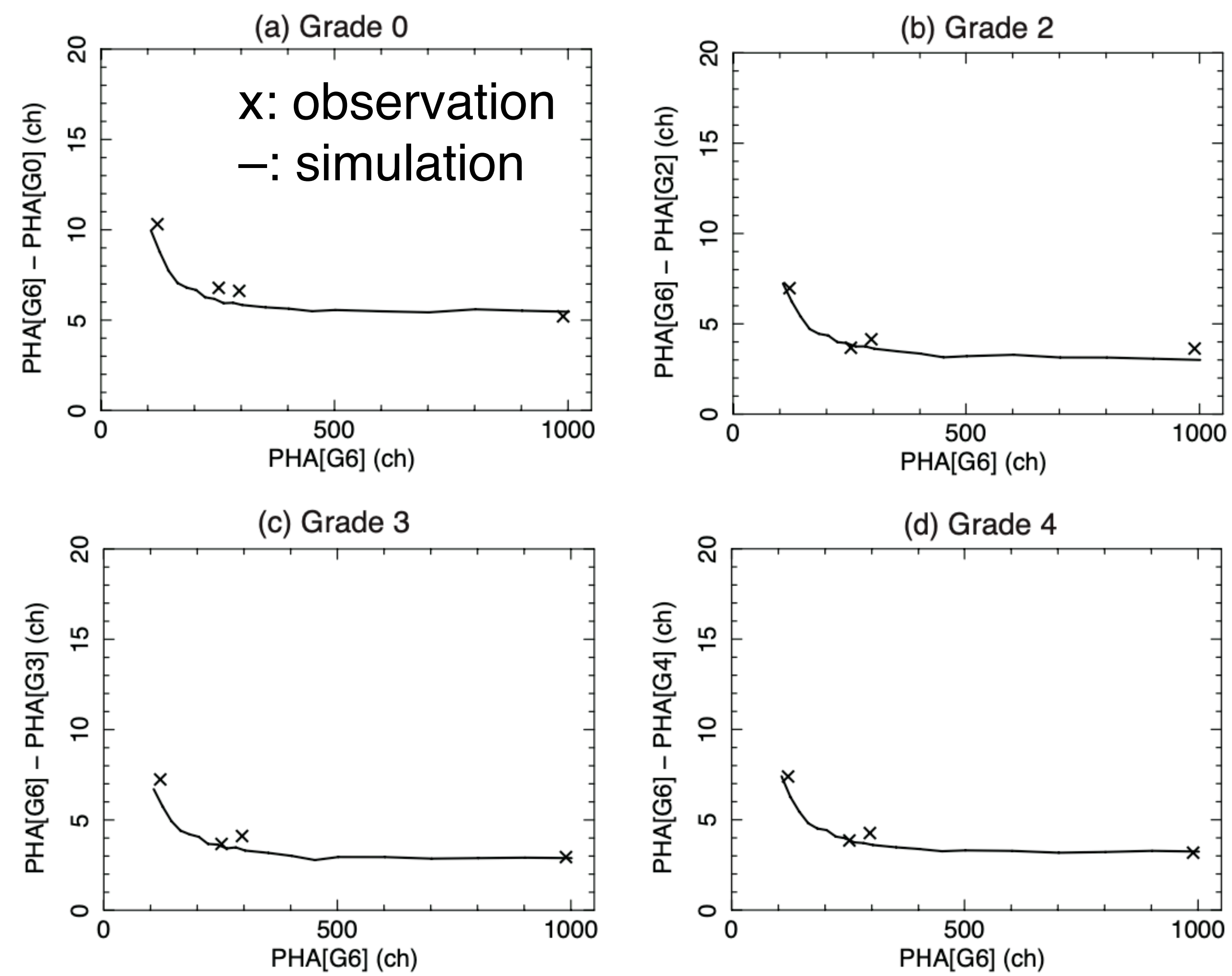
CCD response



2019–2023

(Aoki et al. 2023)

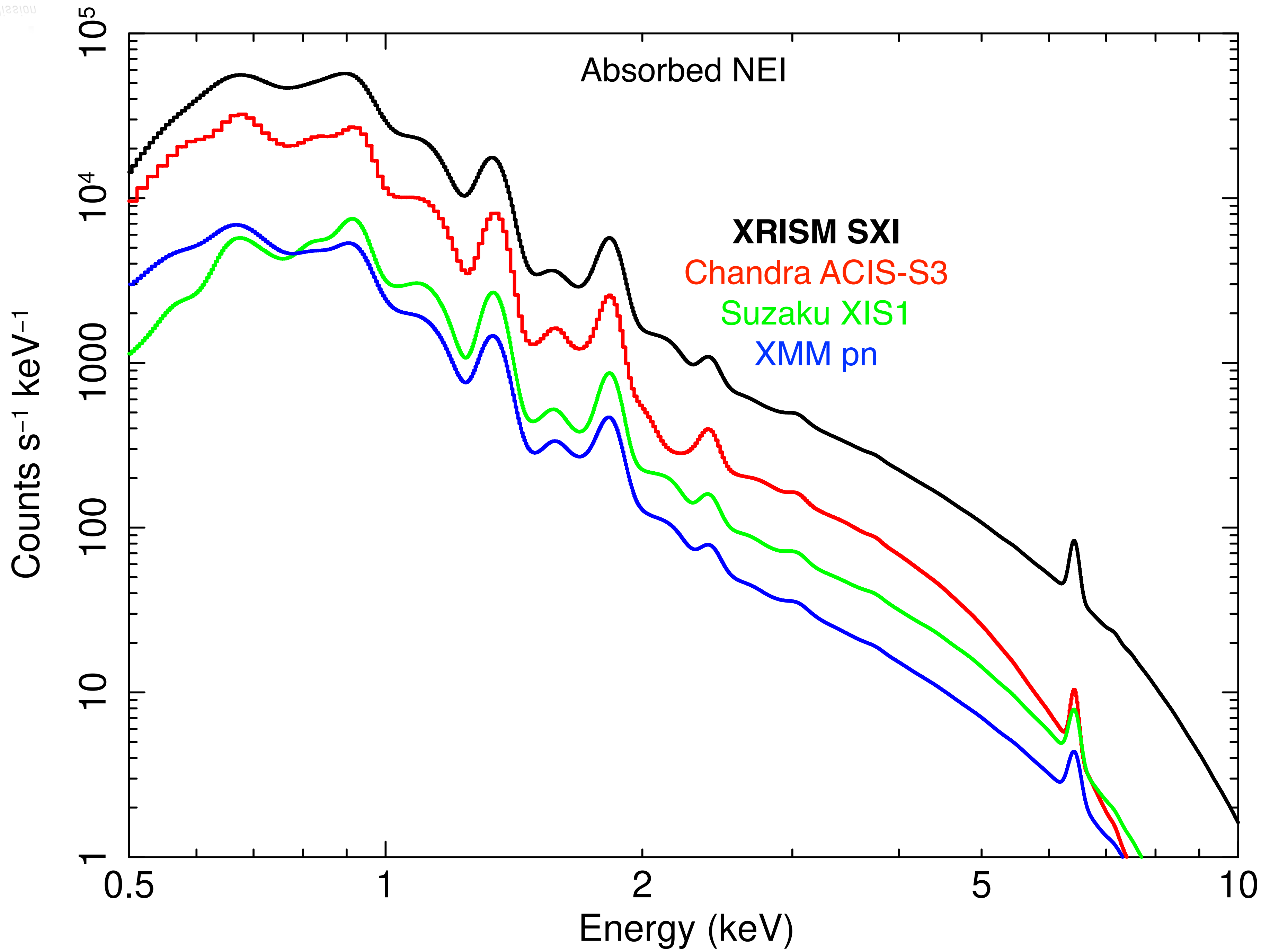




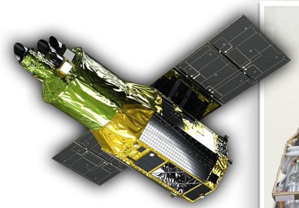
- E centroids differ between different grades
- Explained with charge sharing & noise by comparing observations & simulations

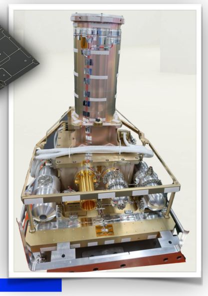
CCD response

2019–2023



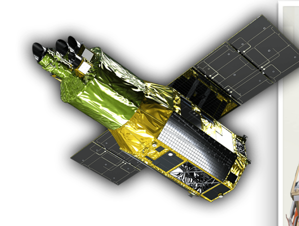
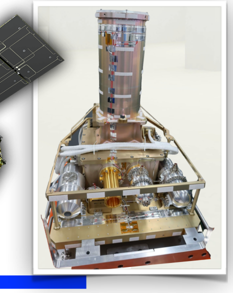
- Comparison of spectral shapes (normalizations are arbitrary)
- Moderate energy resolutions at low energies





Summary

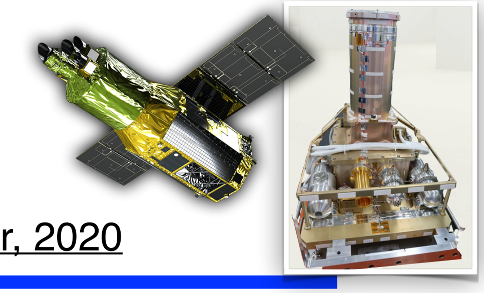
- On-ground calibration of XRISM Xtend has been completed
- Experiments and analyses were done from 2018 to 2023
- Verifications & optimizations included…
    - radiation tolerance
    - modeling CTI (charge transfer inefficiency) correction
    - optical blocking performance
    - quantum efficiency
    - cooler & heater health
    - spectral performance
    - CI (charge injection) amount
    - RI position & intensity
    - nominal operation rehearsal
    - effective area
    - CCD arrangement
    - CCD response

References

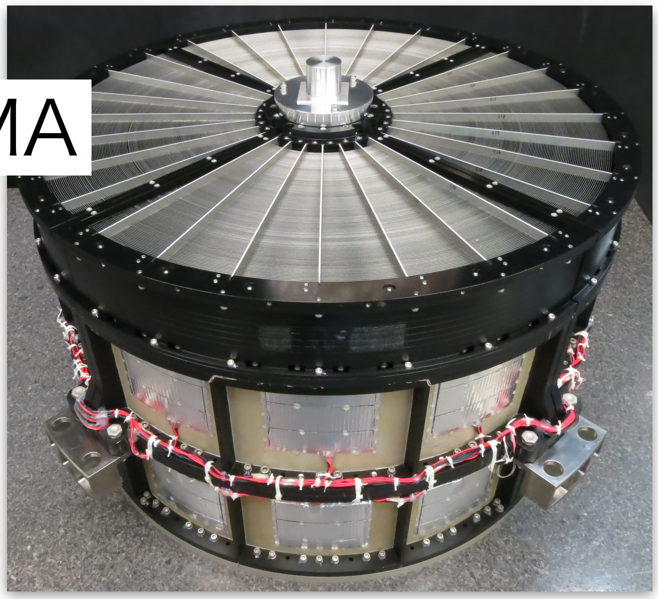
- CTI　Kanemaru et al. 2019, 2020
- light leak　2019-081, Uchida et al. 2020
- CBF　2021-26
- OBL, depletion layer　2022-072
- Thermal vacuum test
    - 1ST health
    - delta E
    - CI
    - nominal operation test
    - light leak
    - RI
- effective area　RPT-0152
- teldef　2022-018
- Grade branching ratio　2023-017
- CCD image anomaly　many
    - countermeasure test
    - possible causes
- CCD response　2022-111, Ode M-thesis, Aoki et al. 2023

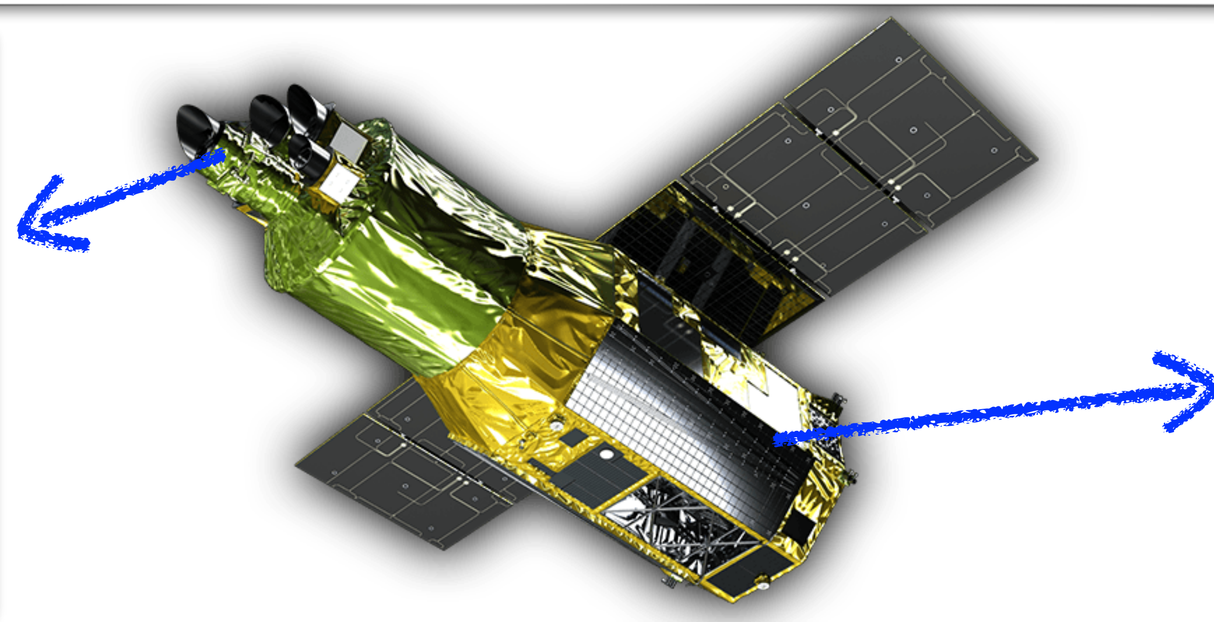
XRISM Xtend

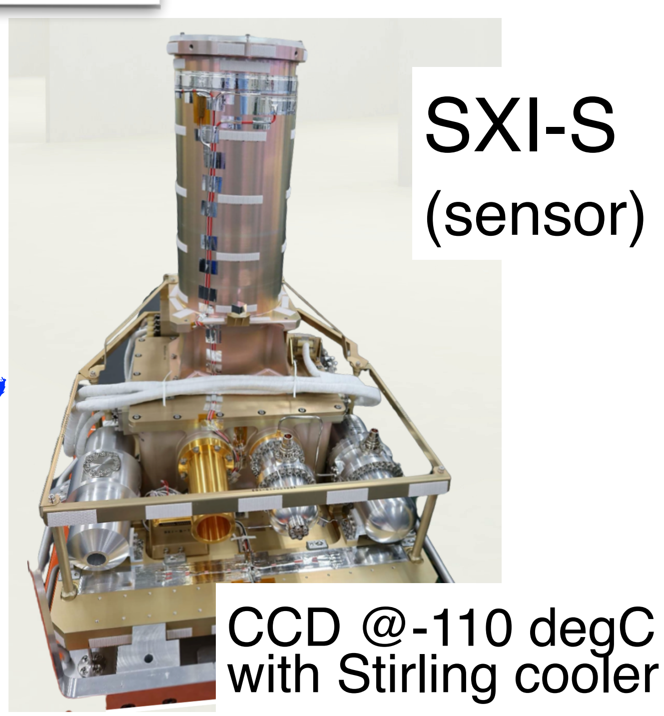


XRISM white paper, 2020

Xtend = XMA (X-ray Mirror Assembly) + SXI (Soft X-ray Imager)



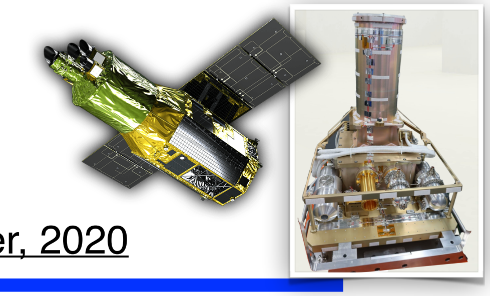




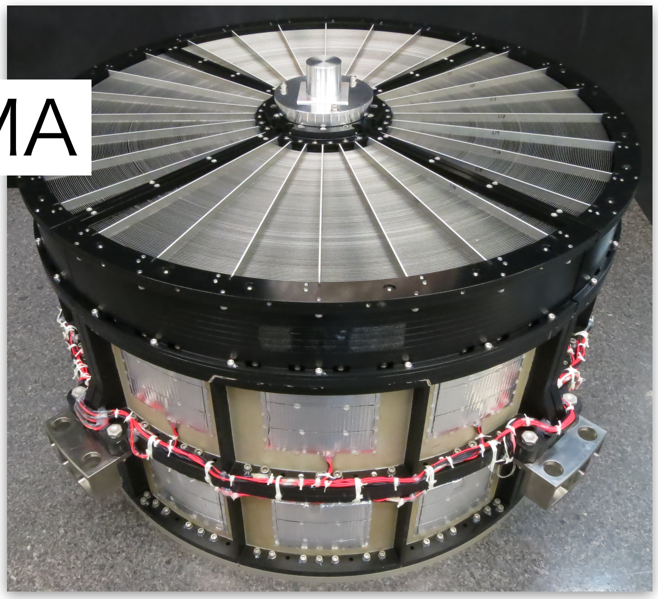
- **XMA** : Wolter type I mirror optics
  - ✓similar to Hitomi SXT
- **SXI** : X-ray CCDs
  - ✓similar to Hitomi SXI
  - ✓fully-depleted back-illuminated P-channel CCD
- Energy range : 0.4–13 keV
- FoV : 38’ × 38’
- Energy resolution : < 200 eV @5.9 keV
- Ang. resolution : < 1.7’ (Half Power Diameter)

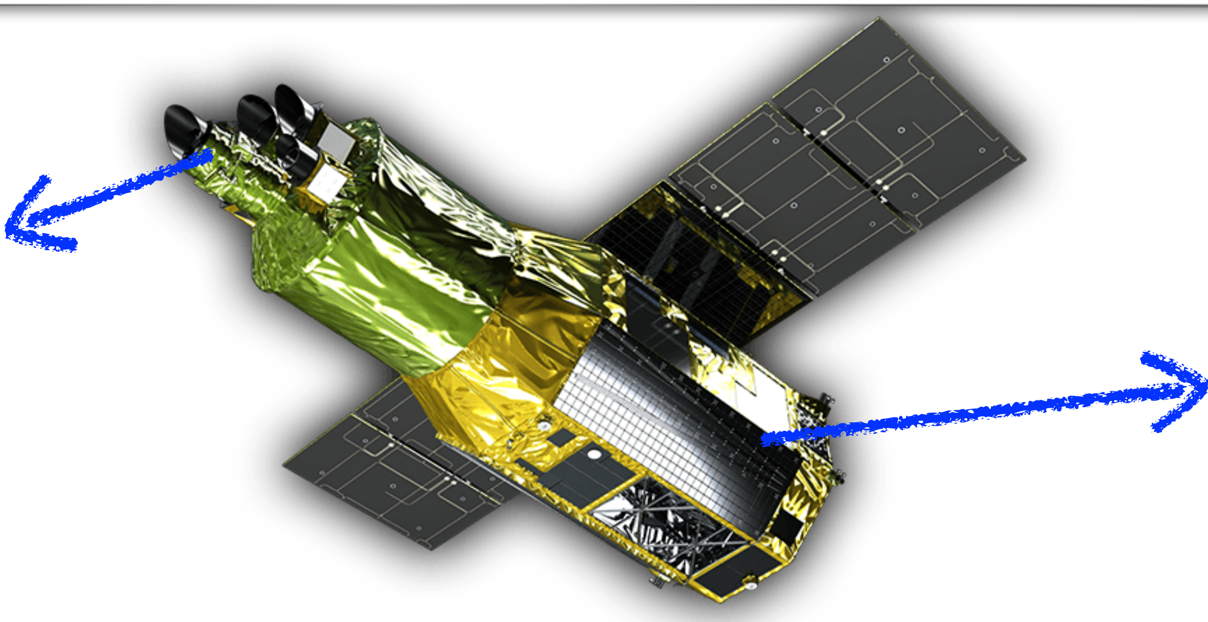
XRISM Xtend

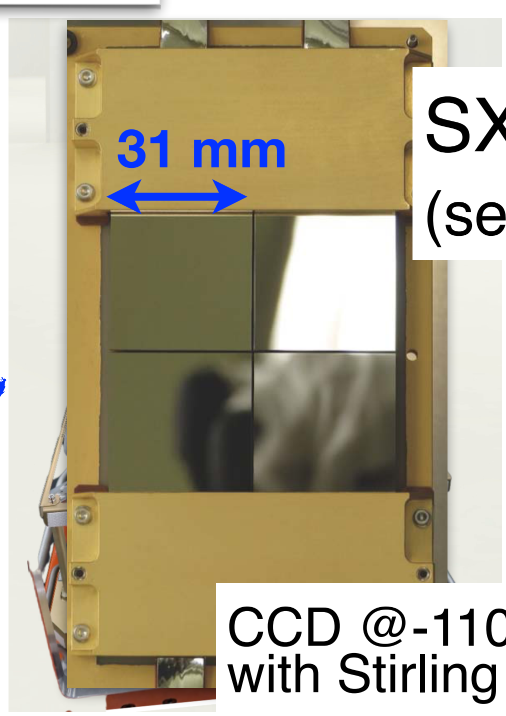
XRISM white paper, 2020



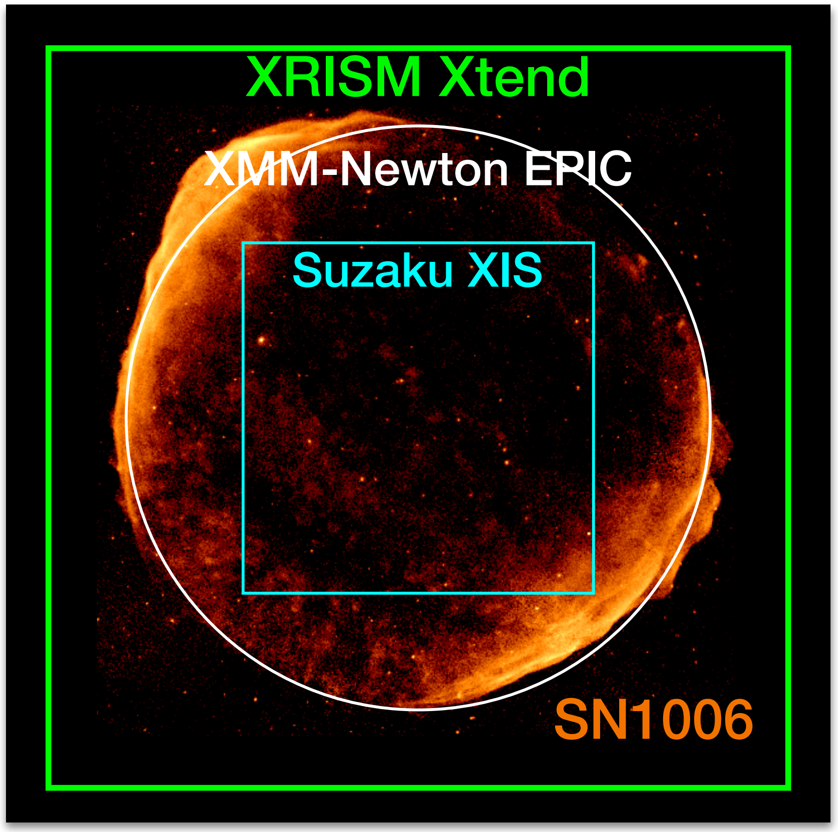
Xtend = XMA (X-ray Mirror Assembly) + SXI (Soft X-ray Imager)





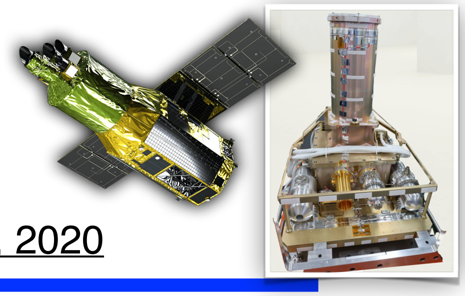


- **XMA**：Wolter type I mirror optics
  - ✓similar to Hitomi SXT
- **SXI**：X-ray CCDs
  - ✓similar to Hitomi SXI
  - ✓fully-depleted back-illuminated P-channel CCD
- Energy range：0.4–13 keV
- FoV：38’ × 38’
- Energy resolution：< 200 eV @5.9 keV
- Ang. resolution：< 1.7’ (Half Power Diameter)

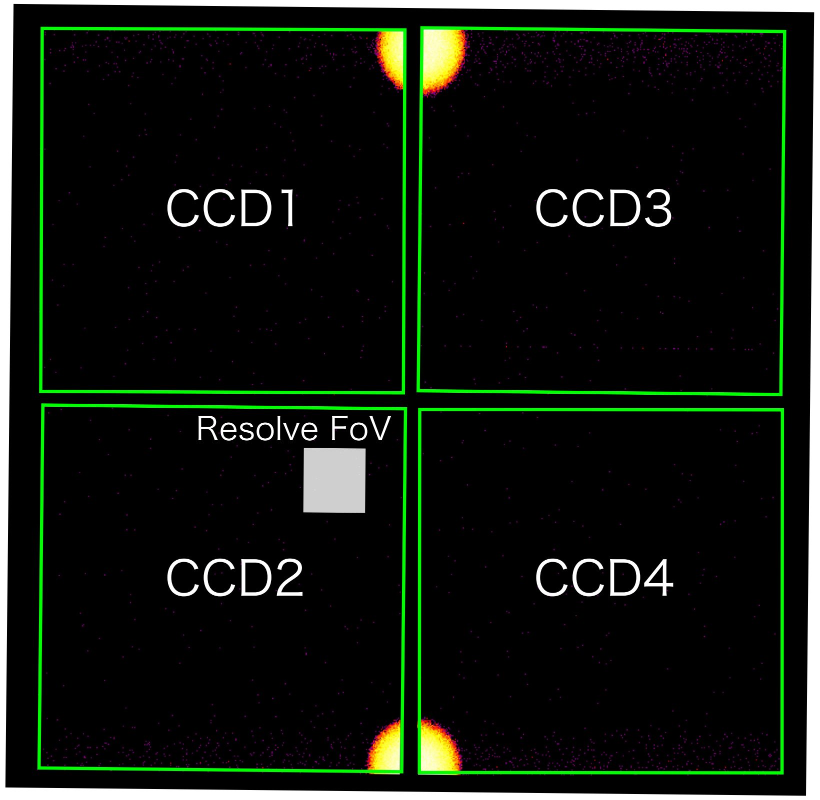


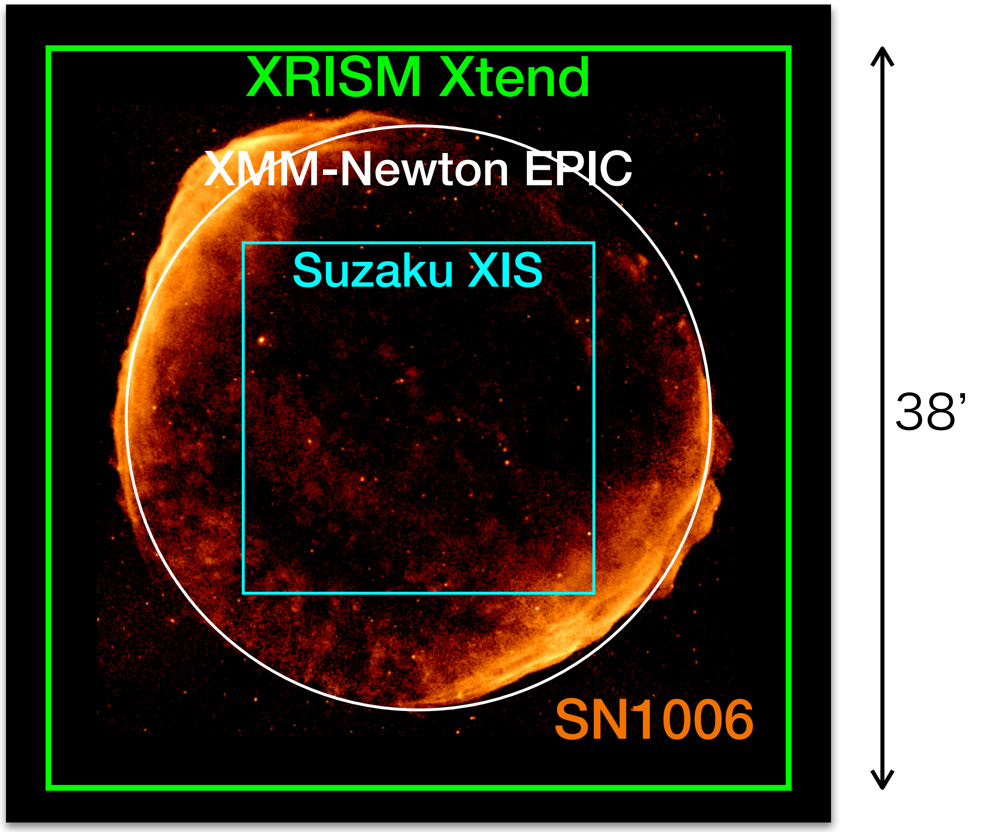
Roles of Xtend

XRISM white paper, 2020

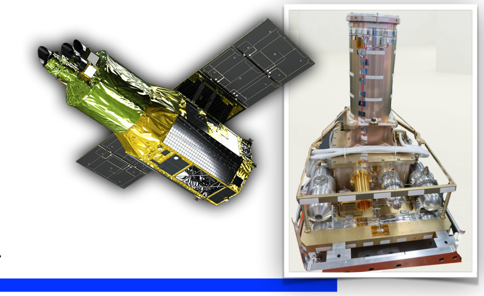


- **Monitor large area around Resolve FoV**
  → Clarify contribution of sources around target
    - sky background
    - contribution of other bright sources
- **Xtend itself will produce scientific achievements**
    - CCDs' good energy resolution
    - Low & stable detector background similar to Suzaku XIS/Hitomi SXI
    - 2x larger FoV than XMM-Newton



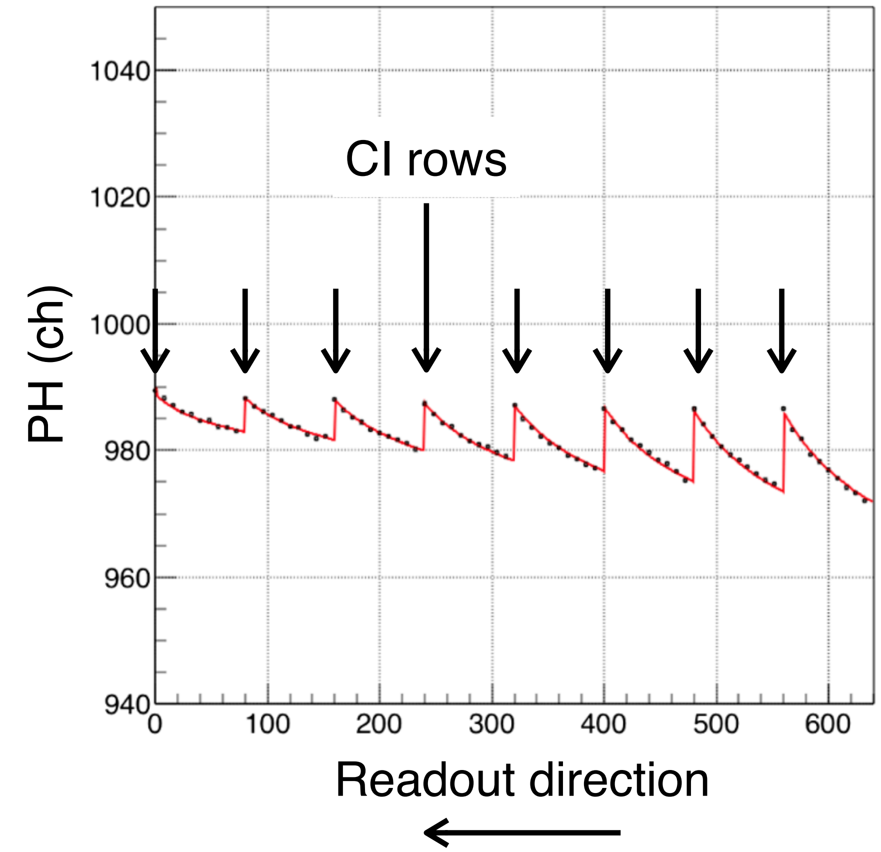


CCDs of SXI

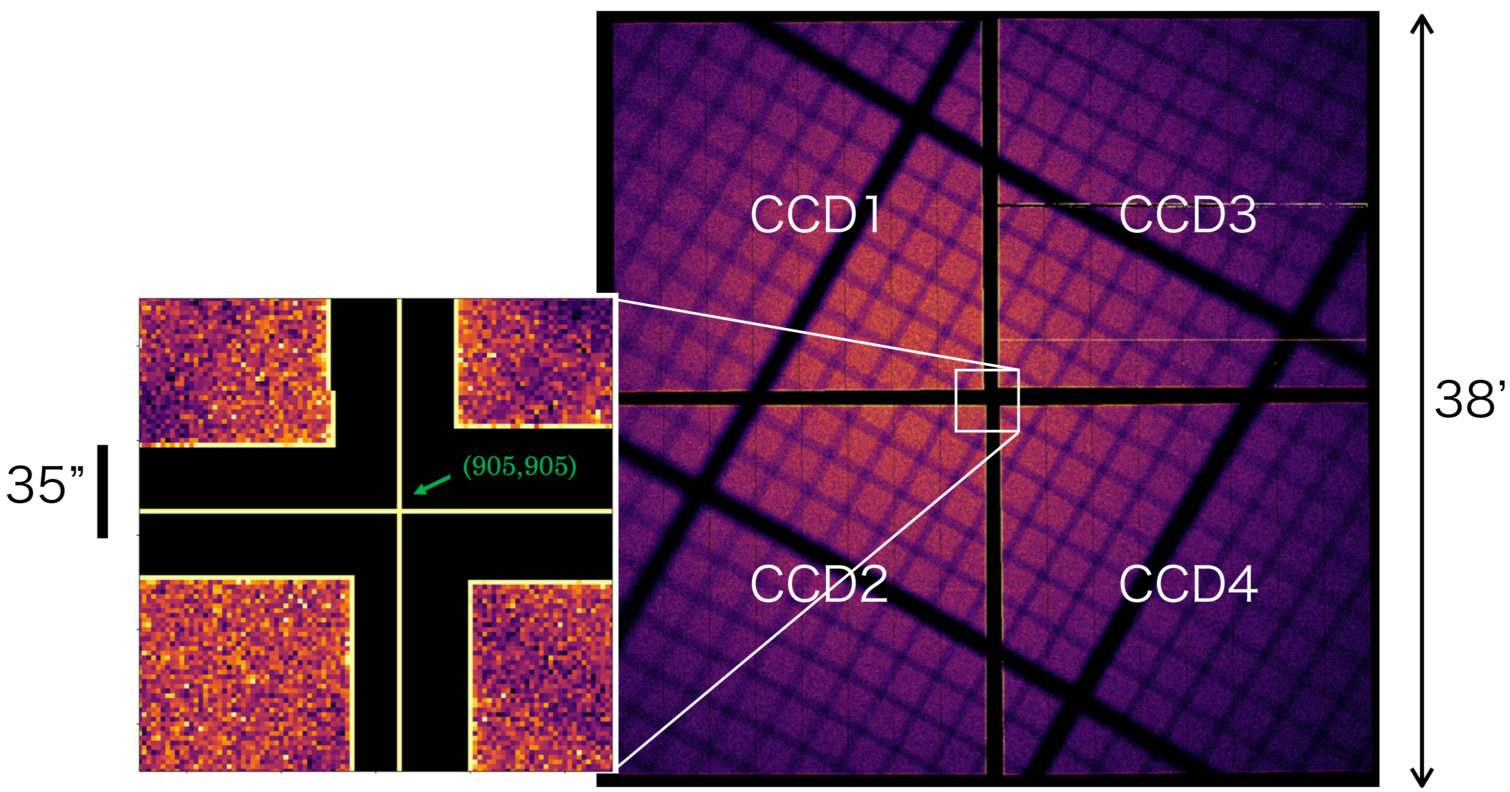


Tanaka et al. 2018

- Frame exposure time: 0.06–3.96 sec (depends on obs. modes)
- Charge Injection (CI) technique:
  - give artificial charges to minimize charge transfer inefficiency
  - similar to Suzaku XIS/Hitomi SXI

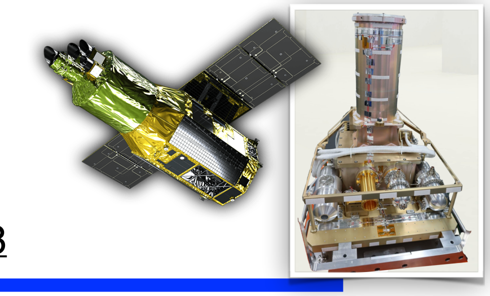


- Mind the gaps between CCDs!!
  - 40”–60”
  - Point sources may fall into the gaps



Observations

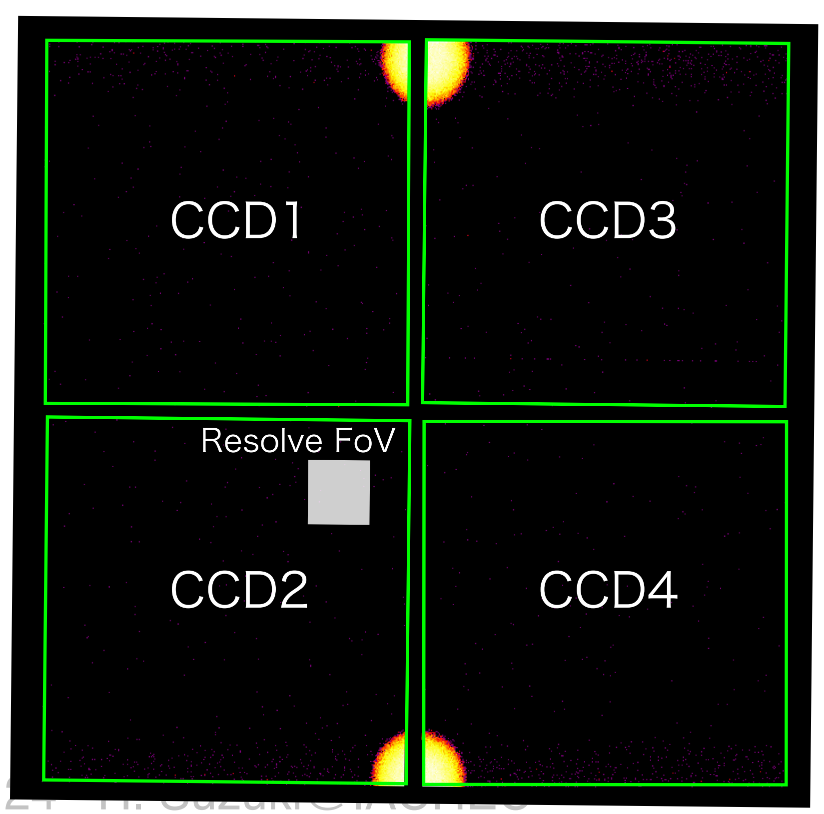
Tanaka et al. 2018

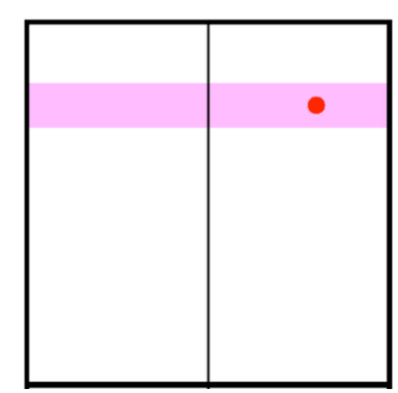


- Observation modes

Mode	Region size	Frame exposure	Time resolution	Live time fraction	Purpose
Full window	1	4.0 sec	4.0 sec	~1	General
1/8 window	1/8	0.46 sec	0.46 sec	~1	Bright/variable sources (against pile-up, etc.)
1/8 window + 0.1-s burst	1/8	0.06 sec	0.46 sec	0.13	Bright/variable sources (against pile-up, etc.)
0.1-s burst	1	0.06 sec	4.0 sec	0.015	Crab mode, not for users

* 1/8 win. & burst: only applied to CCDs 1 & 2 (i.e., CCDs 3 & 4 are Full win.)

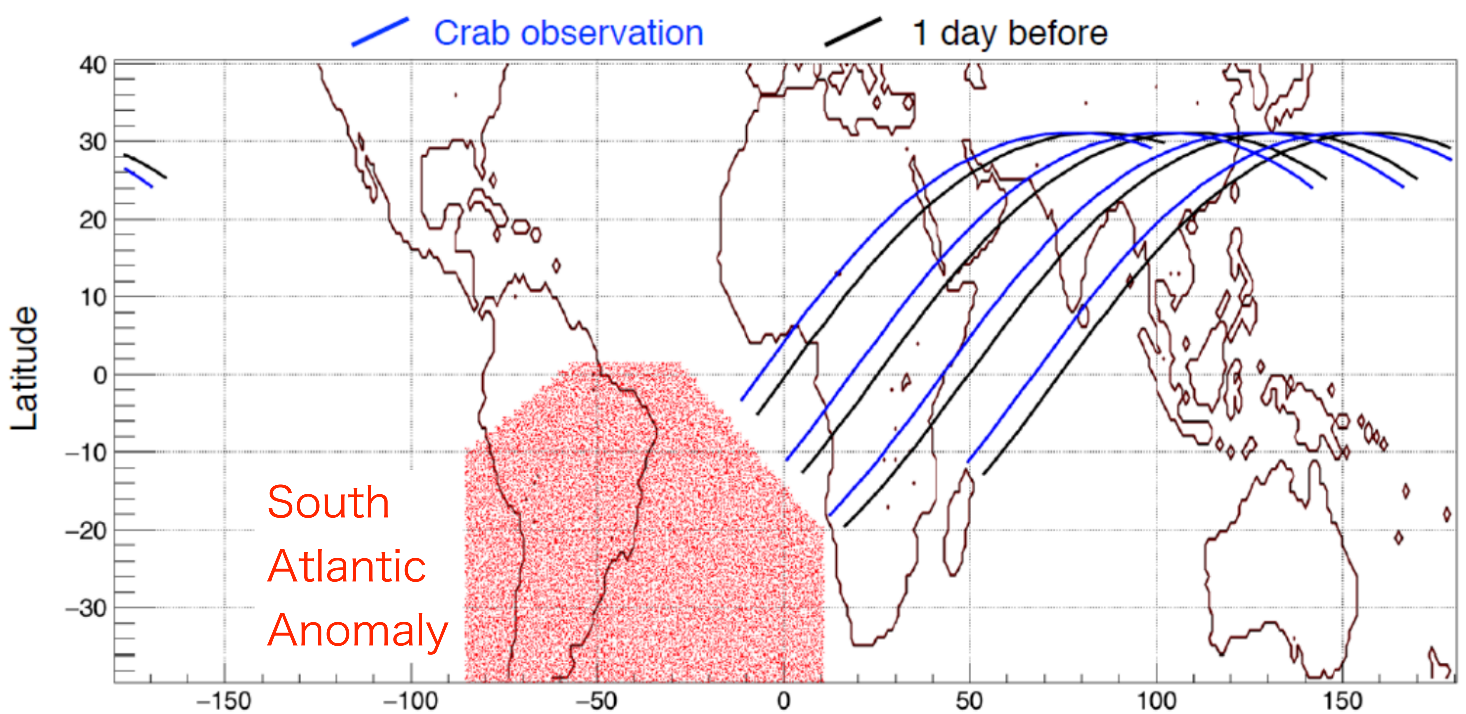




1/8 window

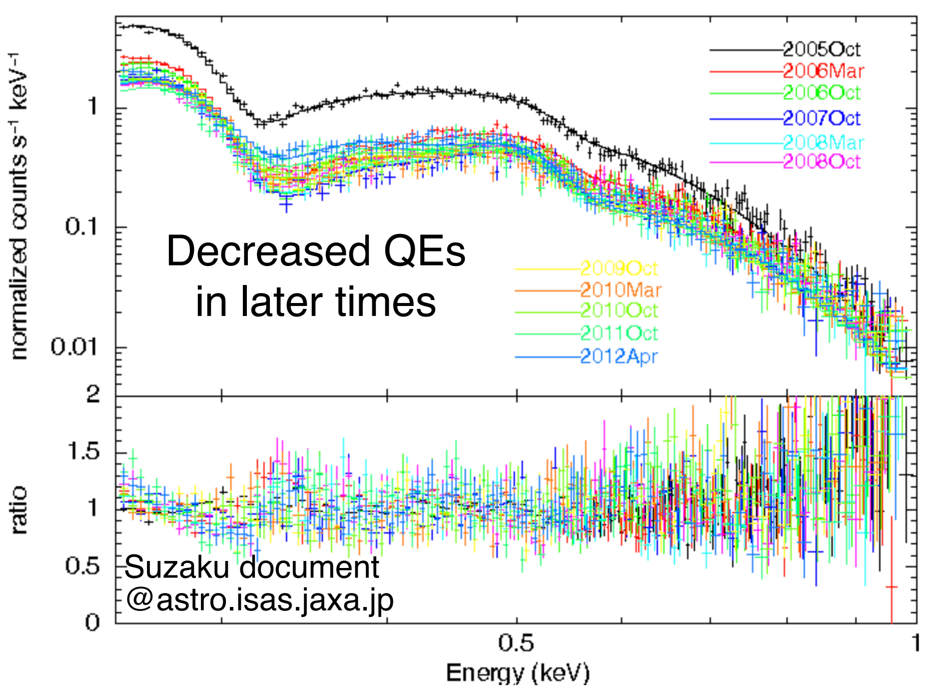
Observations

- Observation efficiency in low earth orbit
  - Earth occultation & day earth give dead times (~50%)
- Degradation of CCDs
  - Increasing Charge Transfer Inefficiency, bad pixels due to radiation
  - Increasing contamination due to outgas = lower quantum efficiencies in low energies



Hitomi collaboration 2018

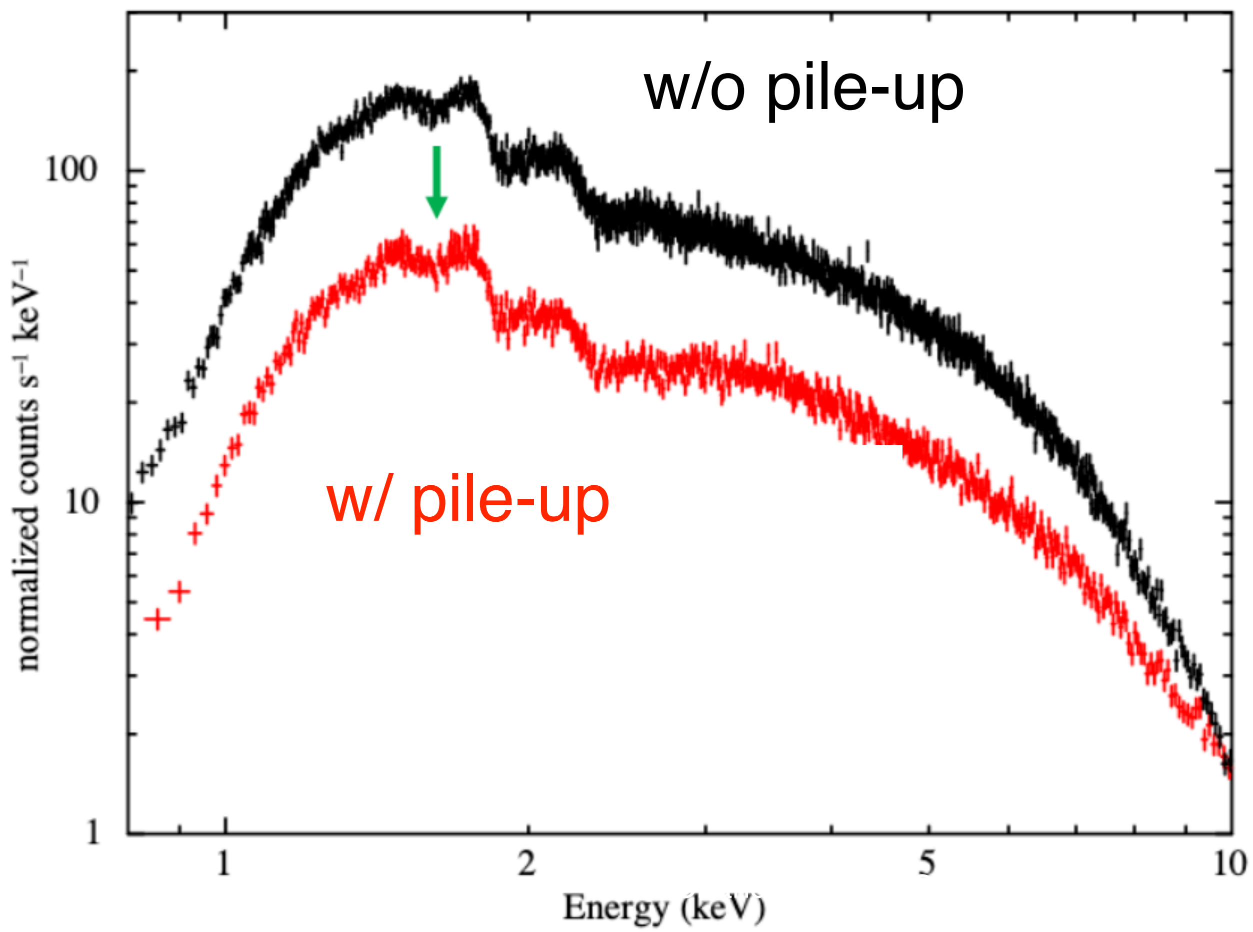
RXJ1856 with Suzaku XIS1



Observing bright point sources

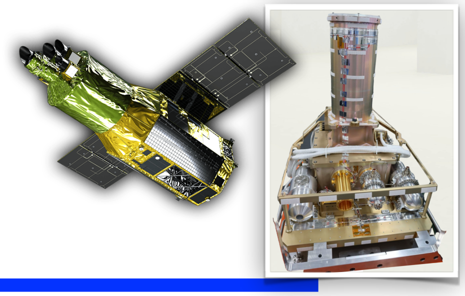
Tamba et al. 2022

- Consider pile-up of photons
- In Xtend, this happens if sources brighter than ~1 mCrab
- Choose suitable obs. mode to avoid pile-up
    - ~1/8 photons if 1/8 window mode, ~1/70 if window-burst mode
- Pile-up estimator will be provided to observers
    - i.e., choose target’s flux & power-law index → check pile-up

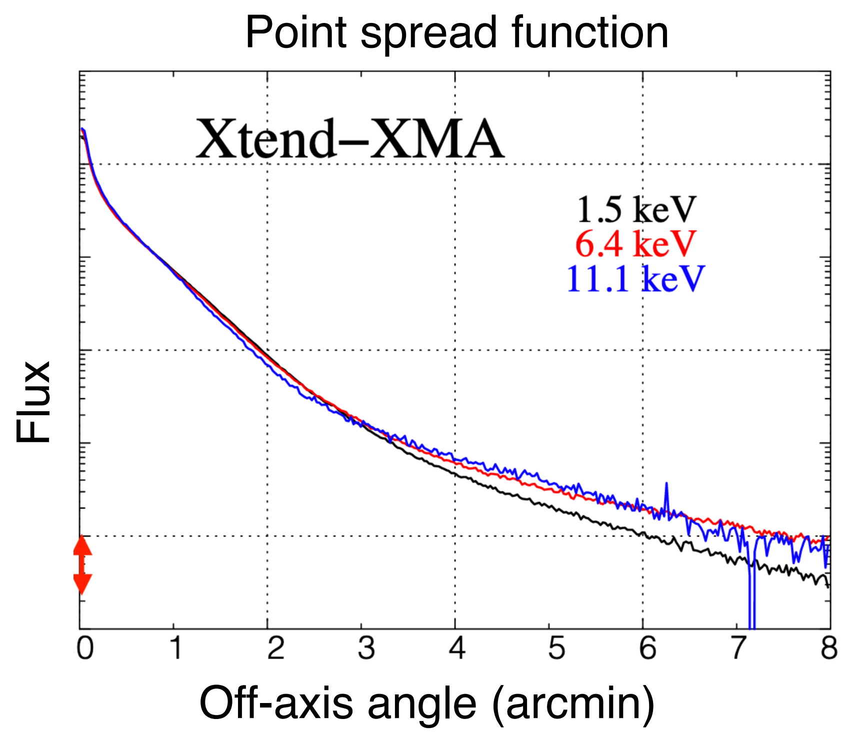


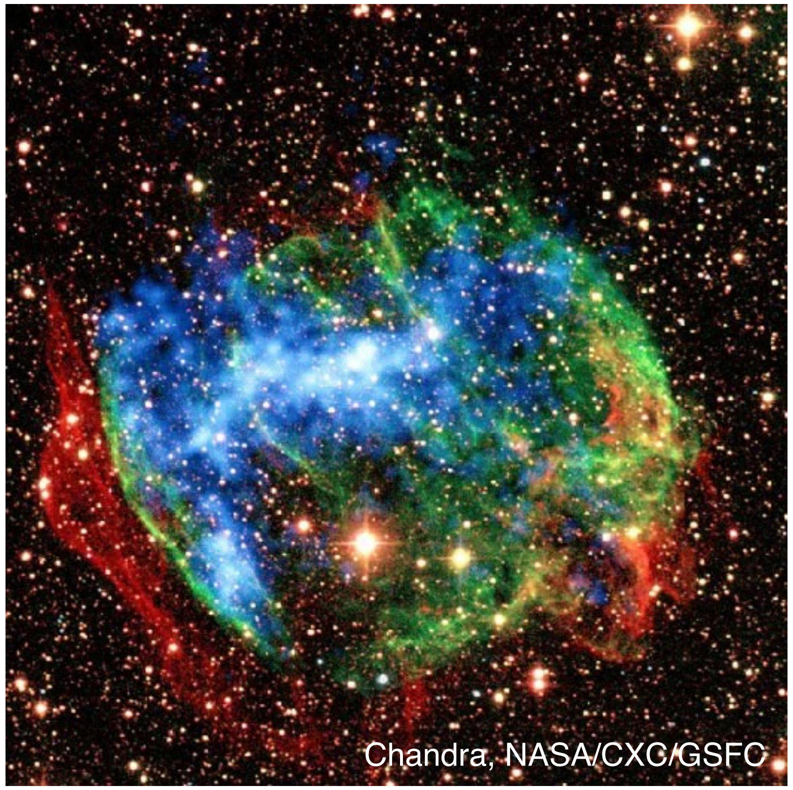
(0.5 Crab, 8 sec frame exposure)

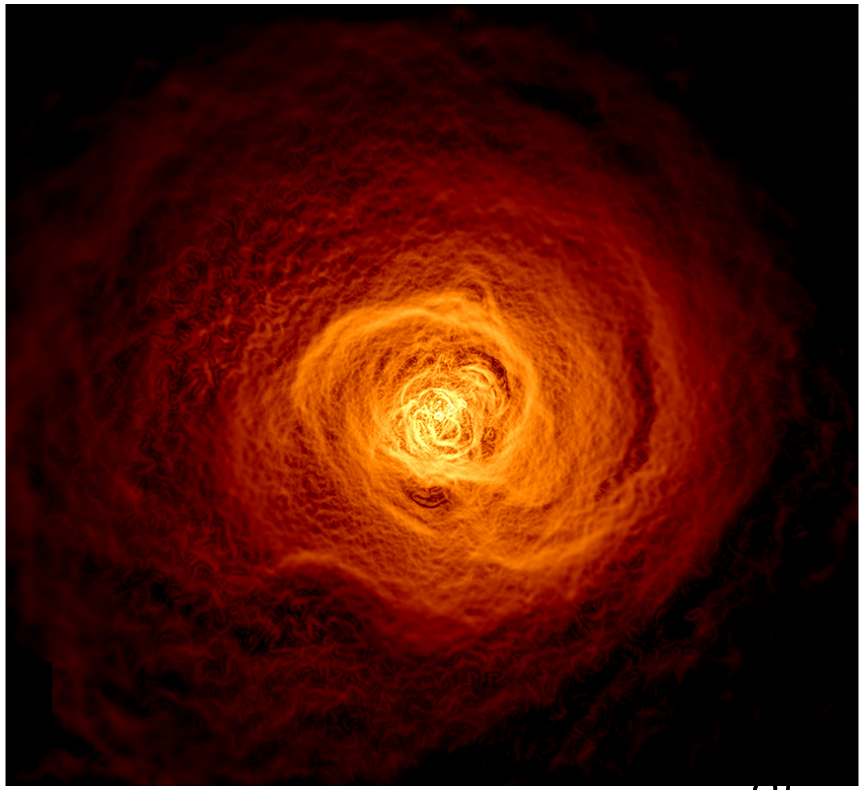
Observing extended sources



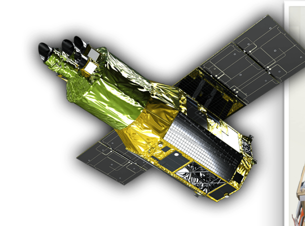
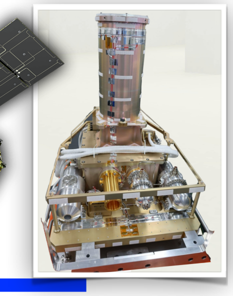
- Consider…
  - Bright sources around the target
  - Sky / detector backgrounds affect more than for point sources







Analysis procedure

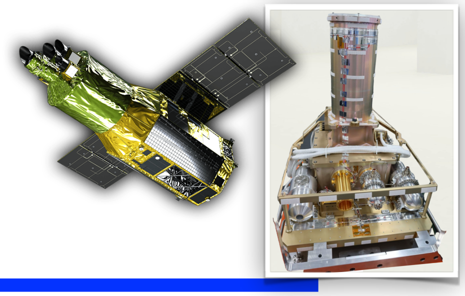



Refer to Hitomi Analysis Guide, Step-by-Step guide
Will be updated for XRISM

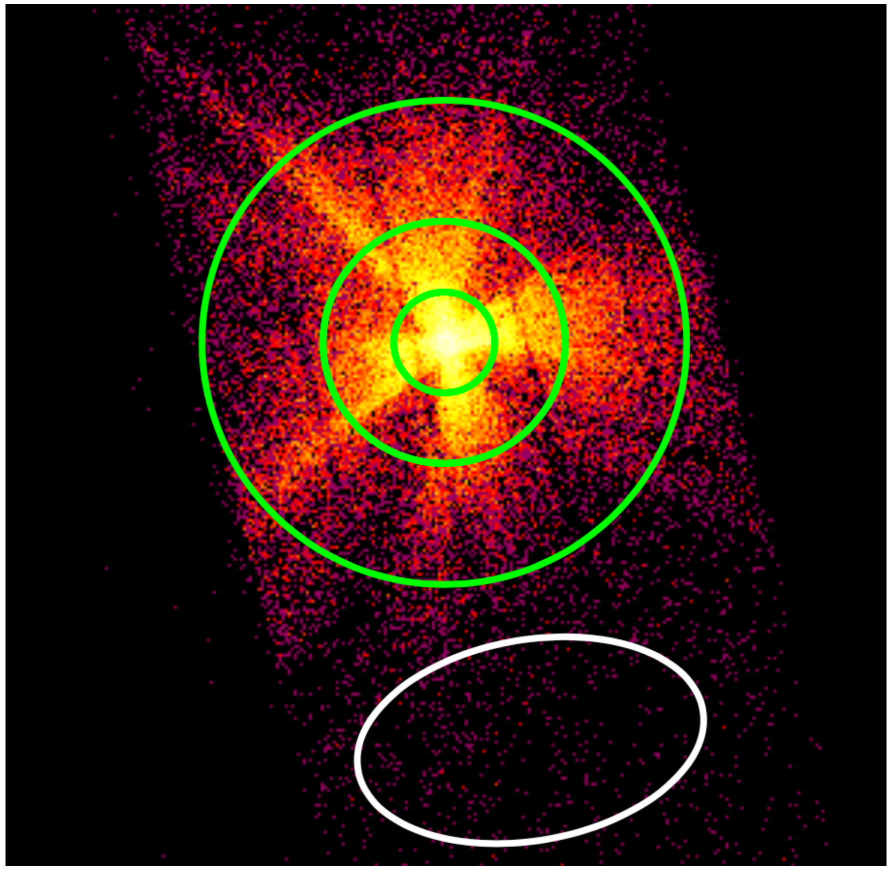
- Similar to Suzaku XIS & Hitomi SXI

1. Reprocess data with latest CALDB (`xapipeline`, `xtdpipeline`)
2. Extract image, spectrum, light curve (`xselect`, `fselect`, astropy, etc.) with more filtering if needed (good time intervals, attitudes, etc.)
3. Make response files for spectral studies (`xtdrmf`, `xaexpmap`, `xrtraytrace`, `xaarfgen`)
4. Other procedures (`barycen`, detector background (`xtdnxbgen`), etc.)
5. Enjoy imaging/spectral/timing studies!!

Analyzing bright point sources

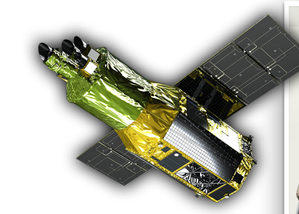


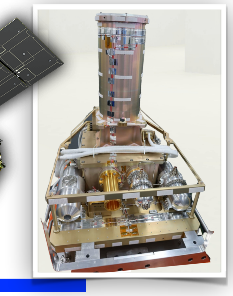
- If so bright that pile-up affects data…
  - first try to avoid this!! but sometimes need good statistics, data might unluckily affected by solar flares, …
  - conventional "core exclusion" method still is a good way
  - simulator-based method is another option, but will not generally provided to users Tamba et al. 2022



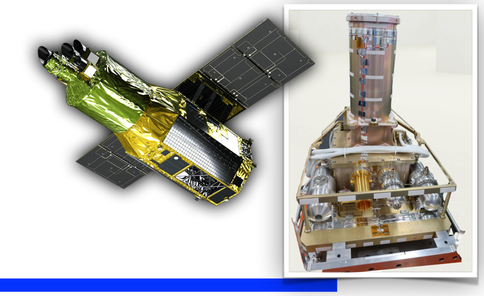
Analyzing extended sources

- Both source & background should be stable… but check light curves!!
- Detector background (similar to Suzaku XIS/Hitomi SXI)
  → Following pages
- Sky background
  - Many contribute, many depends on sky coordinates & time
  - Local Hot Bubble/Foreground Emission e.g., Snowden et al. 1998; Kuntz & Snowden 2000; Yoshino et al. 2009; Masui et al. 2009; Ueda et al. 2022
  - Milky Way Halo/Transabsorption Emission e.g., Kuntz & Snowden 2000; Yoshino et al. 2009; Masui et al. 20
  - Solar Wind Charge eXchange e.g., Cravens et al. 2001; Koutroumpa et al. 2007
  - Near Galactic center e.g., Uchiyama et al. 2013; Koyama 2018; Nobukawa & Koyama 2021
    - Galactic Ridge X-ray Emission
    - Galactic Center X-ray Emission
    - …
  - Cosmic X-ray Background e.g., Kuntz & Snowden 2000; Kushino et al. 2002



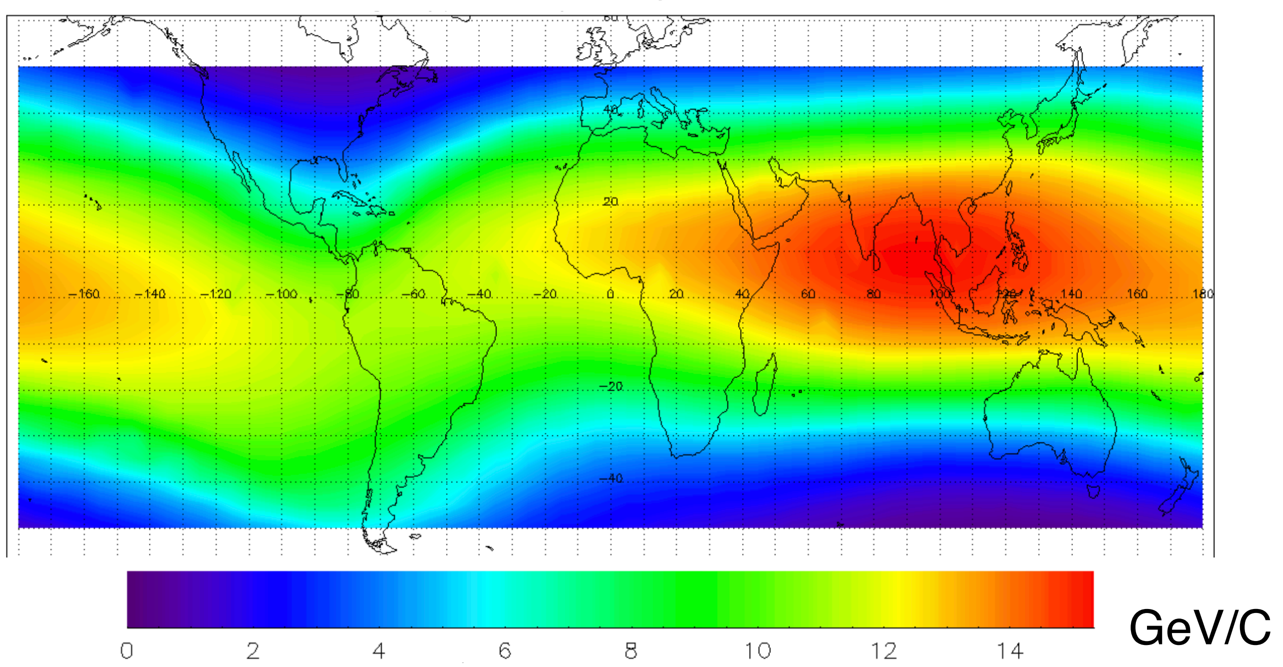


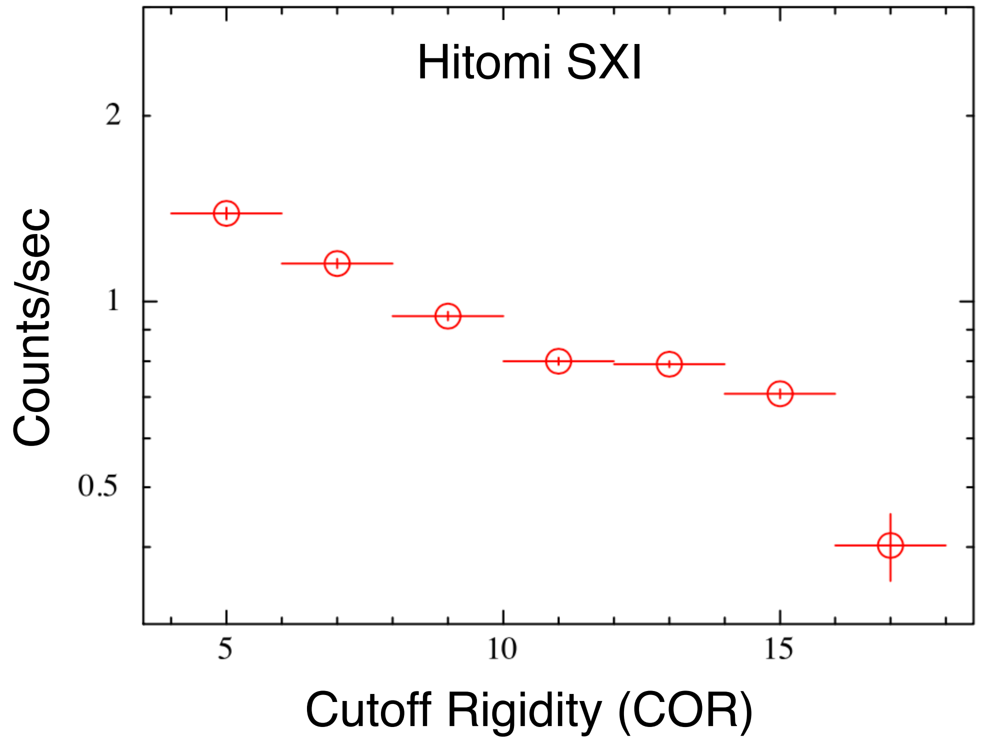
Detector background



- Due to cosmic ray particles
  - Direct hits & stimulate fluorescence
  - Affect if left after event selection
- Dependence on Cutoff Rigidity   Nakajima et al. 2018
  - Total flux varies w/o changing spectral shape
  - Note on year-scale movement of Cutoff Rigidity
- Depends on detector coordinates along readout direction   Nakajima et al. 2018
- Effect of solar cycle almost ignorable

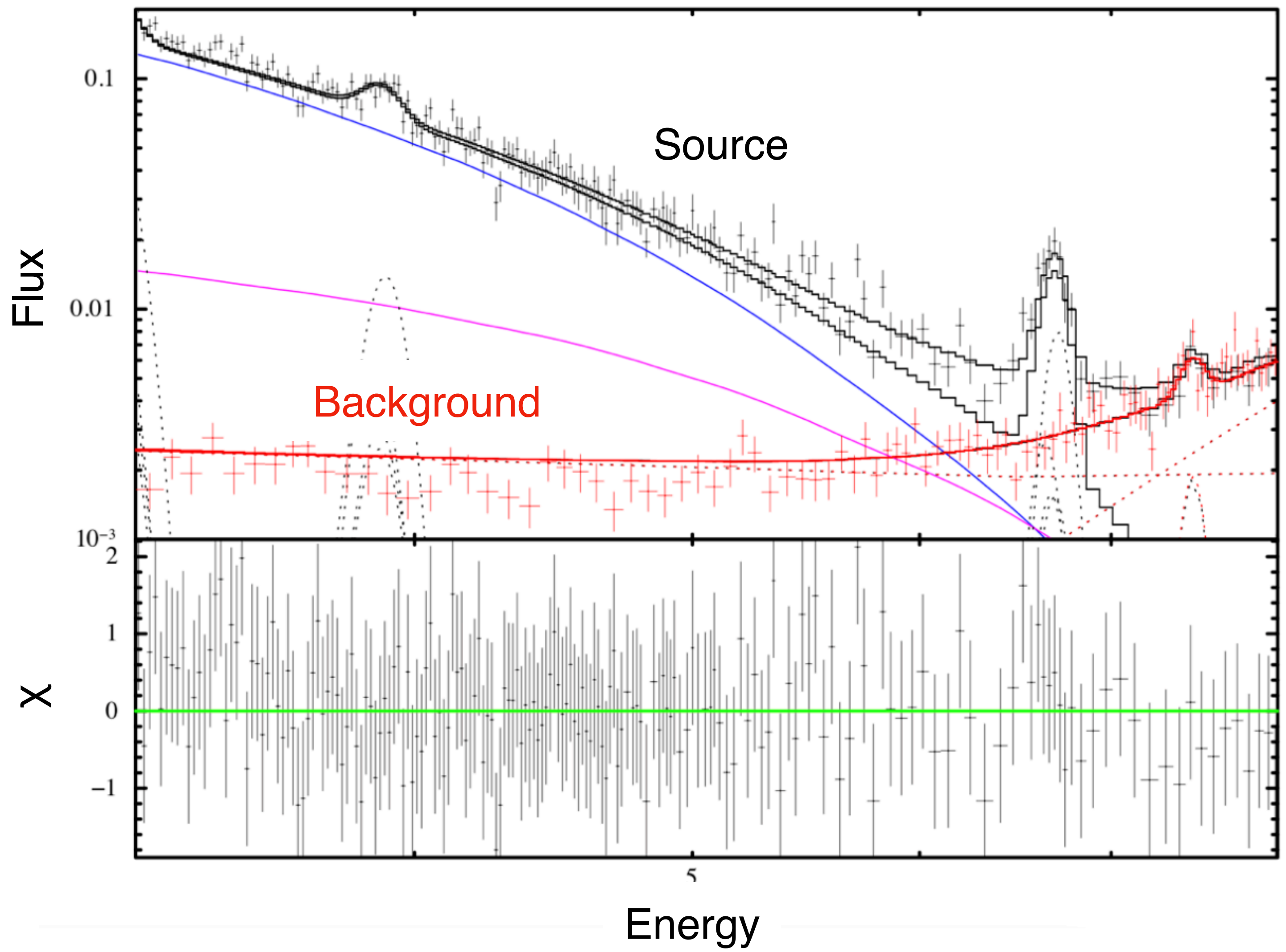
Color: Cutoff Rigidity (COR)



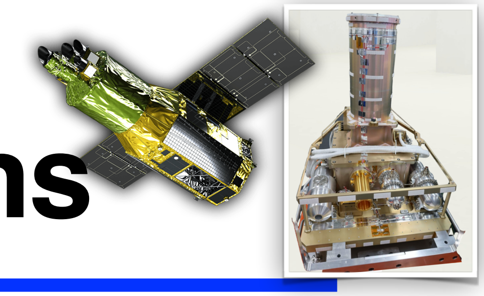


Detector background

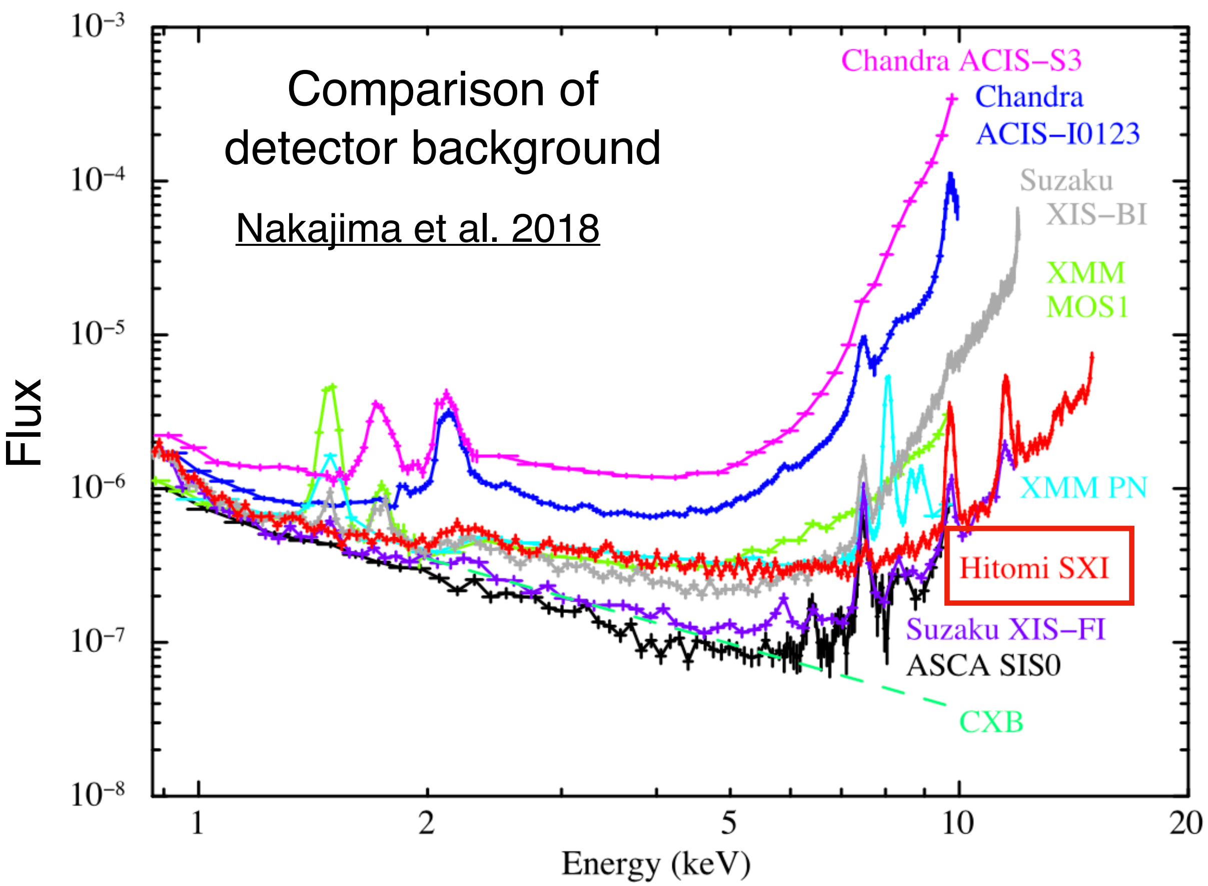
- Background spectra generating tool (`xtdnxbgen`)
- Use C-stat/W-stat in spectral studies XSPEC manual
- W-stat or “Source & Background” better than “Source – Background”



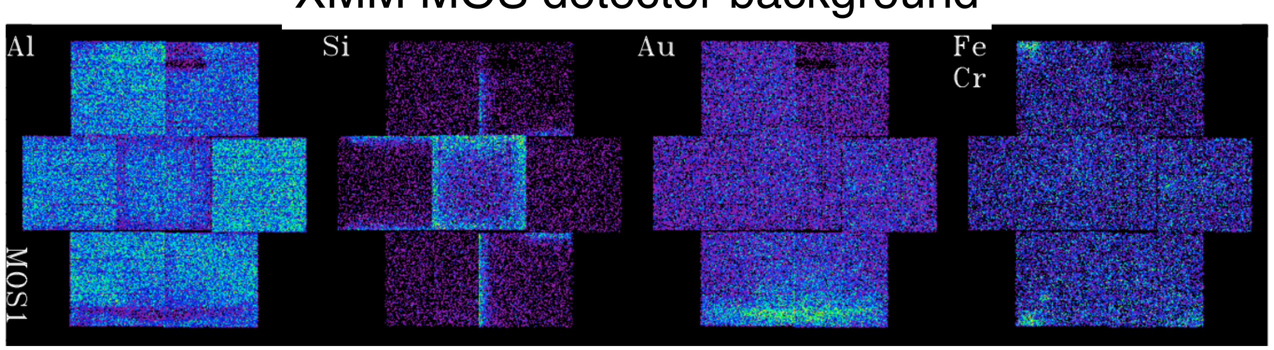
Compare to other satellite missions



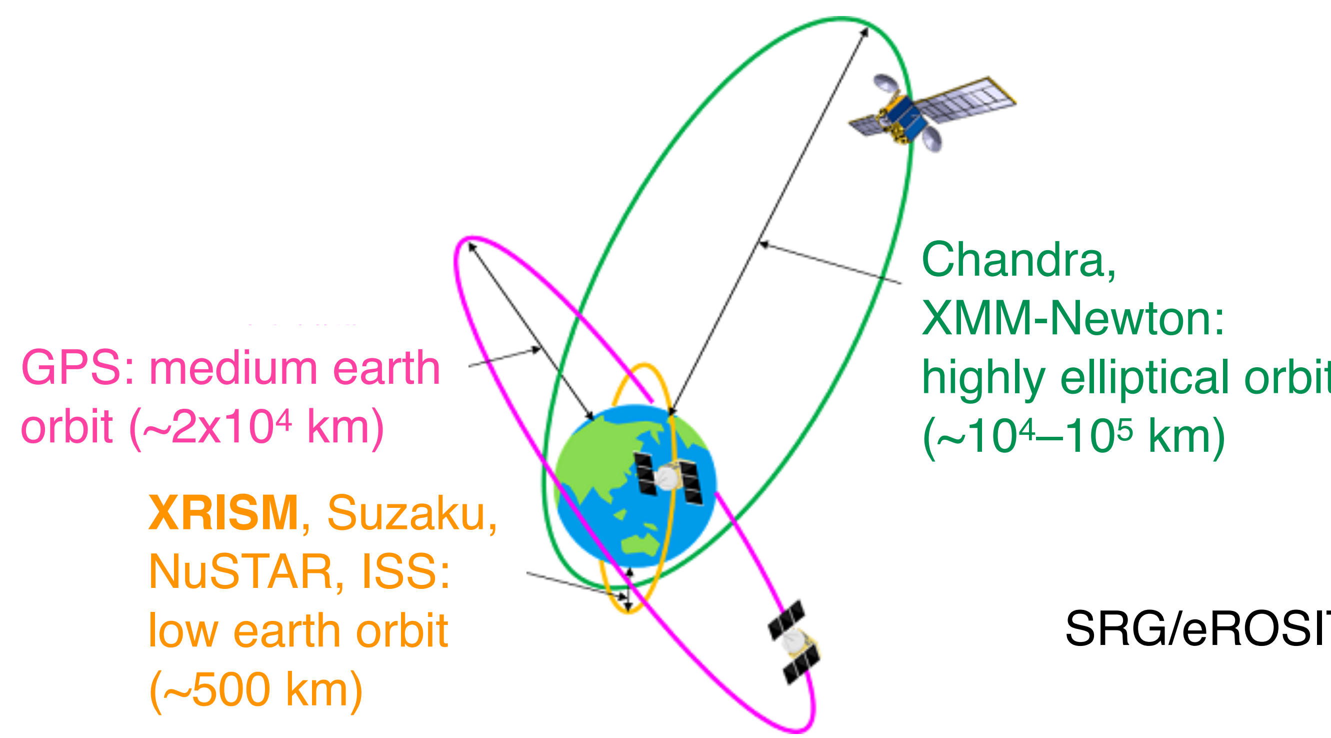
- LL of ASCA, Suzaku, XMM, Chandra, Hitomi have been considered
  - suppressed stray light, background, contamination, CCDs operated at lower temperature



XMM MOS detector background



Kuntz & Snowden 2008

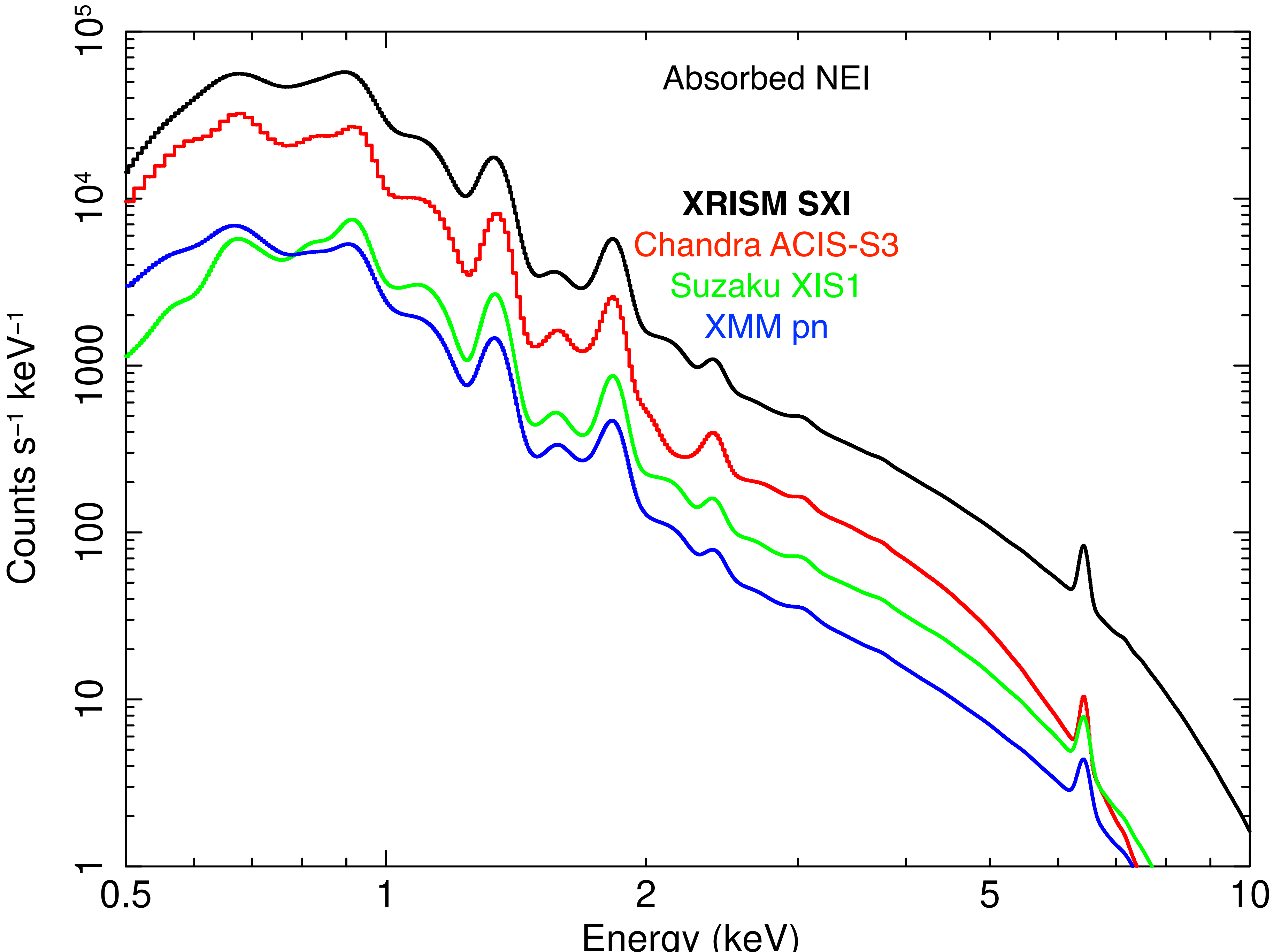


SRG/eROSITA: L2

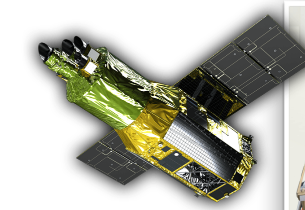
Compare to other satellite missions

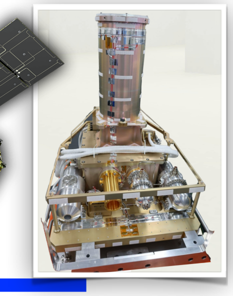
X-Ray Imaging and Spectroscopy Mission

- Detector response
    - basically as good as other X-ray CCDs on satellites
    - moderate energy resolutions at low energies



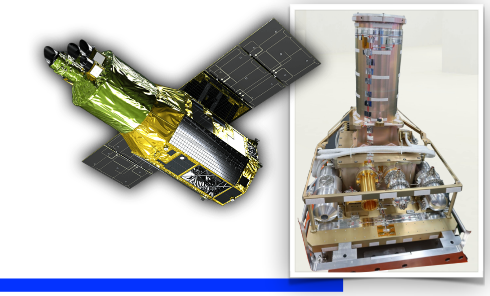
Some other notes

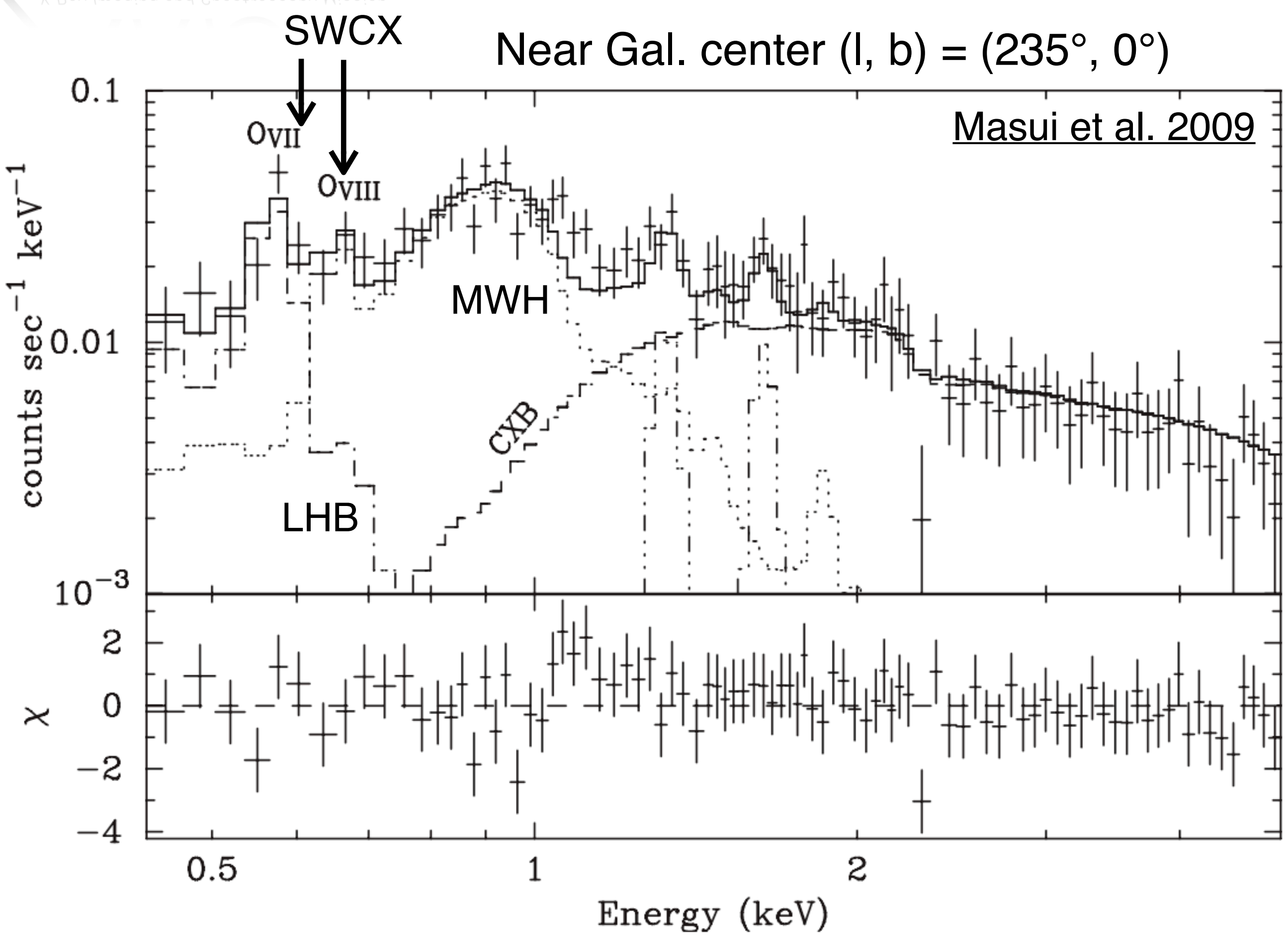


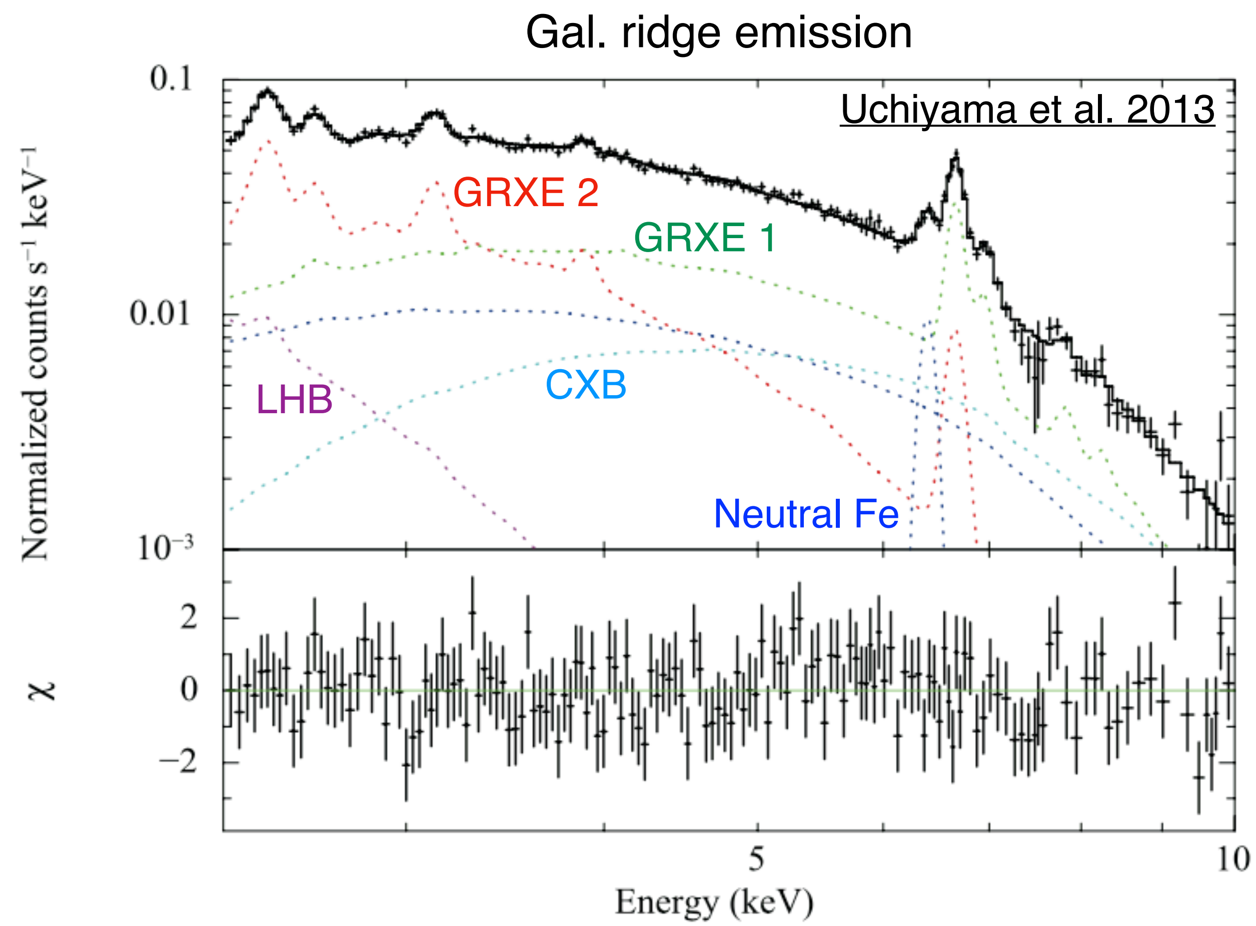


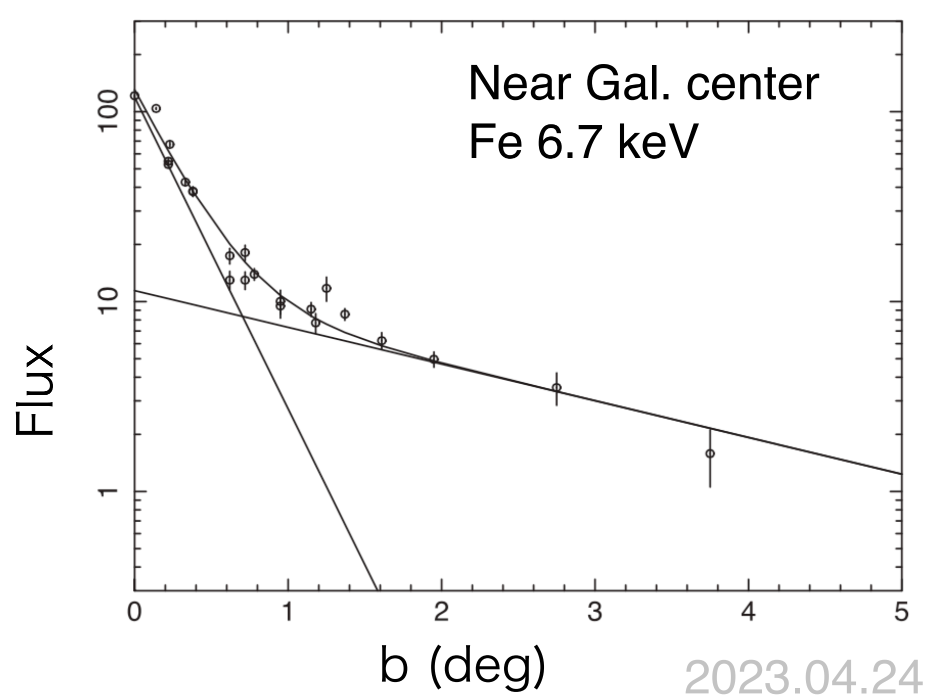
- Transient source search
  - observers' option at proposal submission (yes/no)
  - if yes, XRISM team members see observation data before passed to observers, to search for transient sources
  - if a transient found, XRISM team members post a telegram

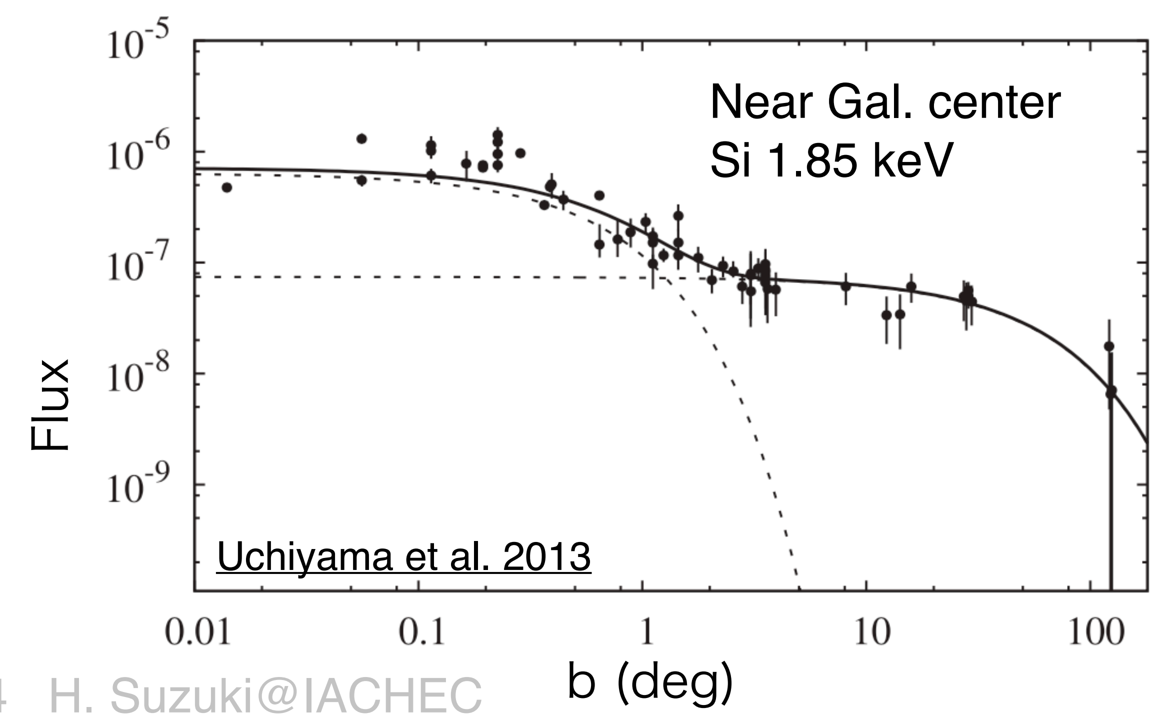
Sky background





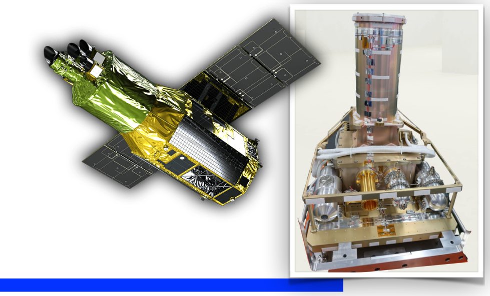




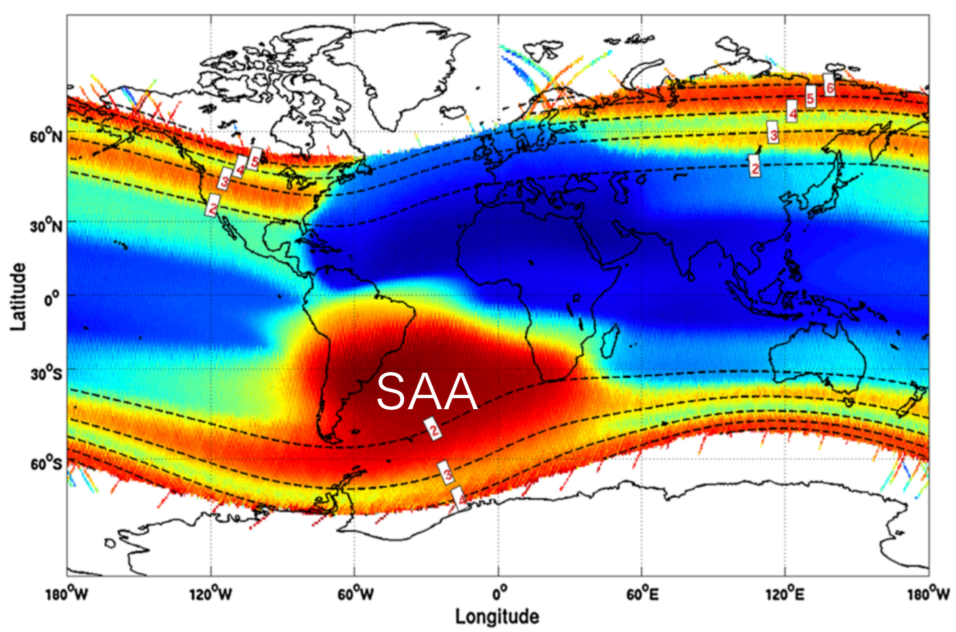


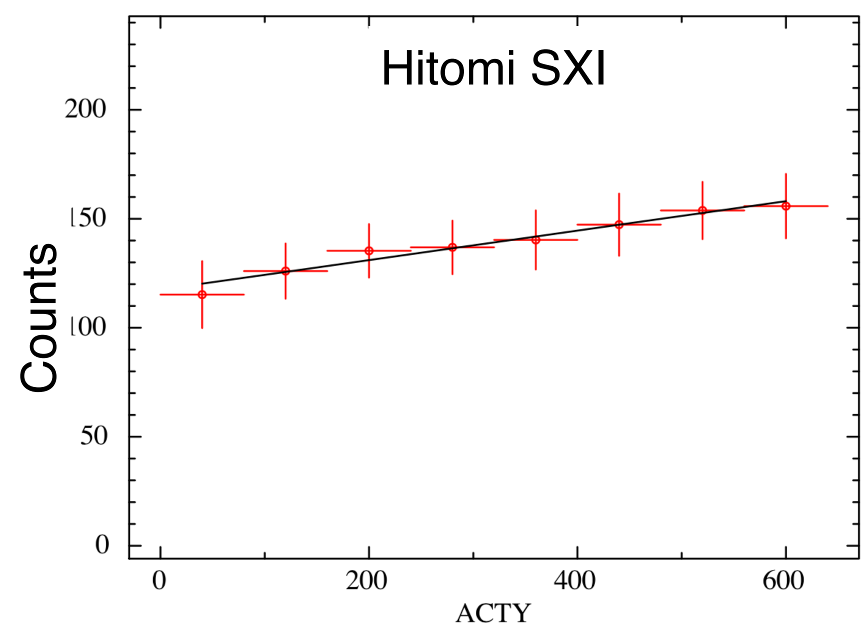
XRISM
X-Ray Imaging and Spectroscopy Mission

Detector background



- Depends on detector coordinates   Nakajima et al. 2018
    - Along readout direction, due to cosmic-ray events in frame store regions
- SXI turned off in SAA but background possibly high just before/after SAA
- Almost ignorable effect of solar cycle





Readout ←