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Temperature Dependence of Gas X-ray Detectors onboard the 6U CubeSat X-ray Observatory NinjaSat

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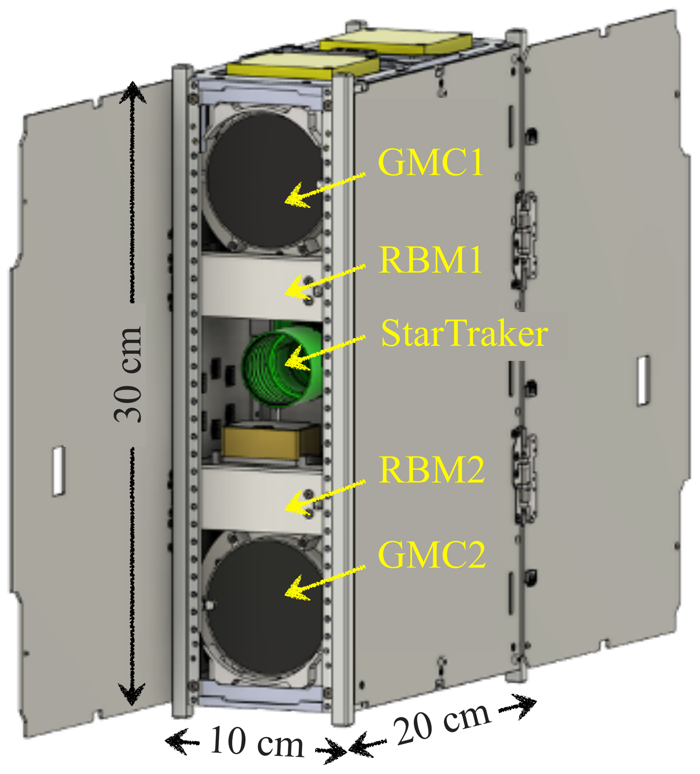
Welcome to NinjaSat's Home Page!
https://astro.riken.jp/ninjasat

Abstract

We report the temperature dependence of Gas Multiplier Counters (GMCs) onboard the 6U CubeSat X-ray observatory NinjaSat. The detector performance of GMC depends on the temperature. The temperature dependence of the gain was calibrated for the detector response function in orbit using data from the Crab Nebula. The fit results using the function created improved the ratio of the fit curve to the data from 12% to 4% before and after gain correction.

NinjaSat: 6U CubeSat X-ray Observatory



NinjaSat is the first CubeSat that detected thermonuclear X-ray bursts from neutron stars!
(Takeda et al, Aoyama et al, 2024)

Basic information on NinjaSat

Size	10 cm × 20 cm × 30 cm (6U)	
Orbit	Sun-Synchronous	
	Altitude ~530 km, LTDN 10:32 a.m.	
Payloads	Gas Multiplier Counter (GMC)	
	Radiation Belt Monitor (RBM)	

Observation Purpose

- Long-term monitoring observations
- Simultaneous multi-wavelength observations
- Follow-up observations of X-ray transient

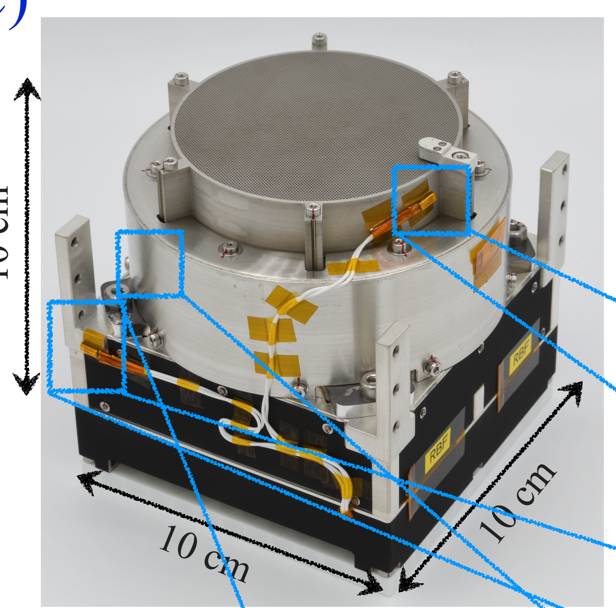
Observation Results

- 12 objects, X-ray sources (like neutron stars, black holes, active galactic nuclei)
- The period of the Crab pulsar, whose spin period is known, was identified as 33.8 ms.

Gas Multiplier Counter (GMC)

Basic information on GMC

Energy band	2–50 keV
Inclusion Gas	Xe/Ar/DME (75%/24%/1%, 0°C, 1.2 atm)
Effective Area	32 cm^2 / 2GMC (6 keV)
Feild of View	2.1° (FWHM)



commercial inexpensive

Thermometer

- The thermometers (AD590LF)
- Liner current output: 1 μA/K
- Temperature range: −55°C ~ +150°C
- Power supply range: 4 V ~ 30 V

AD590LF
https://mou.sr/3Wo0YZf
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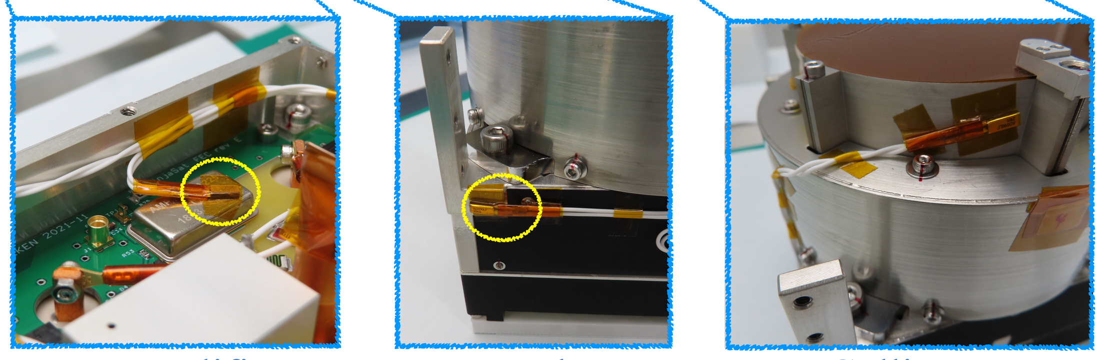
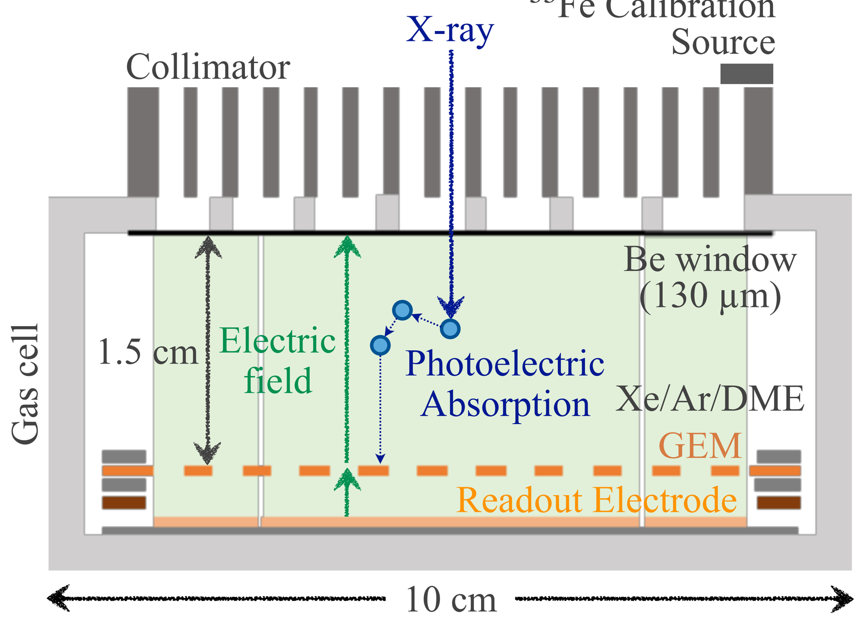


X-ray detection process of GMC

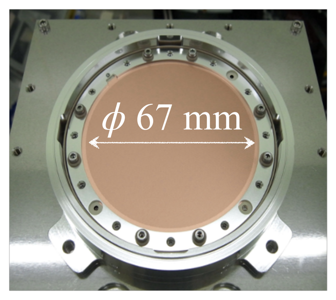
- The X-ray incident on GMC occurs with gas photoelectric absorption, generating a cloud of electrons.
- GEM amplifies the electrons.
- Read out as a charge signal by the readout electrode.

Cross-section of GMC

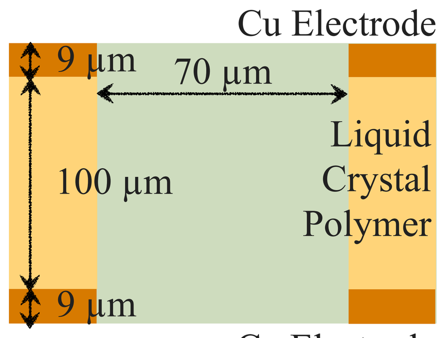


Gas Electron Multiplier (GEM)

- Apply high voltage (590 V) between the Cu Electrode.
- Generate an electron avalanche inside the hole in the GEM

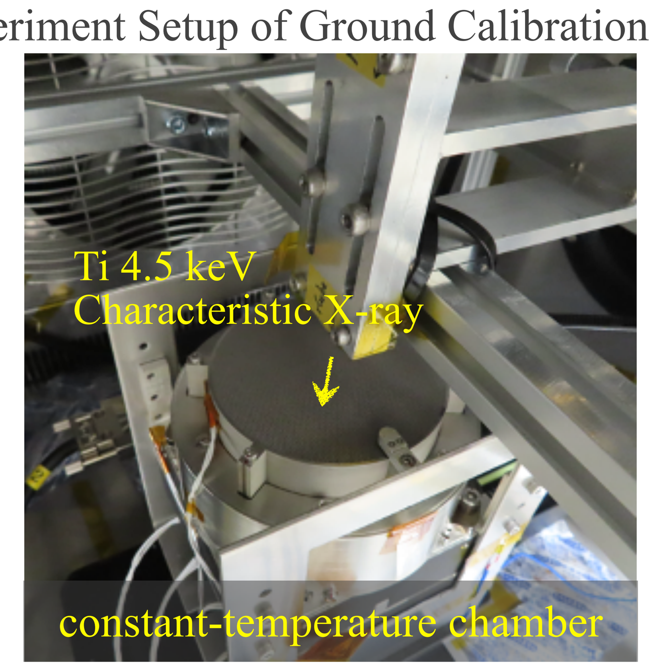


Cross-section of GEM



Detector Response Function on the Ground

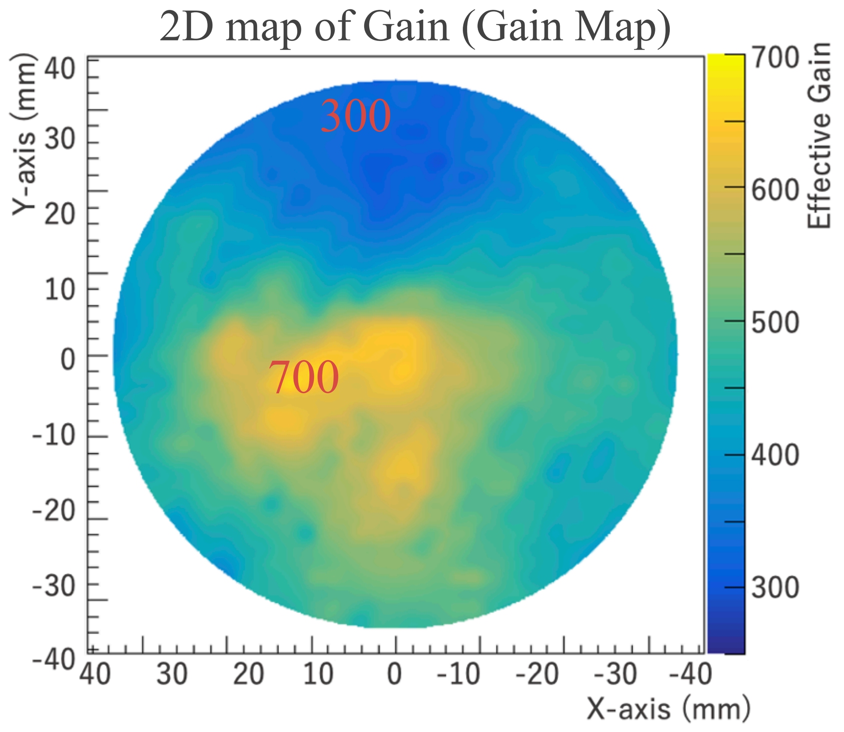
Experiment Setup of Ground Calibration Test



−10, 0, 10, 15, 27°C for 5 temperatures, including the operational temperature range.

→ At a maximum temperature of 27°C, the gain varies by a factor of two, depending on location.

2D map of Gain (Gain Map)



GEM sags due to temperature rise
↓
Electric field becomes non-uniform
↓
The collection efficiency of electrons is non-uniform
↓
The effective gain of GEM is non-uniform

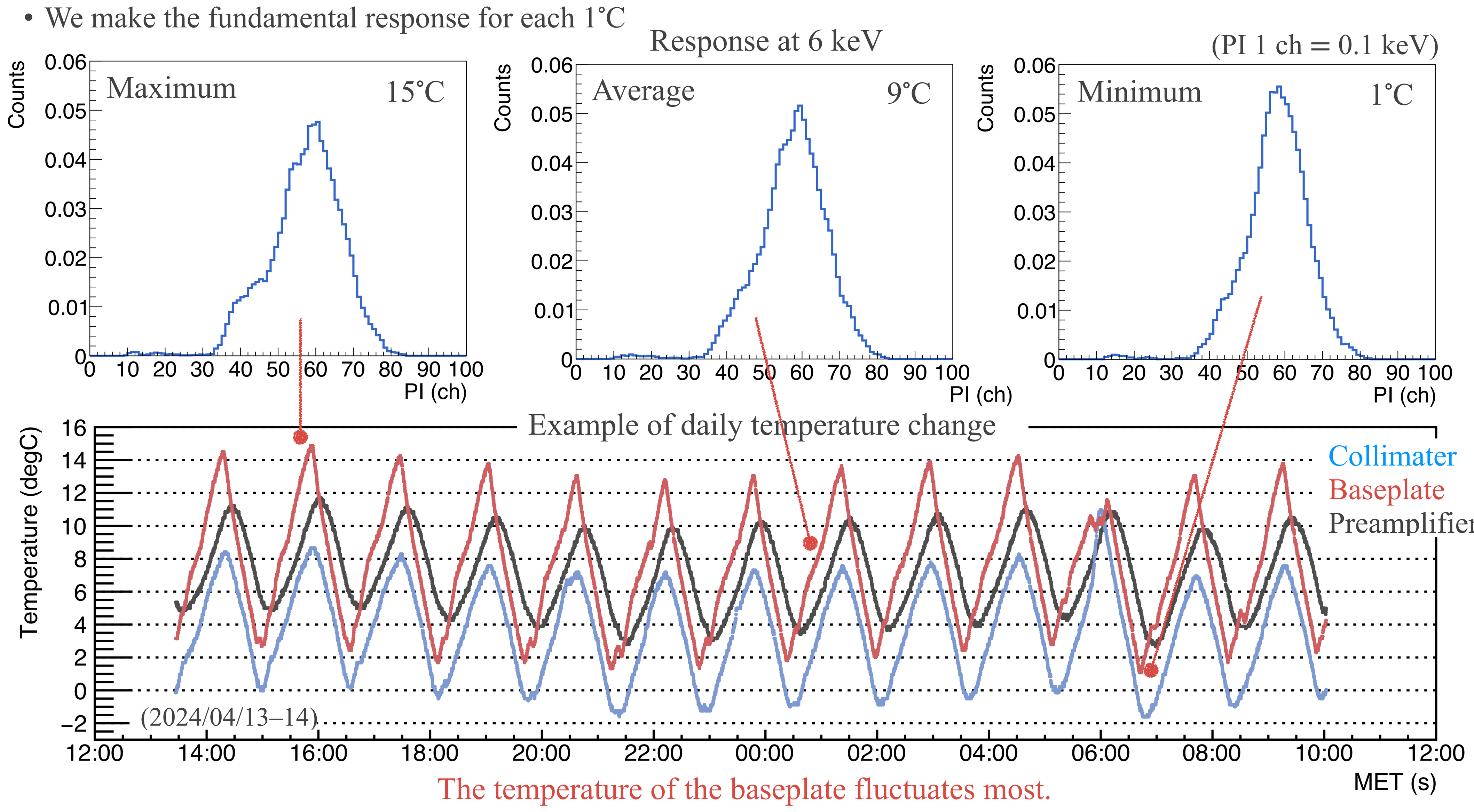
My Purpose

Create a detector response that fits the actual measurement, taking into account the location and temperature dependence of the gain.

Detector Response Function on the Orbit

Detector Response Function of GMC

- Matrix of energy spectra corresponding to each incident X-ray energy of the detector
- Gain maps are implemented into the response simulator (Location Correction)
- We make the fundamental response for each 1°C



The temperature of the baseplate fluctuates most.

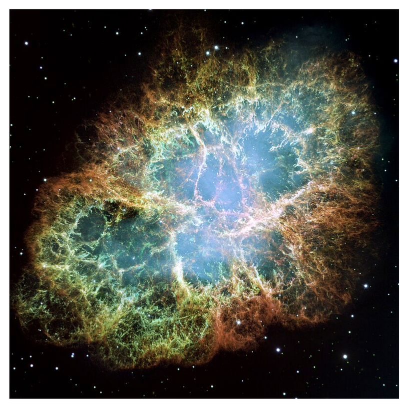
- The temperature fluctuates approximately 15°C in a 95-minute cycle (one-orbit).

Weight Average
- Calculate the frequency distribution of the temperature assigned to each event.
- Weighted average of each temperature response by number of events (Temperature Correction)

Observation of Crab pulsar

- Observation period: 2024/02/13–04/20
- Total Exposure Time: about 114 ksec
- GMC temperature range of variation: 1.2–15.4°C (Average 9.3°C)

Standard X-ray candle Crab pulsar →



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Model Parameters for Crab Spectra

$$F = \exp(-N_H\sigma(E)) \times K\left(\frac{E}{1\ \mathrm{keV}}\right)^{-\Gamma}$$

(photon s^{-1} cm^{-2} keV^{-1})

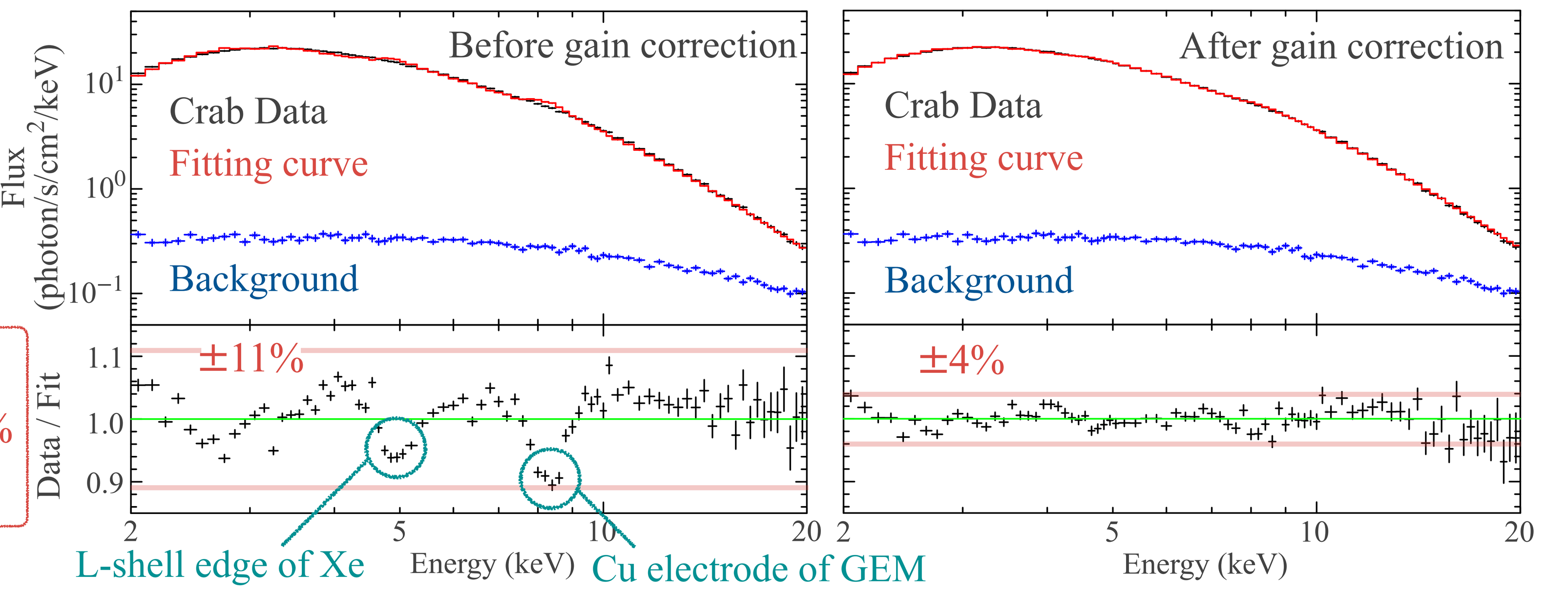
- N_H: 4.5 × 10^{21} (atmos cm^{-2})
- Photon Index Γ: 2.07
- Norm: 8.26 (photon s^{-1} cm^{-2} keV^{-1} at 1 keV)

(Kirsch et al, 2005)

Importance of location and temperature dependence of gain

Count rate in 2–20 keV (Inner)
- Crab
  - 11.1 counts/s
- Background
  - 0.4 counts/s

The ratio of the data to the fit curve improved from 11% to 4% in the range of 2-10 keV.



nH (× 10^{21} cm^{-2})	4.5	2.8 ± 0.2	4.1 ± 0.2
Photon Index	2.07	1.985 ± 0.003	2.007 ± 0.004
Normalization	8.26	5.36 ± 0.04	5.72 ± 0.04
χ^2 / dof	—	1907/78	247/78

χ^2 / dof is improved →

After location and temperature correction, the ratio is almost flat, with a small amount of structure remaining before correction.
→ No significant improvement in response is needed since a systematic error of 1.3% yields χ^2 /dof = 1.0

Summary

- The detector response function that fits the actual measurement was created by considering the location and temperature dependence of the gain of the gas X-ray detector GMC.
- The dependence of the gain is corrected for the Crab Nebula spectrum
  - The ratio of the data to the fit curve improved from 11% to 4% in the range of 2-10 keV
  - χ^2 / dof is improved from 24.5 to 3.2.
- We expect improvement in the detector response function by correcting the effective area.

Reference

- A. Aoyama et al., 2024, June 28, The Astronomer's Telegram, 16678.
- T. Takeda et al., 2024, March 1, The Astronomer's Telegram, 16495.
- T. Takeda et al., 2023, Proceedings of the Small Satellite Conference 2023, SSC23-WIII-01.
- T. Tamagawa et al., 2023, Proceedings of the Small Satellite Conference 2023, SSC23-WIV-06.
- M. G.F. Kirsch et al., 2005, Proc of SPIE, 0277-786X.

Thank you for watching my poster!