Simulation study of pulse height difference between pixel patterns of X-ray CCDs onboard the XRISM satellite

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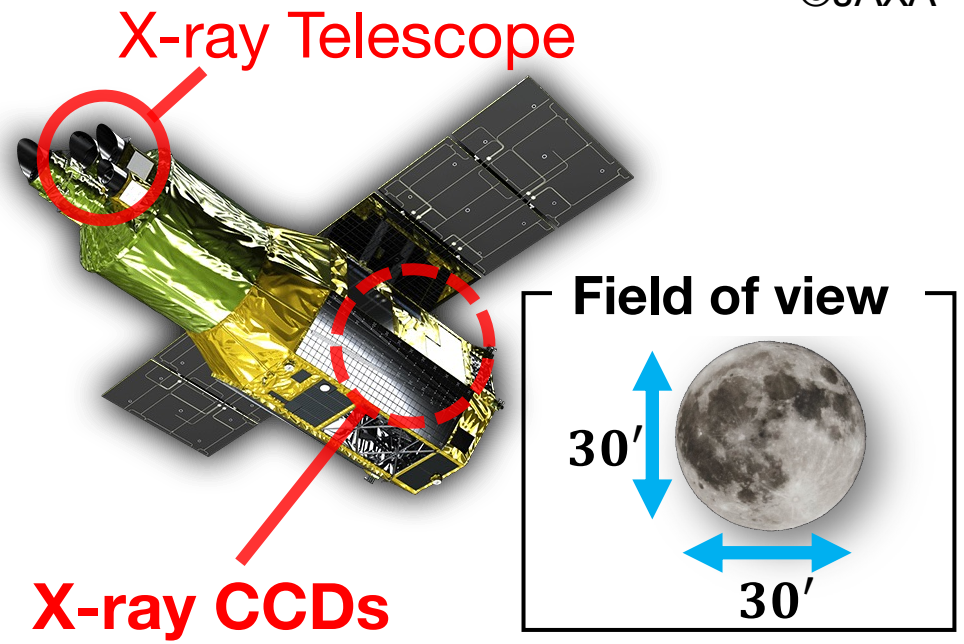
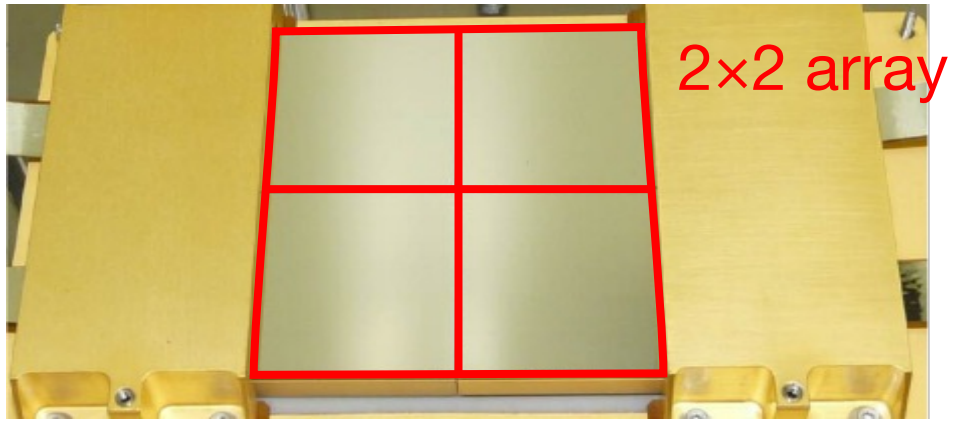
X-ray CCD detectors onboard XRISM satellite

XRISM/Xtend



Field of view

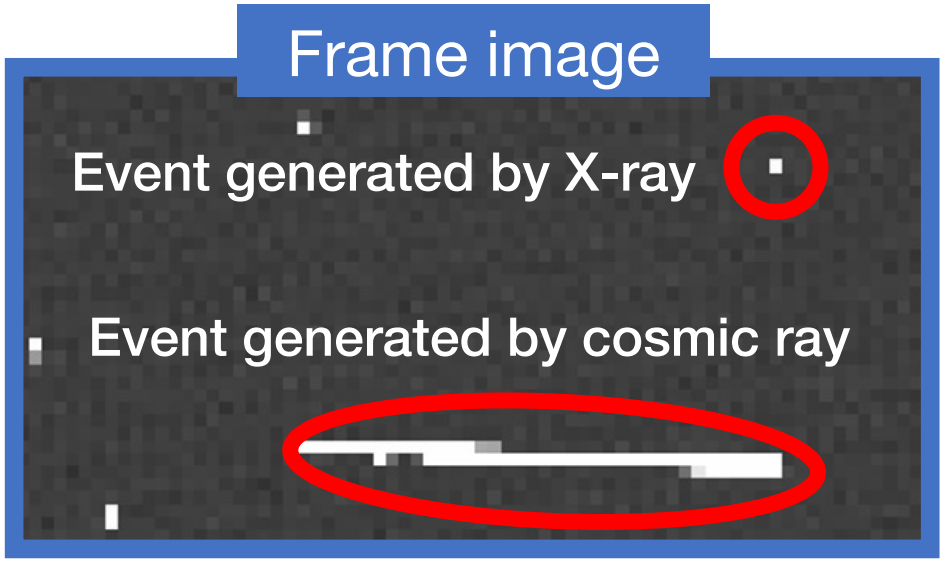


- Will be launched in FY2023.
  - Equipped with two detectors : Resolve and Xtend
- Xtend consists of an X-ray telescope and **X-ray CCDs**.
  - **4 CCDs** mounted in a 2×2 array for a wide field of view, $\mathbf{30'\times 30'}$. (= the Moon's angular diameter.)

Specifications of CCDs onboard XRISM

- Back-illuminated Pch type
  (manufactured by Hamamatsu Photonics K.K.)
- Pixel size: $24\ \mu\mathrm{m} \times 24\ \mu\mathrm{m}$
- Imaging area size: $31\ \mathrm{mm} \times 31\ \mathrm{mm}$ /CCD
  Pixel number: 1280×1280 pixels /CCD
- Depletion layer thickness: $\sim 200\ \mu\mathrm{m}$
  - Enhancing X-ray quantum efficiency above 6 keV.
- Energy range: $\mathbf{0.4 - 13\ keV}$
- Energy resolution: $\leq \mathbf{200\ eV}$ @ $\mathbf{5.9\ keV}$

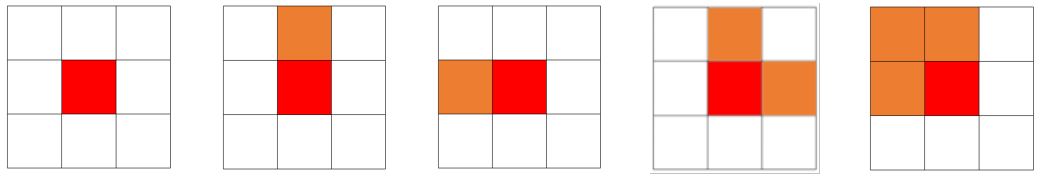
Grade method in X-ray astronomy CCDs



- Charges generated by X-rays are confined in a single pixel or split into at most a few pixels.
- Charges generated by cosmic rays are split into many pixels.
- We use pixel patterns to distinguish between X-ray and non X-ray events. => “Grade method”
- Grade method has been used in X-ray astronomy CCDs since the ASCA satellite.

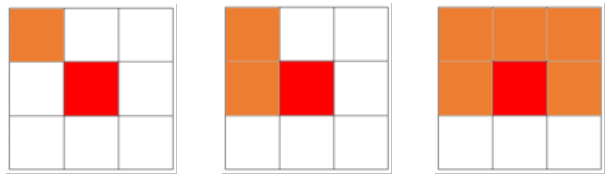
Example of pixel patterns in Grade method

X-ray Grades



- Single pixel events
- Vertically or Horizontally split events
- Events split into up to four pixels

Non X-ray Grades



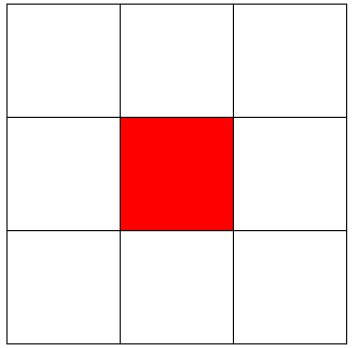
- Diagonally split events
- Events split into more than four pixels

- **Split threshold** is used to determine the pixel pattern. If signal of a pixel is above the split threshold, the signal is considered to be split to that pixel.

Signals and spectra of X-ray Grades

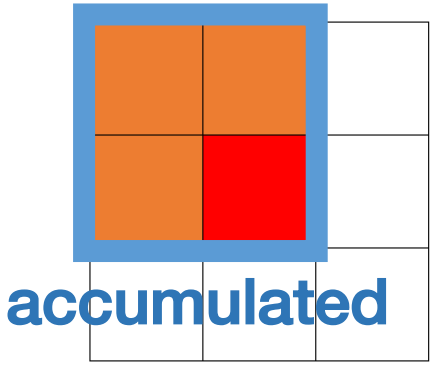
Event signals of X-ray Grades

Single pixel events



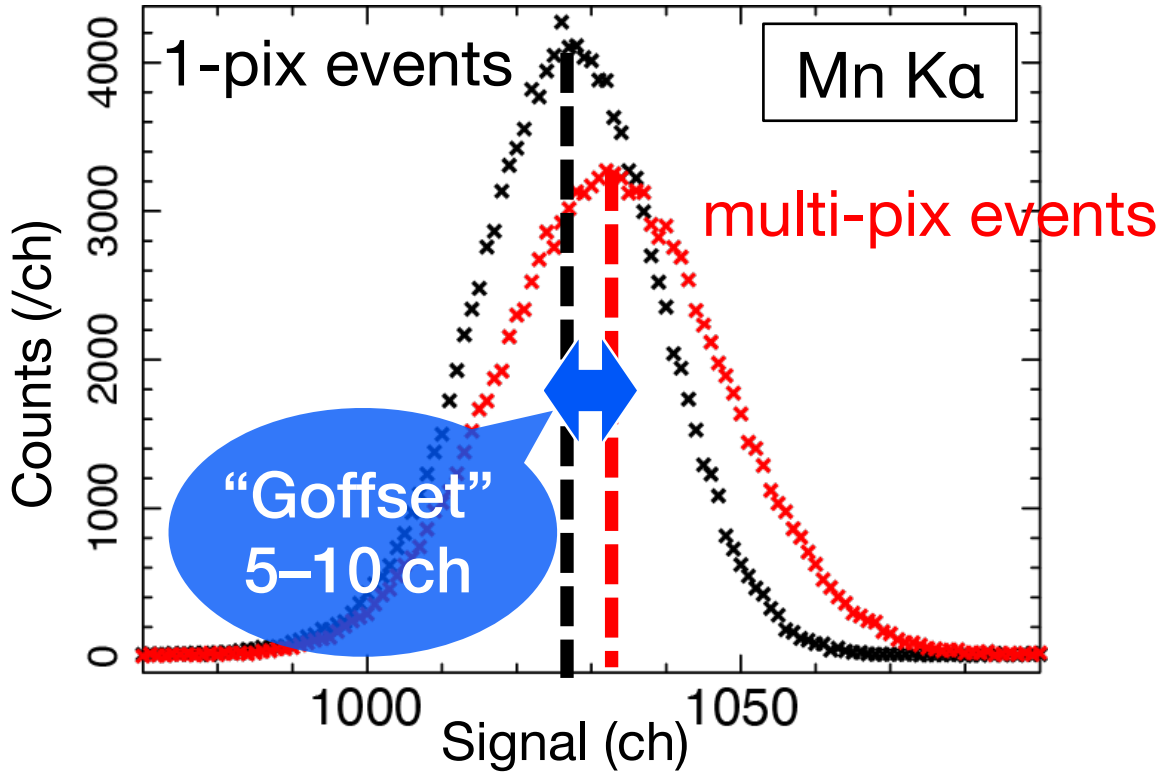
- Total signal is exactly the same as signal of the pixel.

Events split into multiple pixels



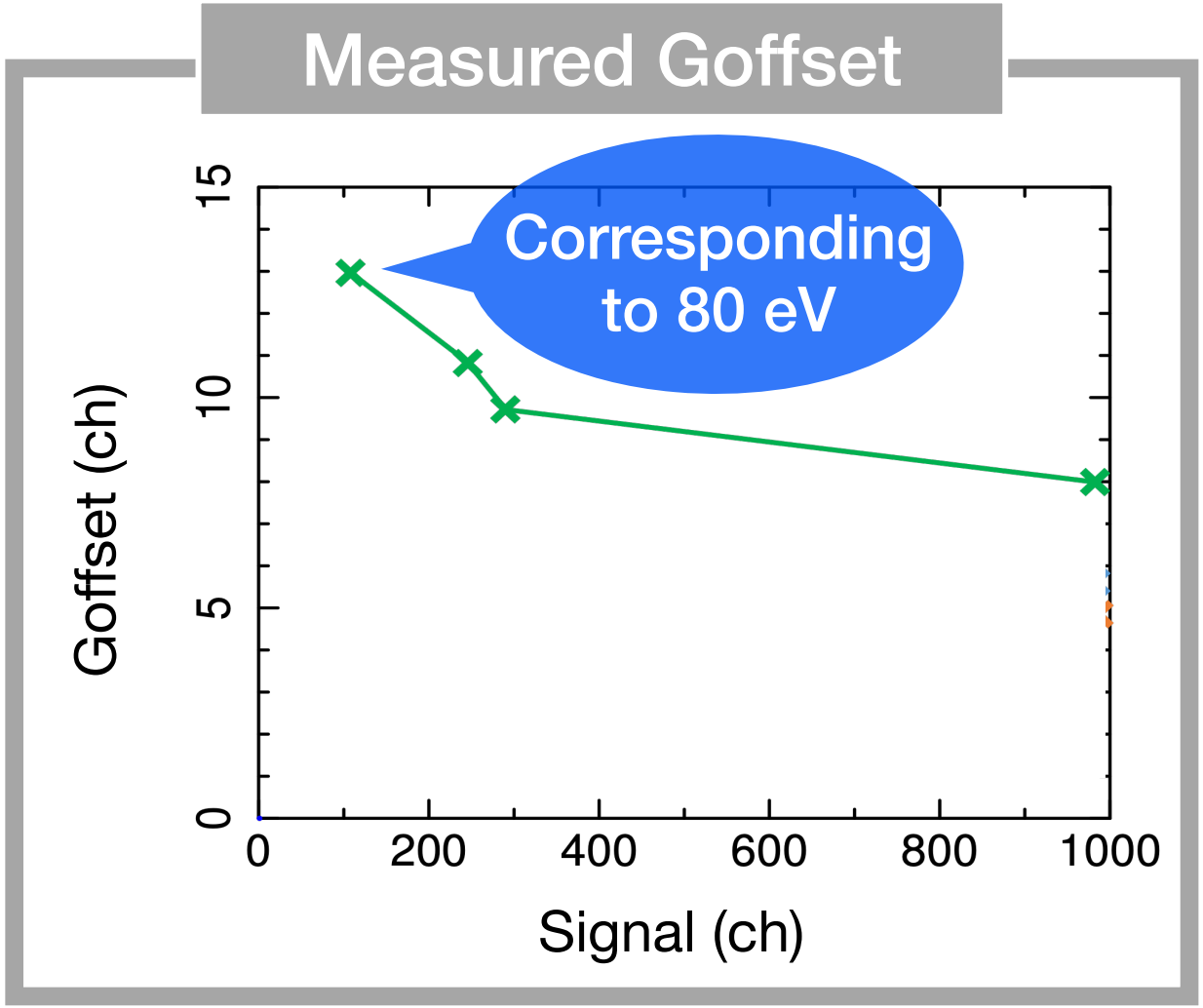
- Signals of pixels above split threshold are accumulated into the total signal.

X-ray Grade spectra of Xtend



- Ideally, the two spectra are expected to exactly overlap.
- There is an offset of 5–10 ch between the two spectral peaks. = **"Goffset"**
- Its mechanism is not obvious.

Energy dependence of Goffset



- Goffset depends on the X-ray energy.
  - increasing especially at low energies.
- Goffset is up to 13 ch (= 80 eV)
  ⇨ causing large uncertainties of energy determination accuracy of Xtend.

- Goffset varies with readout electronics for the same CCD.
- Physical mechanism of Goffset is unknown.
  - Goffset has been corrected by a phenomenological model.
  - Performance of the detectors changes in orbit. The phenomenological model may not be adapted to variable Goffset.
  - Accurate correction of Goffset requires understanding of physical mechanism.
- A possible mechanism is that the readout noise induces Goffset.

Purpose and method

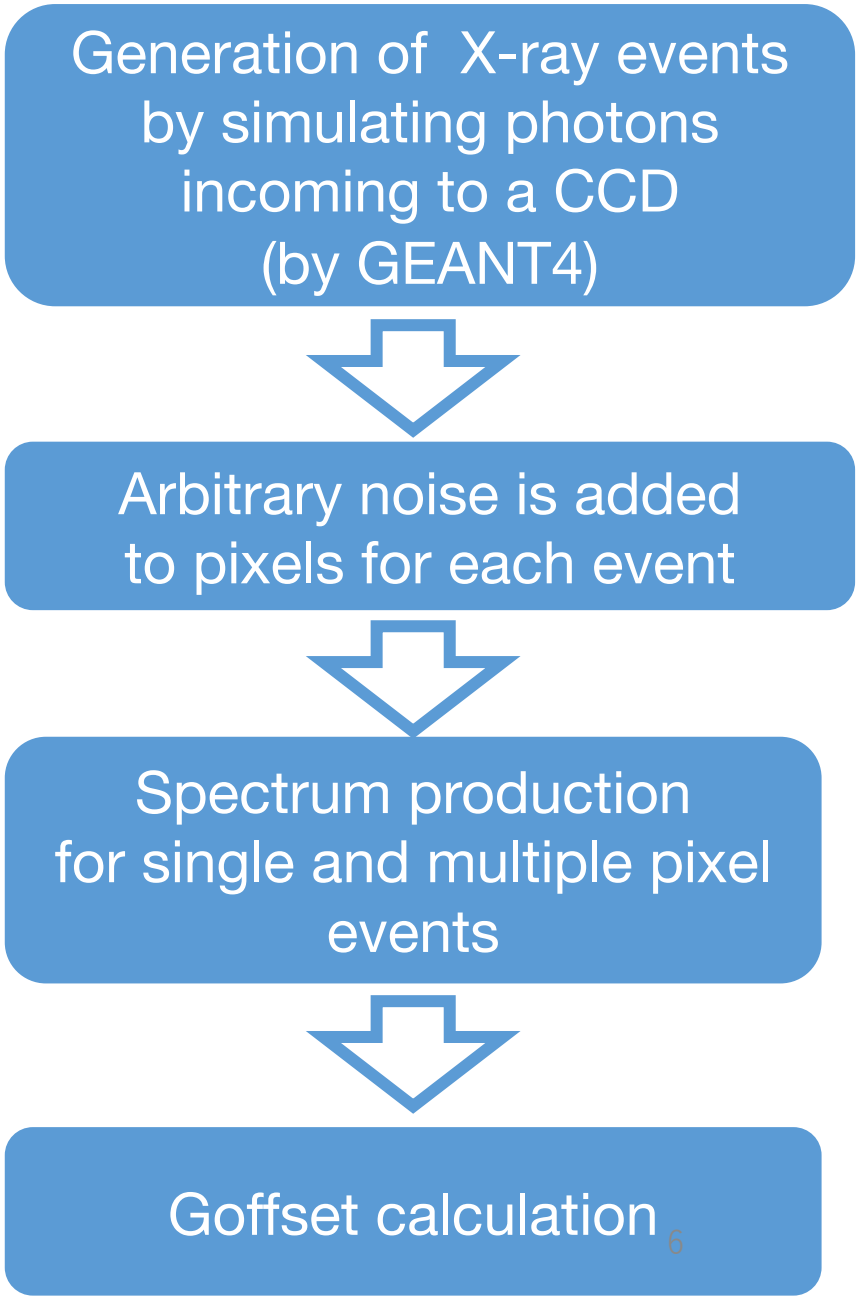
Purpose

To investigate physical process of Goffset, especially noise contribution.

Method

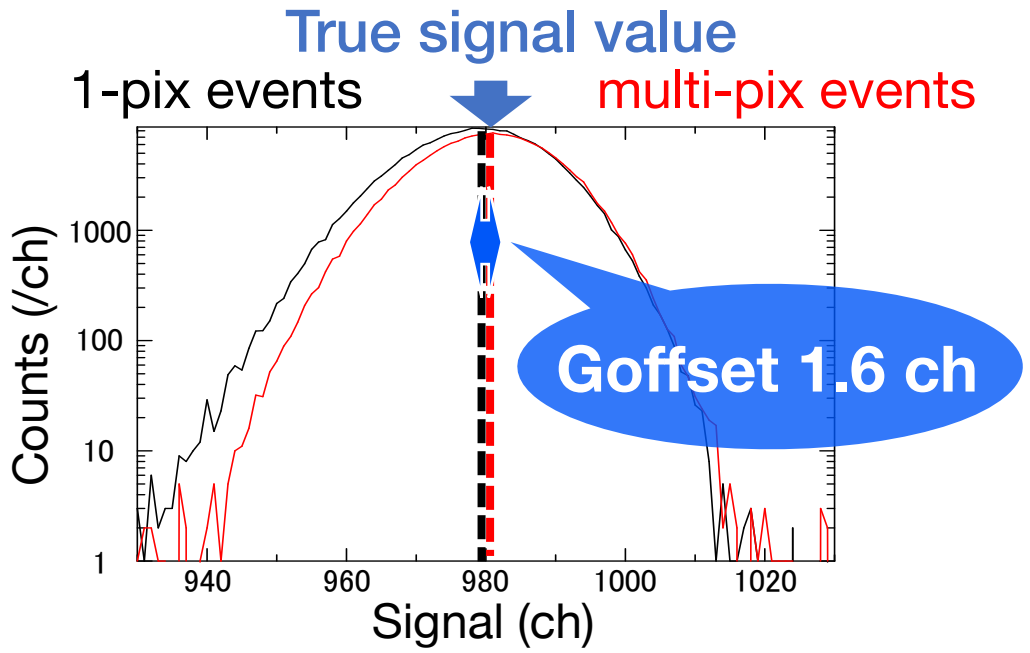
To simulate Goffset with various signals and noise values.

Flowchart

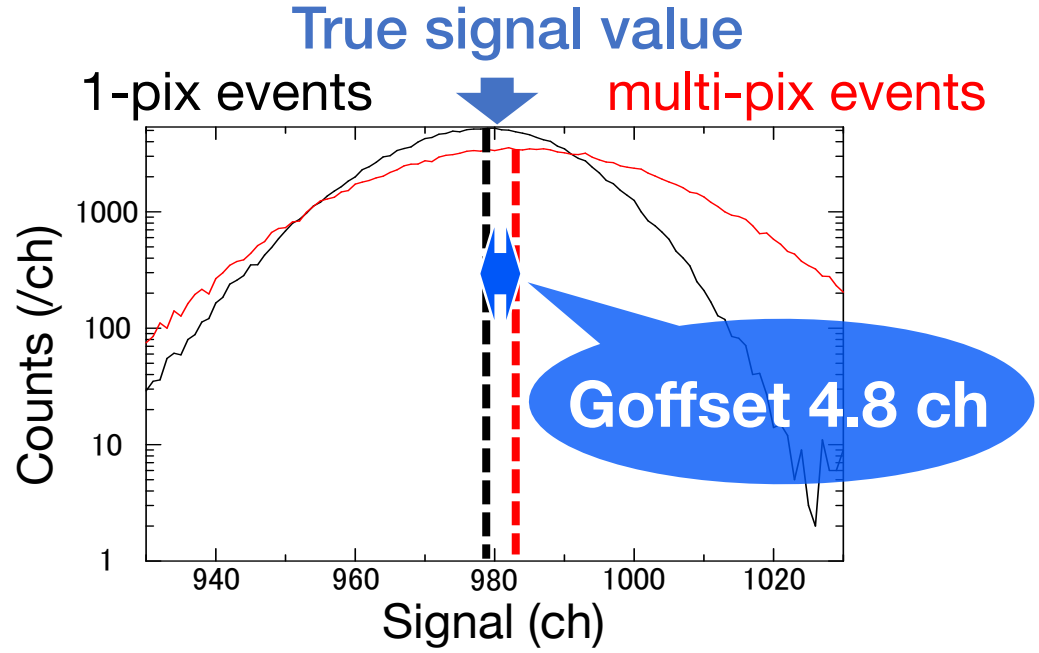


Simulated spectra (Mn Ka)

w/o noise (0 ch)

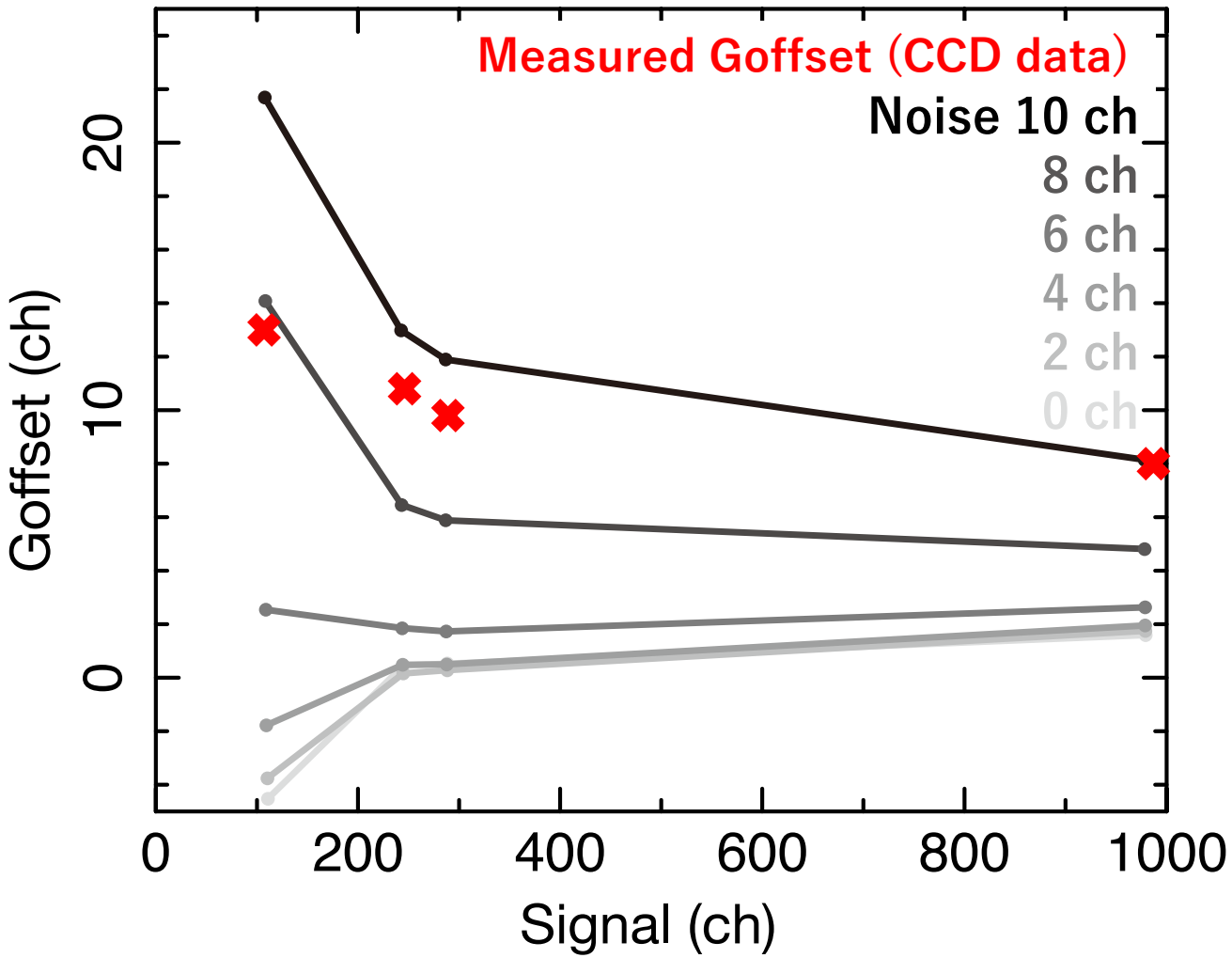


w/ noise (8 ch)



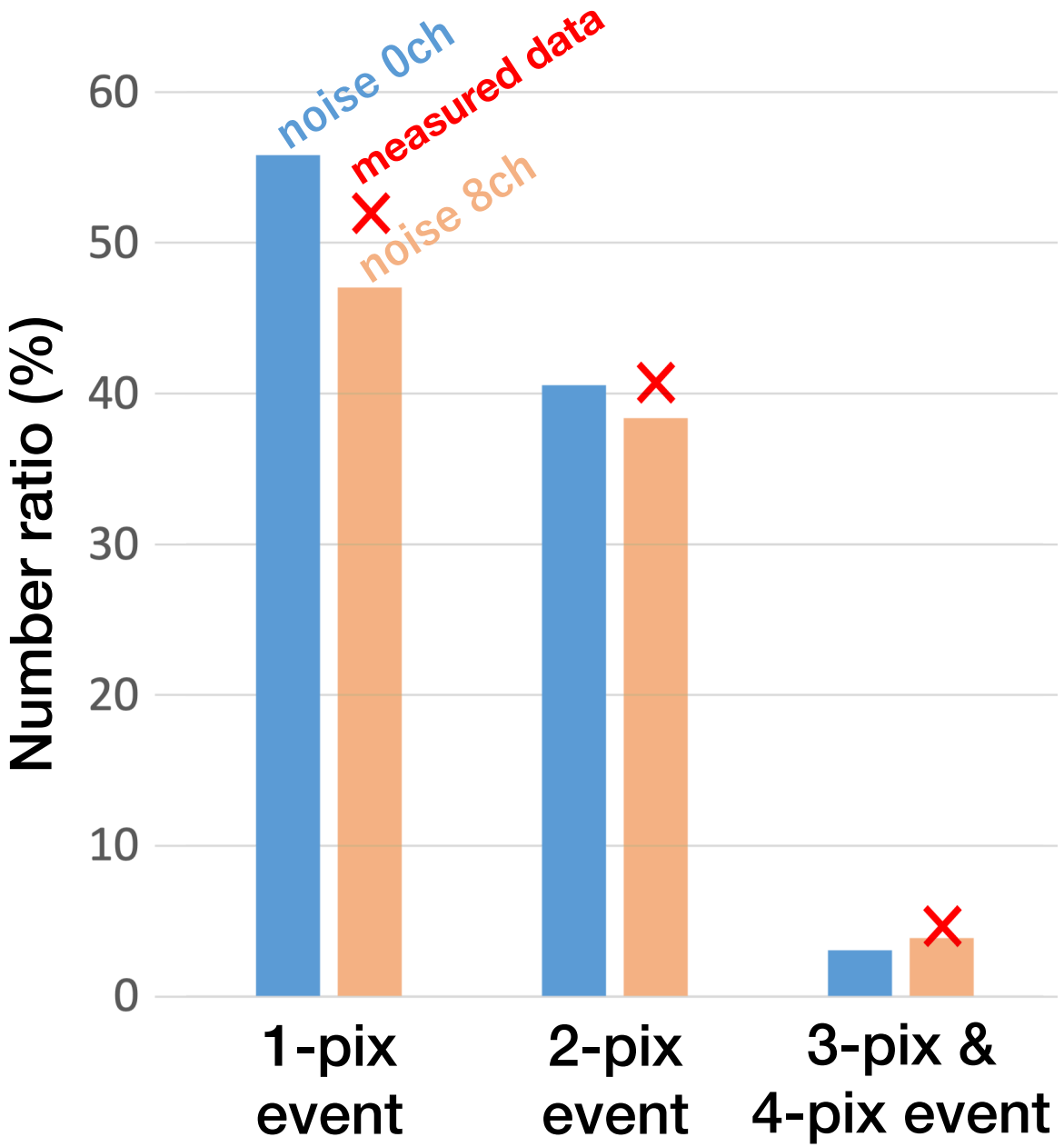
- As noise increases, Goffset increases as well as the lines broaden.
- In the without noise spectrum : Peak of 1pix events < the true value
  Peak of multi-pix events ≃ the true value
- In the with noise spectrum : Peak of 1pix events < the true value
  Peak of multi-pix events > the true value
- Noise would be accumulated in the spectrum of multi-pix events.

Comparison between simulated and measured Goffset



- Simulated with various energies and noises.
- Goffset is increasing with increasing noise.
- In the high noise conditions, Goffset rapidly increases in lower energy.
  - The simulated Goffset with noise 8 – 10 ch reproduces the measured Goffset.
- Noise of Xtend is necessarily not the same between on the ground and after launch.
  - The simulator will enhance the accuracy of the Goffset correction after launch.

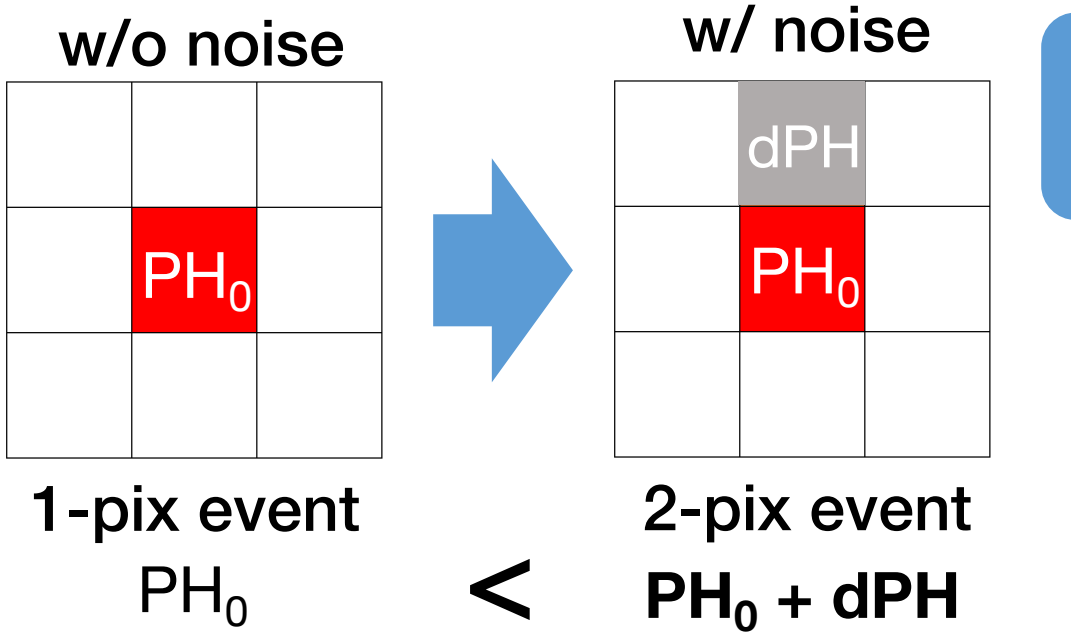
Discussion: How noise increases Goffset?



Noise can increase more multi-pix events.

- Simulation results indicate that as noise increases...
  - Number ratio of 1-pix events significantly decreases.
  - Number ratio of 2-pix events slightly decreases.
  - Number ratio of 3-pix and 4-pix events increases.
- Note that **each number ratio of the 8 ch noise reproduces the measured data.**

Discussion: How noise increases Goffset?



Noise can increase more multi-pix events
=> **Averaged total event signal increases.**

- When signal of a surrounding pixel become higher than the split threshold due to positive noise...
  - Noise can change the pixel patterns from a 1-pix to 2-pix event.
  - Averaged total event signal increases.
- Similarly, noise can change the pixel patterns from a 2-pix to 3-pix event.
- Negative noise does not well change the pixel patterns.

Summary

- We are developing the X-ray CCDs onboard the XRISM satellite.
- There is Goffset between the spectra of 1-pix and multi-pix events obtained by XRISM CCDs, and Goffset rapidly increases in the low X-ray energy.
- Although physical mechanism of Goffset is unknown, one possibility is that noise induces Goffset.
- We investigated the noise dependence of Goffset by simulation.
- We confirmed that noise increases Goffset.
- Simulated Goffset with noise of 8-10 ch reproduces the measured Goffset.
- Positive noise vary pixel patterns and is accumulated in the spectra of multi-pix events, which causes Goffset.