Status of the CubeSat X-ray observatory NinjaSat one year after operation start

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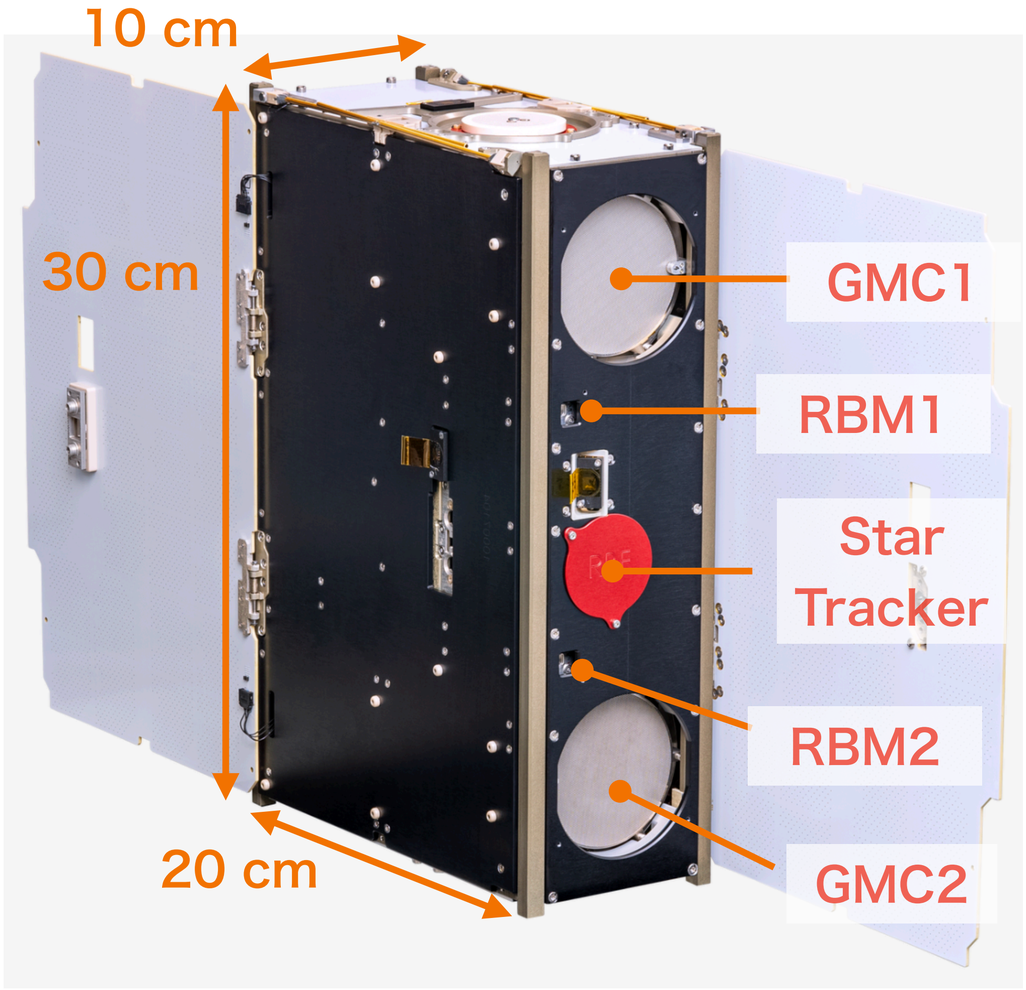
NinjaSat overview

Objectives

- Long-term monitoring of bright X-ray sources.
- Follow-up observations of unexpected objects.

Science payloads

	Gas Multiplier Counter (GMC)	Radiation Belt Monitor (RBM)
Role	Main instrument X-ray detector	Environment monitor Issue alert
Mass, Power	1.2 kg, 1.8 W	70 g, 1 W
Sensor	Xe/Ar/DME gas	Si-PIN diode
Energy	2–50 keV	>200 keV electron >5 MeV proton

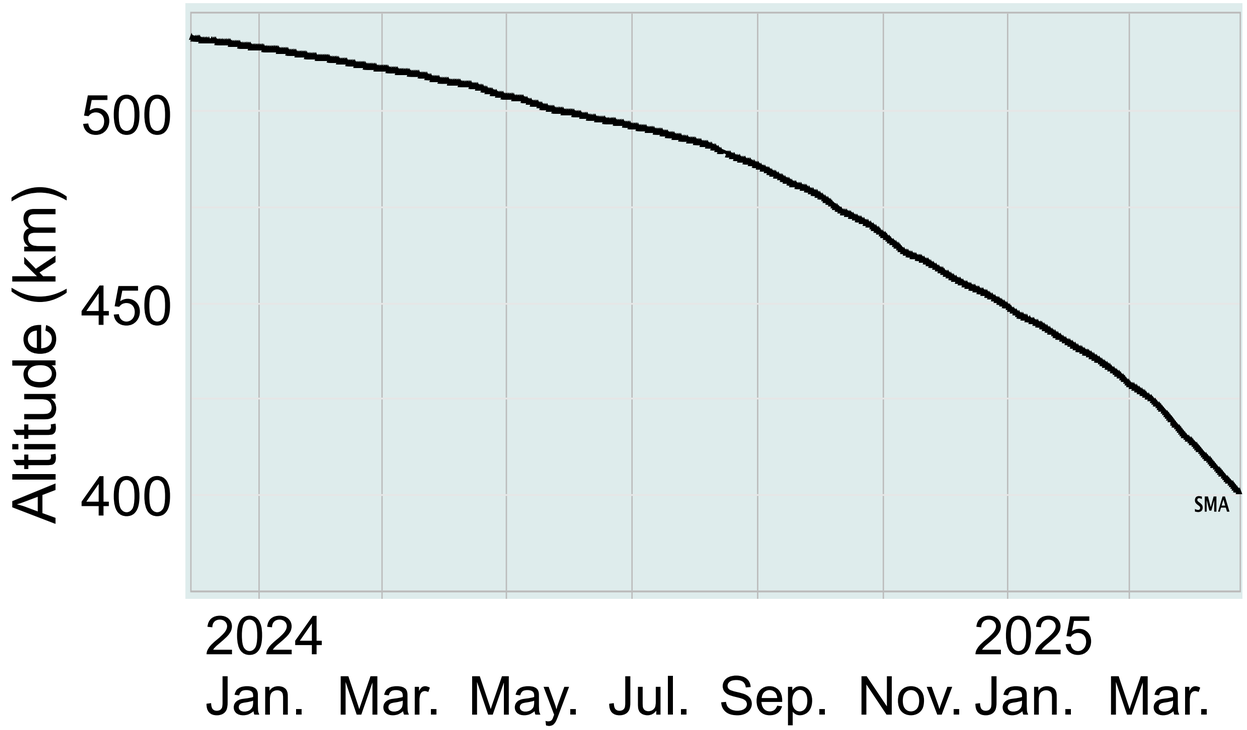


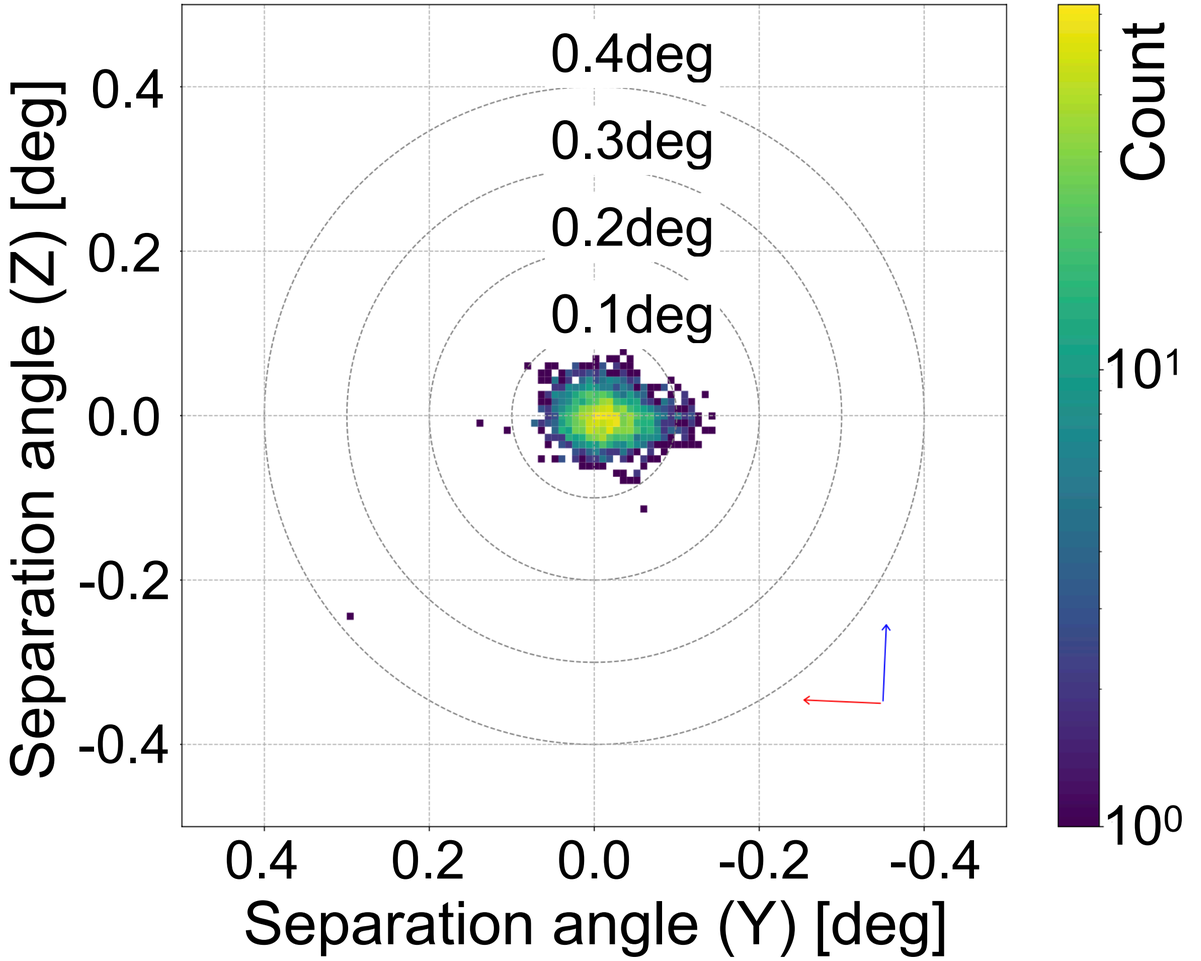
Satellite bus (NanoAvionics)
Mass: 8 kg, Power: 16 W.

Project history

NinjaSat satellite bus

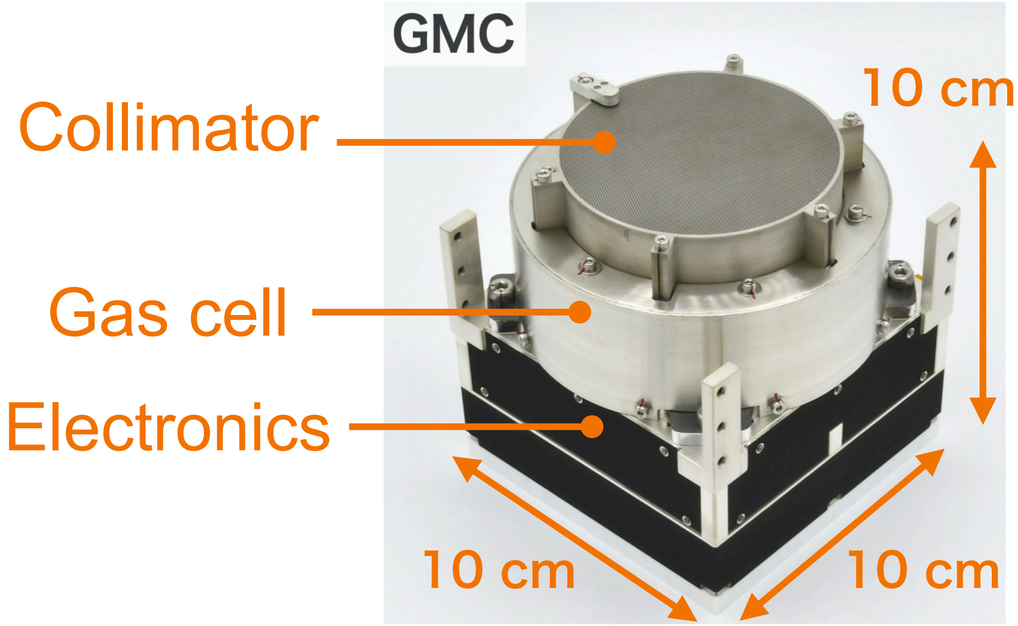
- Sun-synchronous polar orbit
  - Deployed altitude: 530 km (Nov. 2023)
  - Re-entry prediction
    <350 km in summer of 2025
- GPS module receives absolute time and location data (NMEA format).
- Star Tracker sun avoidance: 35˚
- Satellite pointing accuracy < 0.1˚ (2σ)

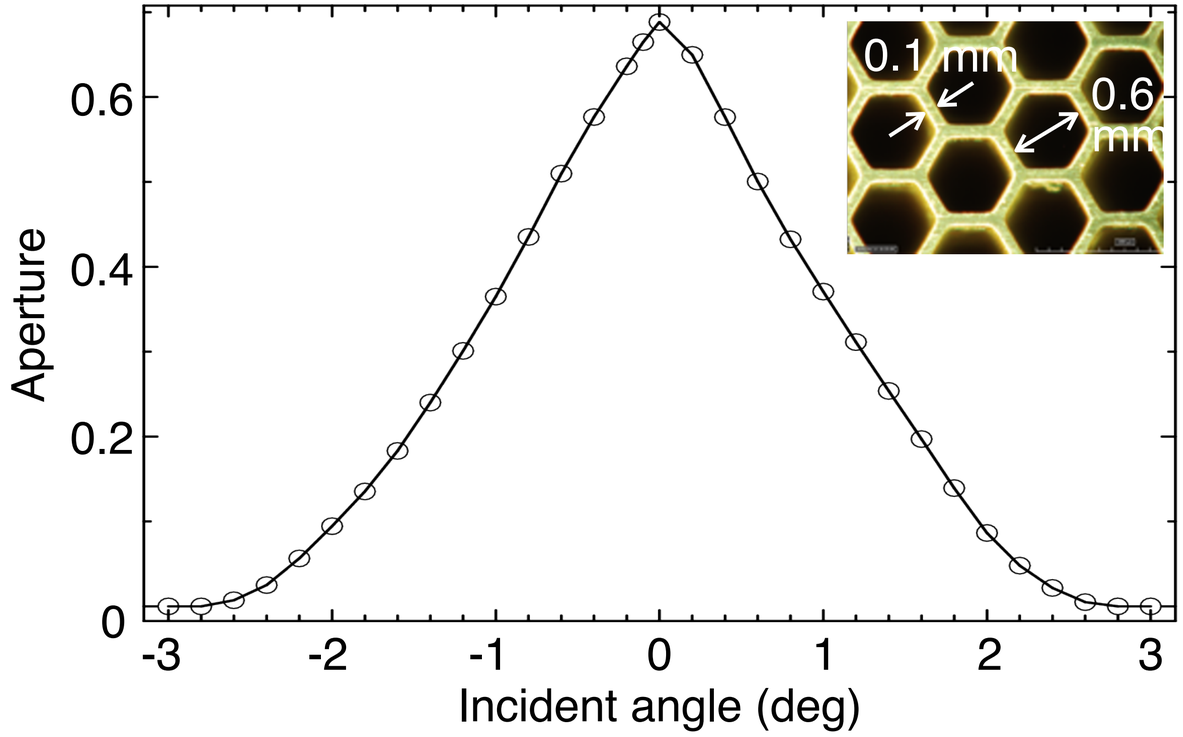


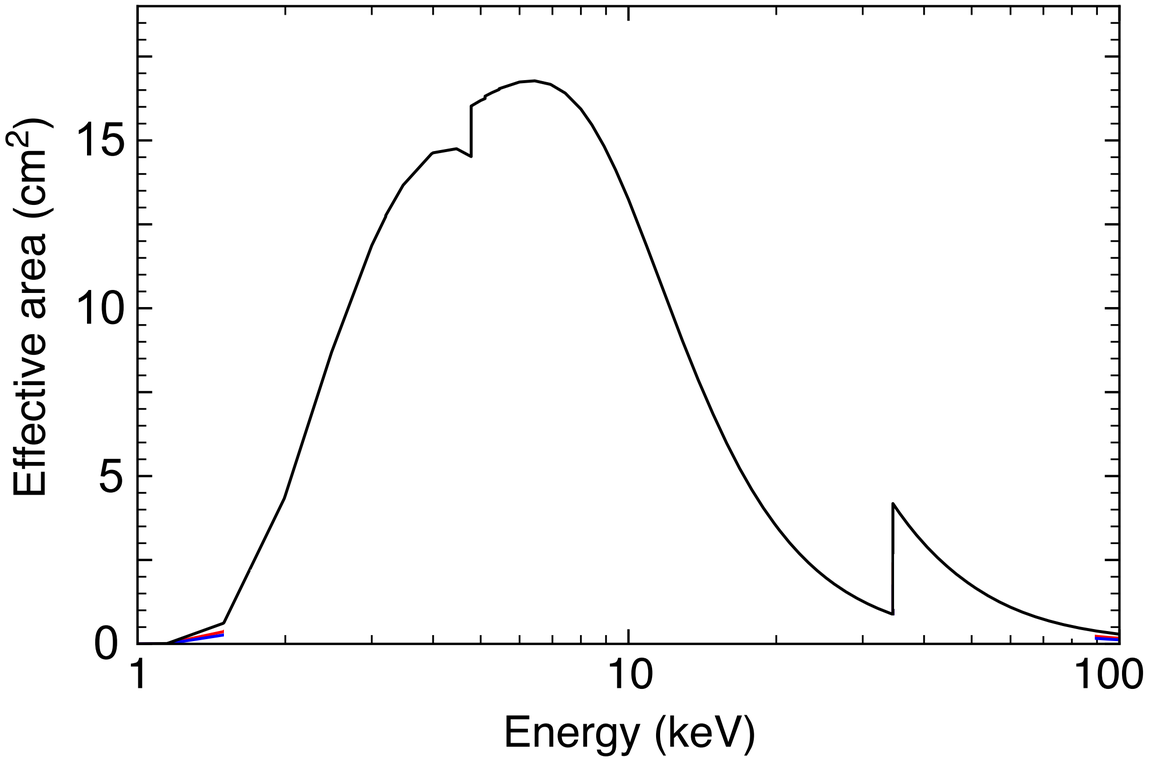


Specification of GMC

- Field of view : 2.1˚ (FWHM)
- Effective area (1 units): 16 cm² @ 6 keV
- Time measurement resolution: 61 μs

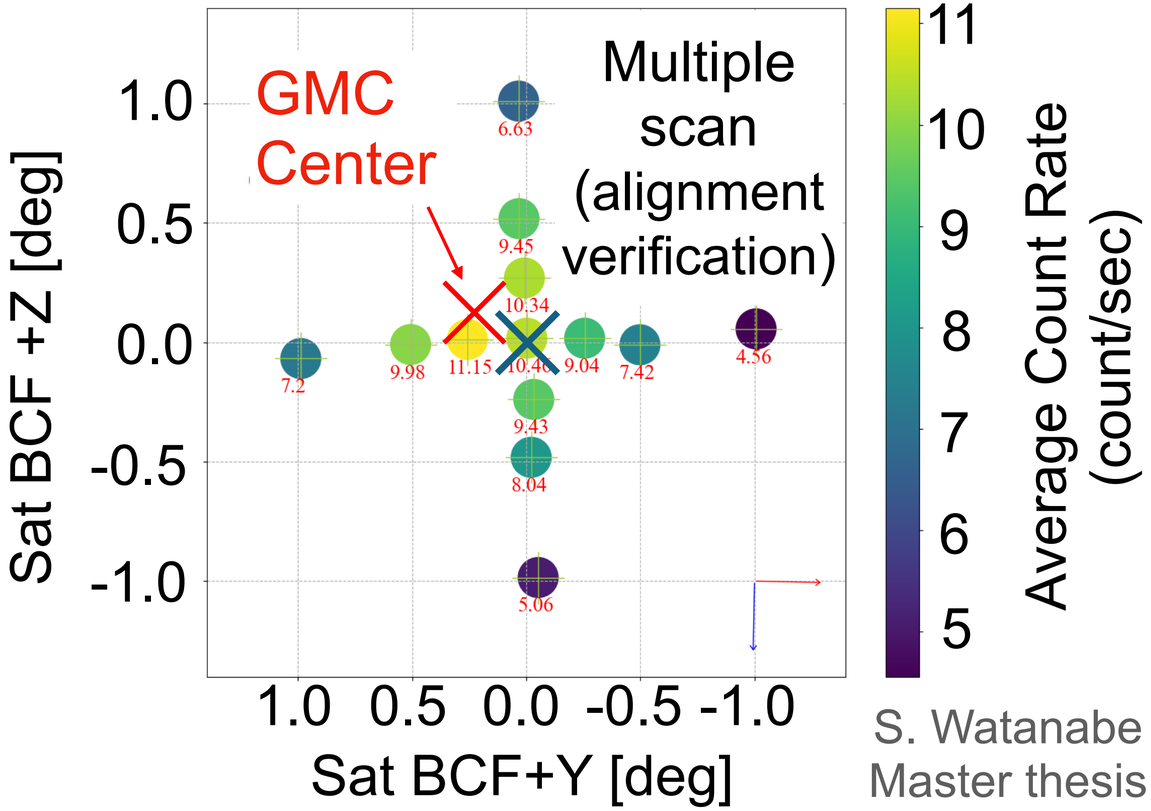




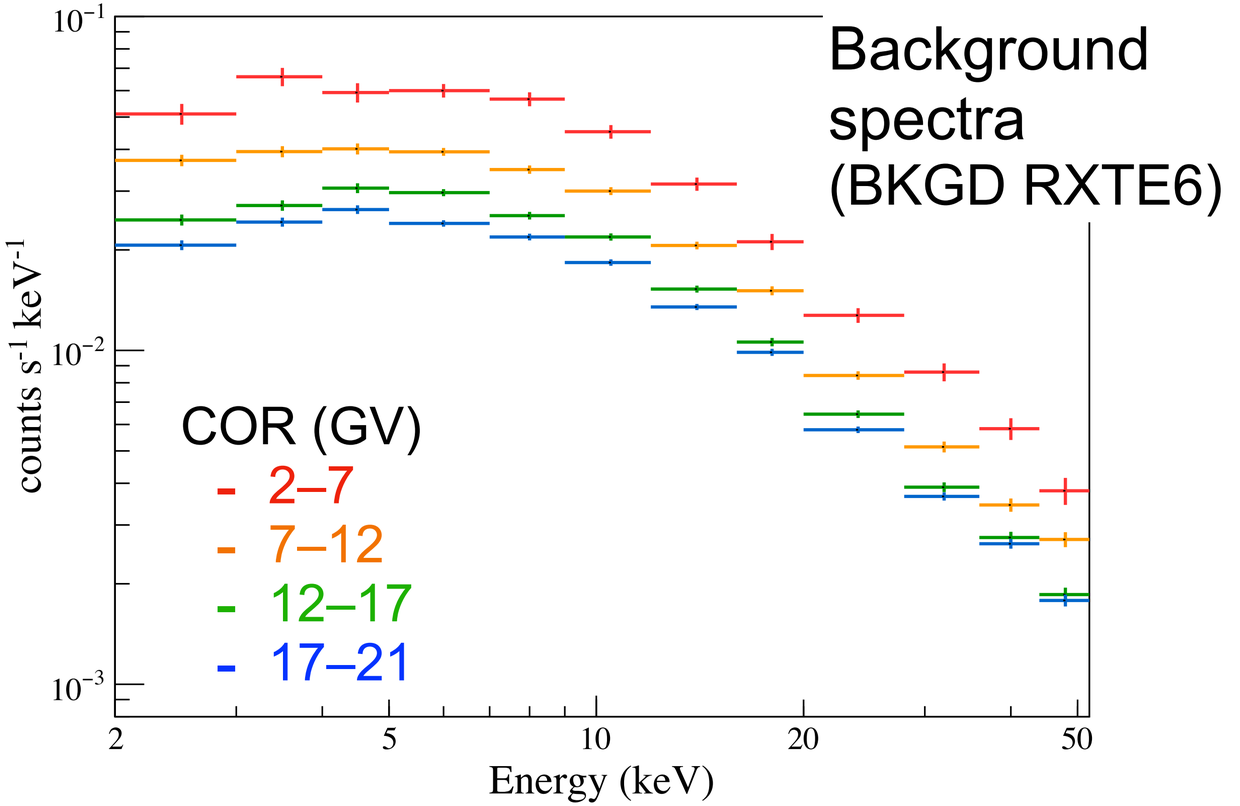


In-orbit calibration history

		2024											2025		
		2	3	4	5	6	7	8	9	10	11	12	1	2	3
Crab	Normal pointing	→	→	→						→	→	→	→	→	→
	Specific operation		Scan →									Scan →	Polar obs. →	→	→
Blank sky				→	→		→			→	→	→	→	→	→

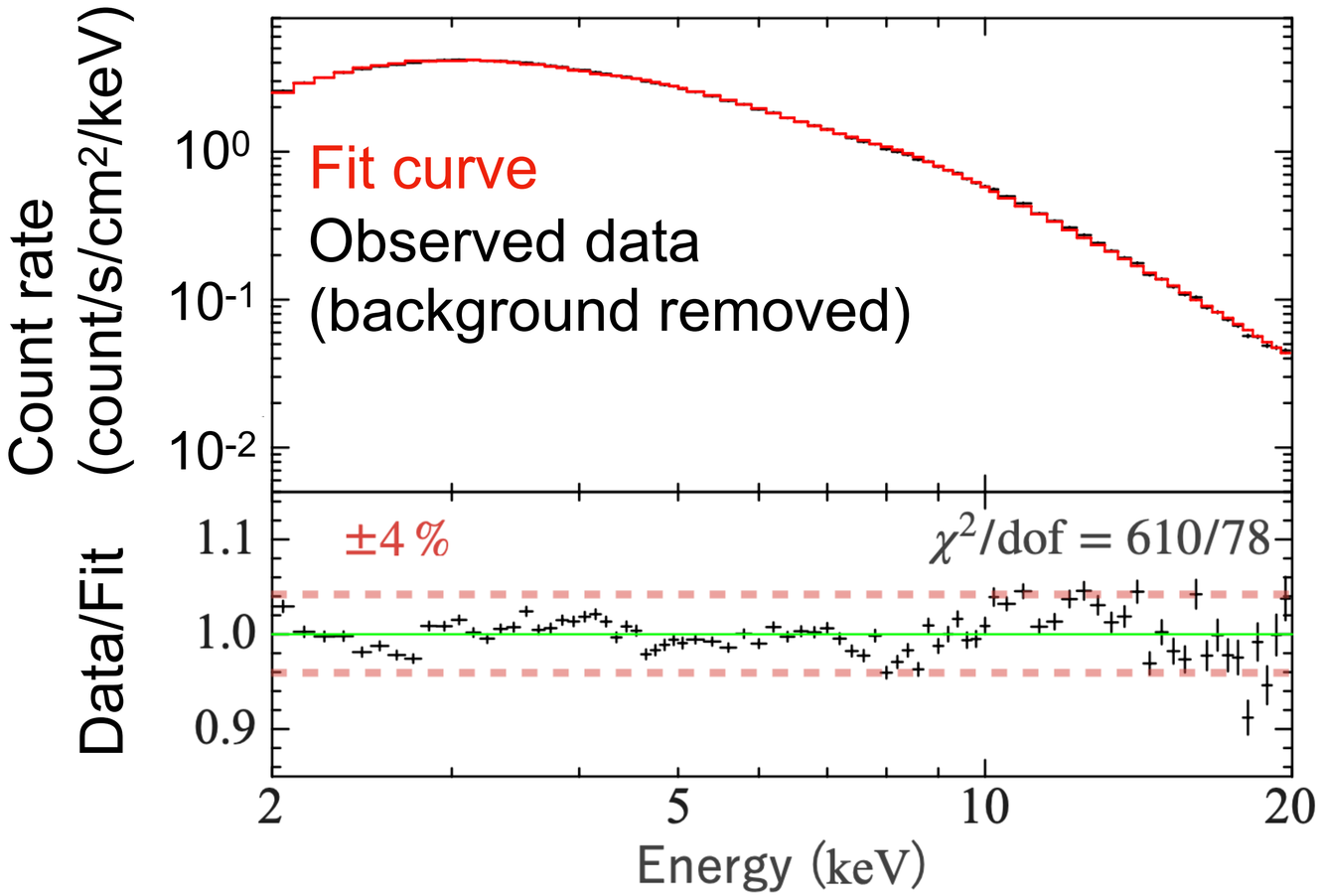


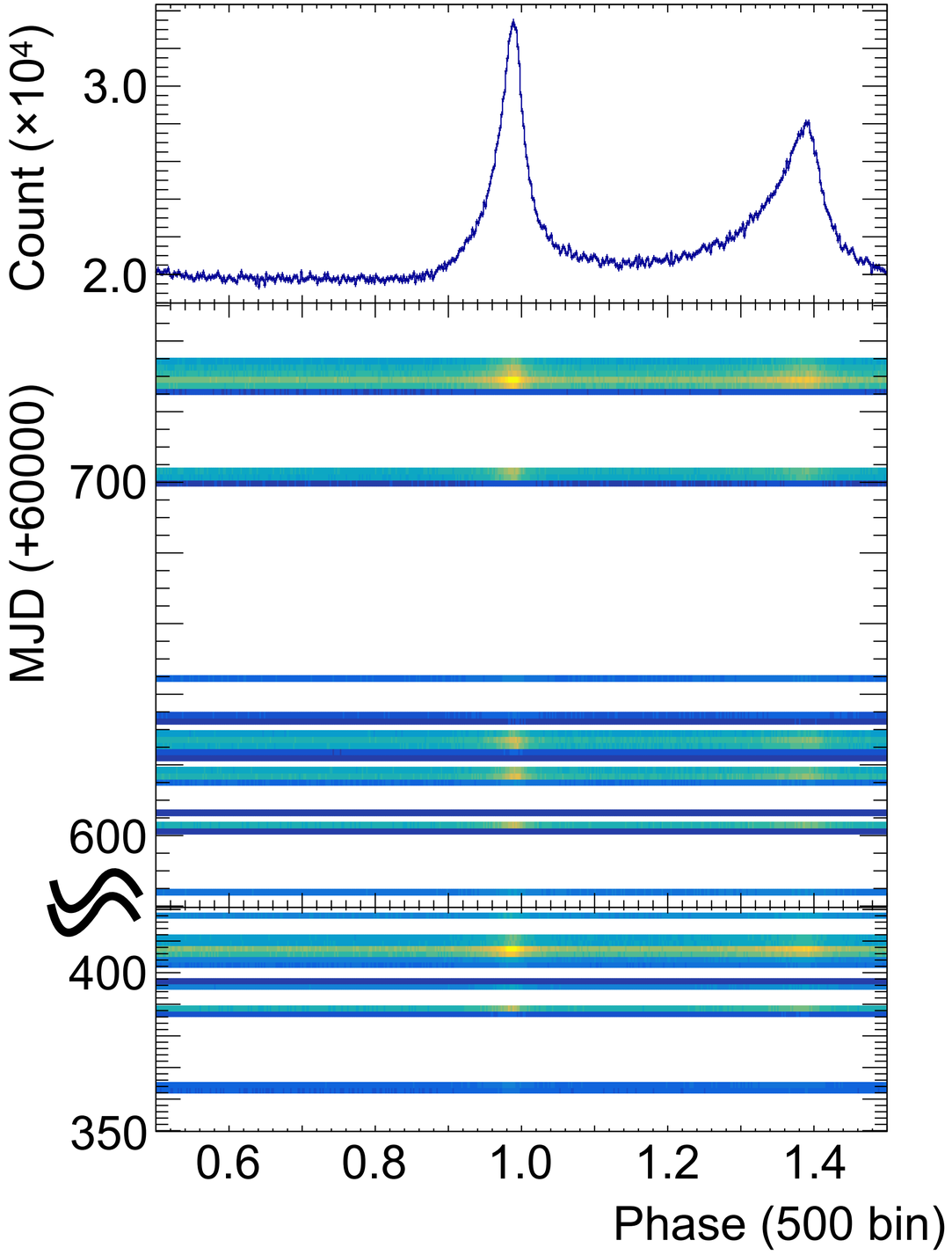
S. Watanabe
Master thesis



Crab nebula observation

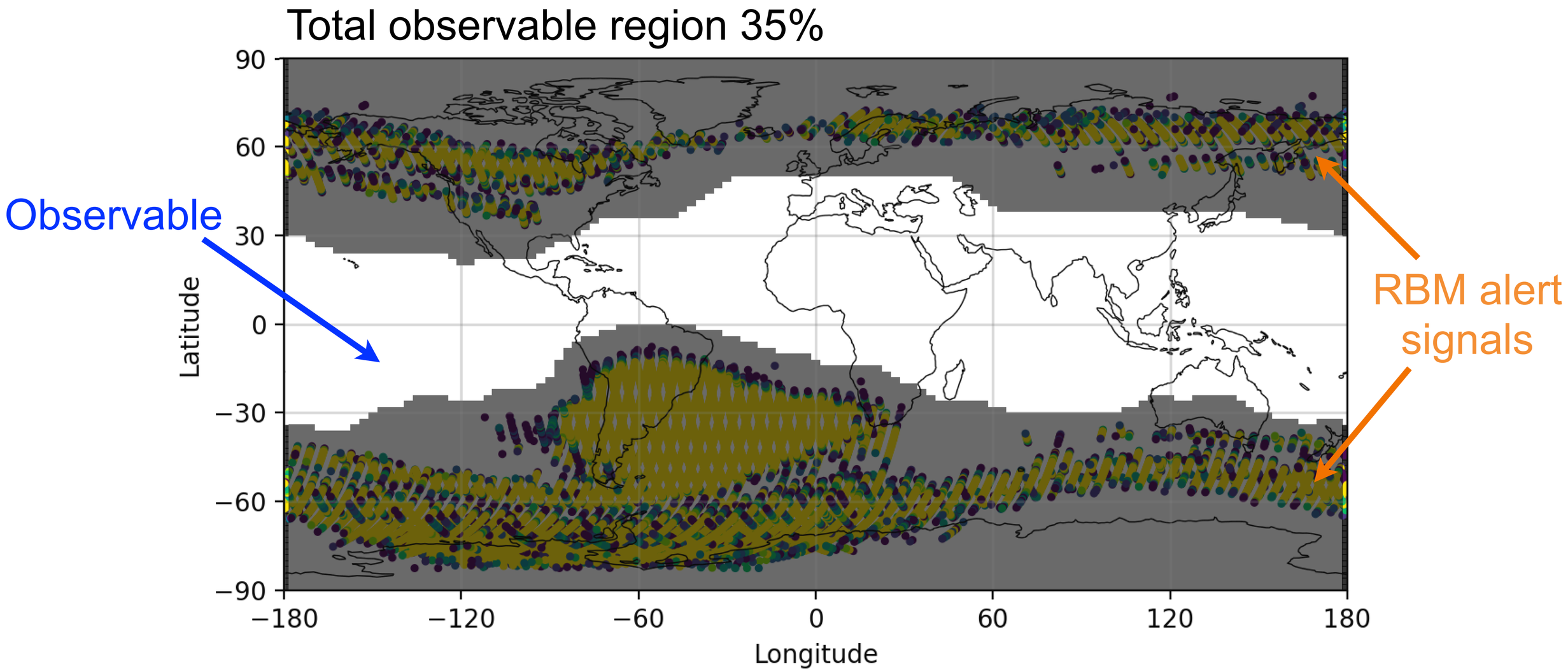
- Spectrum calibration
  (given by Amira Aoyama's talk)
- Timing calibration
  (given by Takuya Takahashi's talk)





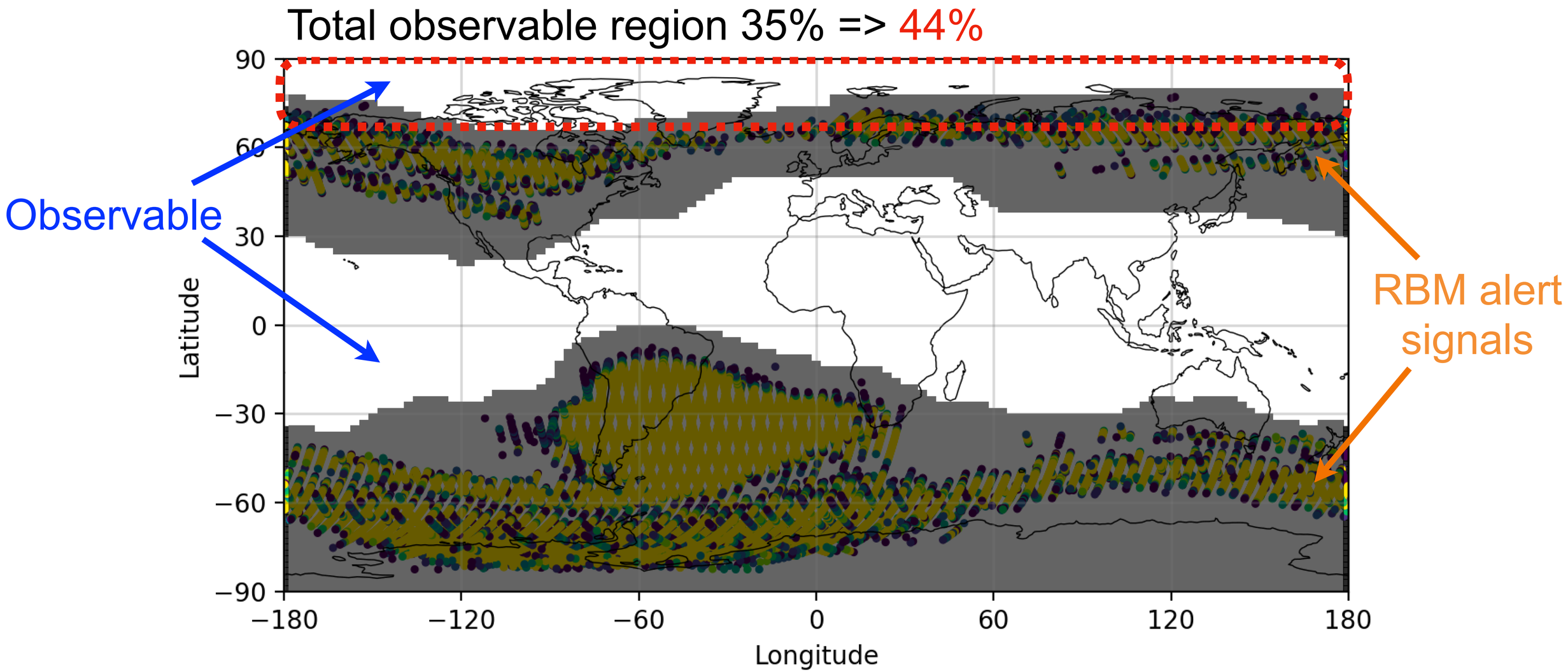
Demonstration of observation at polar region

- CubeSats are launched as ride-shares and the available orbits are restricted.
- Operational time of GMC is limited by radiation belts.



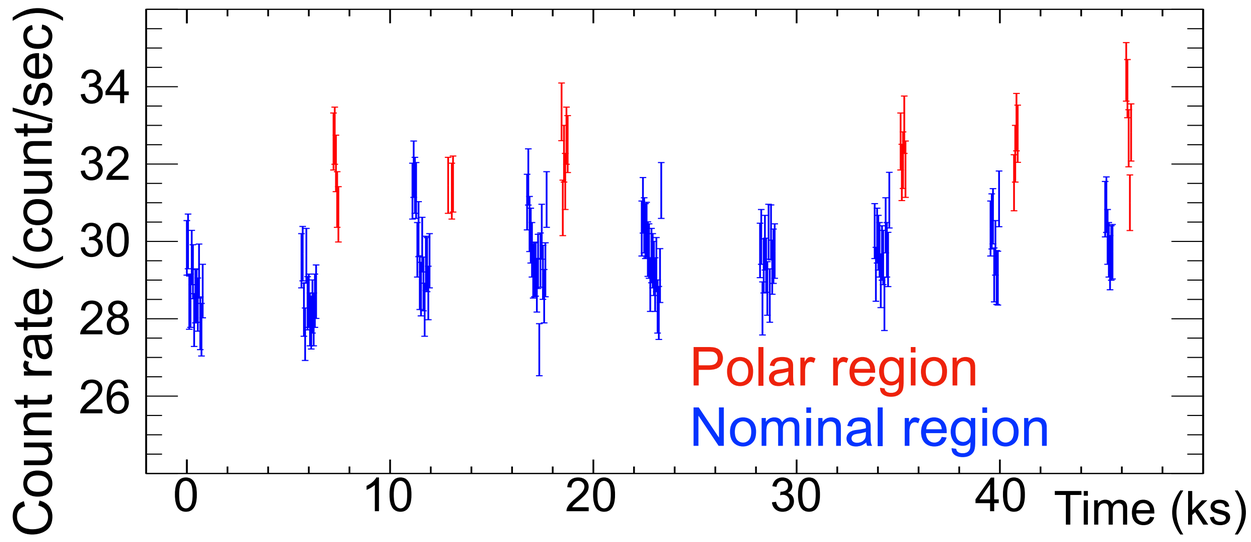
Demonstration of observation at polar region

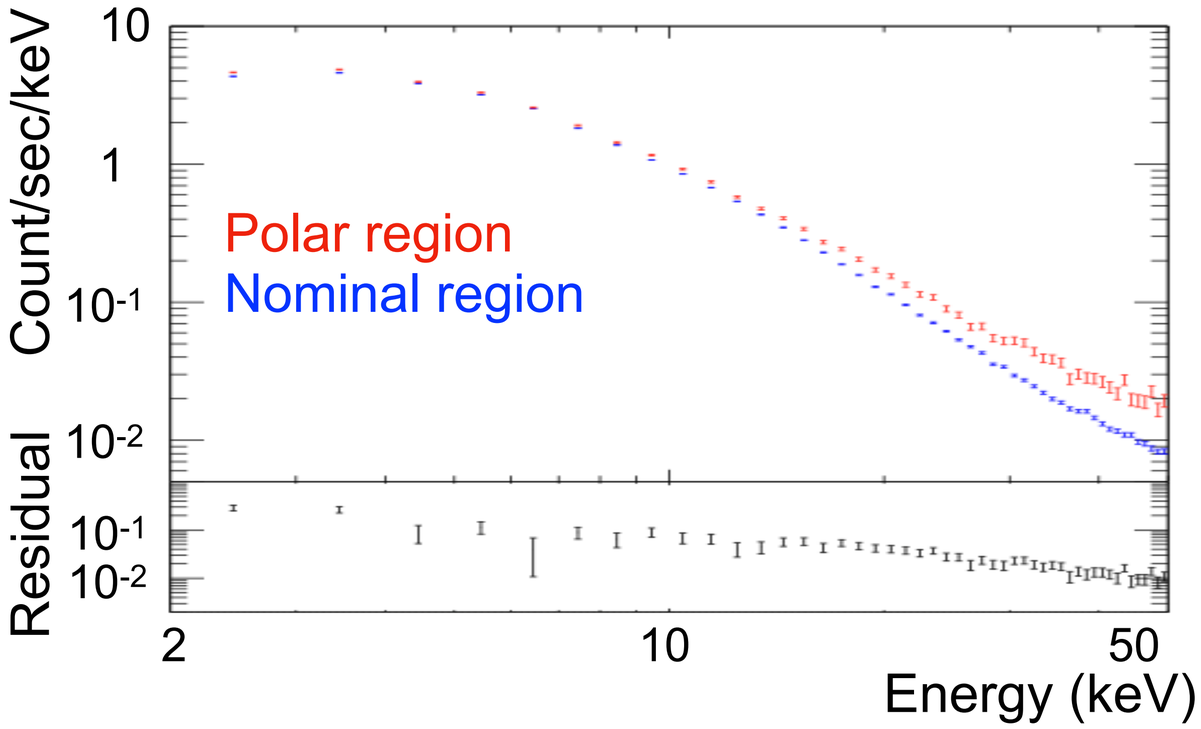
- RBM alert is calm above northern aurora belt.
- We perform Crab Nebula pointing at north polar region.

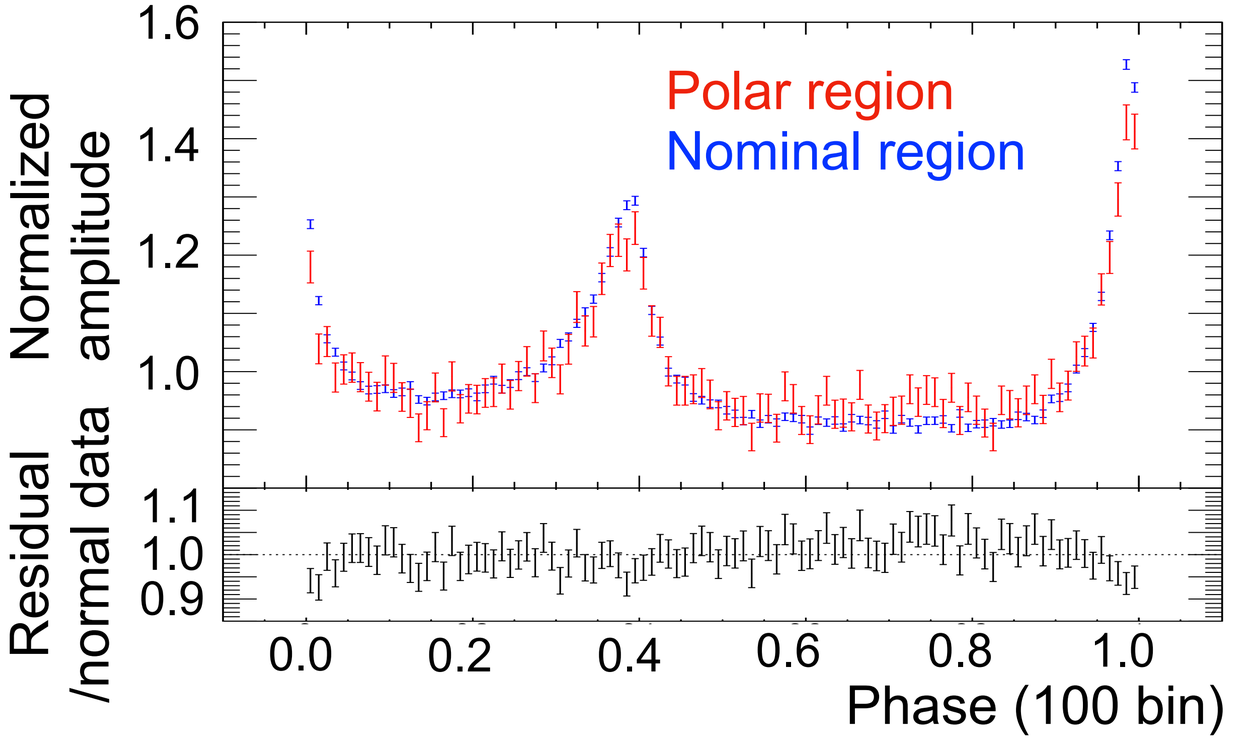


Results of Crab observation at polar region

- Background ratio increase in high energy band (>10 keV).
  - Need background model.
- Pulse phase is consistent and pulsed fraction residual < 10%.
  - Useable for timing measurement of bright source.







Observed source list

Neutron Star: 22 Black Hole: 2 Active Galactic Nuclei: 3 White Dwarf: 1

	Source name	Type
1	Crab Nebula	NS
2	Sco X-1	NS
3	SRGA J144459.2-604207	NS
4	EXO 0748-676	NS
5	4U 1636-536	NS
6	GX 17+2	NS
7	Cyg X-1	BH
8	Cyg X-2	NS
9	MXB 1730-335	NS
10	Her X-1	NS
11	SMC X-1	NS
12	GX 301-2	NS
13	4U 0115+63	NS
14	1E 1841-045	NS

	Source name	Type
15	GX 339-4	NS
16	NGC 4151	AGN
17	NGC 526	AGN
18	T CrB	WD
19	Aql X-1	NS
20	GX 1+4	NS
21	MAXI J1752-457	NS
22	Cen X-3	NS
23	IC 4329A	AGN
24	MAXI J1744-294	BH
25	Cir X-1	NS
26	4U 1700-377	NS
27	4U 1538-52	NS
28	4U 0614+091	NS

Scientific results

Astronomical papers: 3

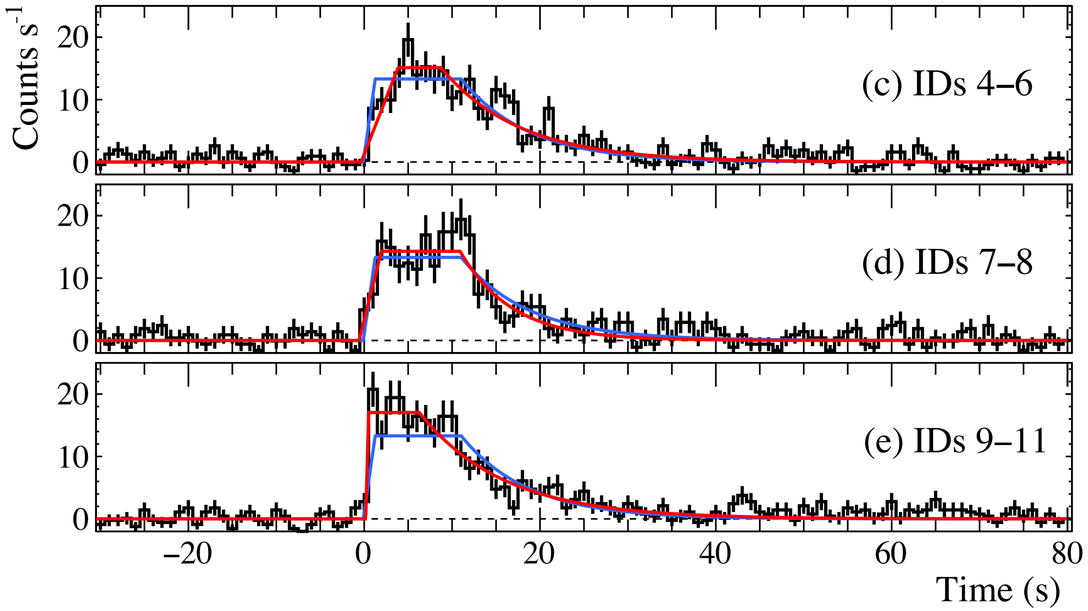
- SRGA J144459.2−604207
  Clocked burster
  - Takeda et al., PASJ77 2025
  - Dohi et al., PASJ77 2025

- MAXI J1752−457
  Super-burst
  - Aoyama et al. (under review)
    given by Amira Aoyama's talk
  - Separation angle from sun: 40–50˚
    ➡ **NinjaSat can observe** >35˚

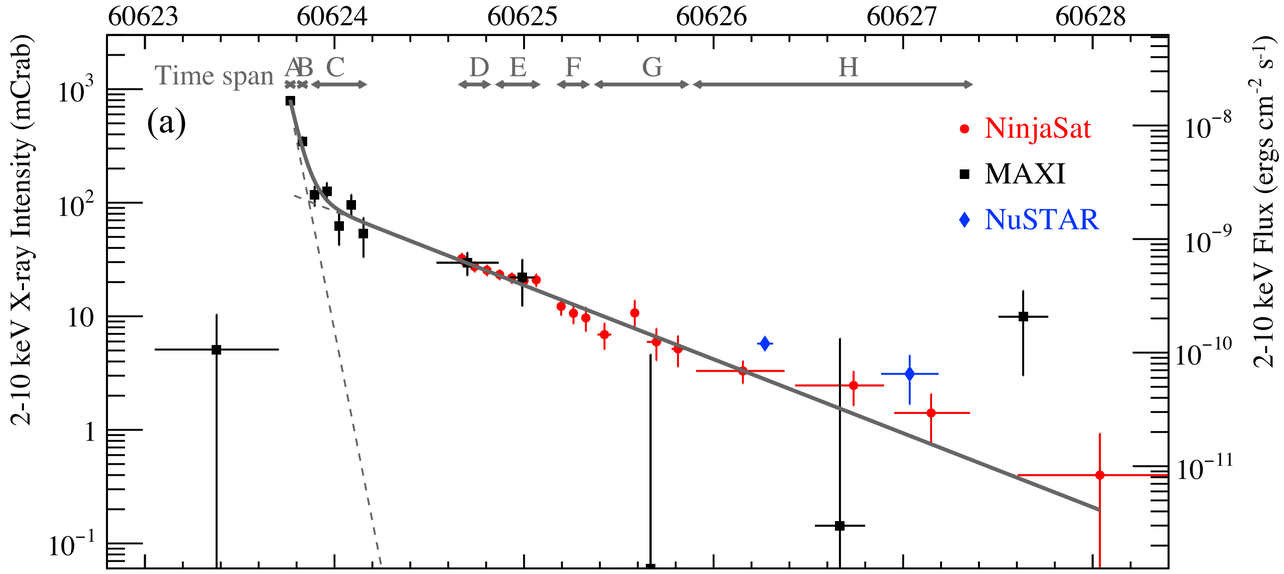
- Other papers are in progress

The Astronomer's Telegram: 4

SRGA J144459.2−604207 burst profile



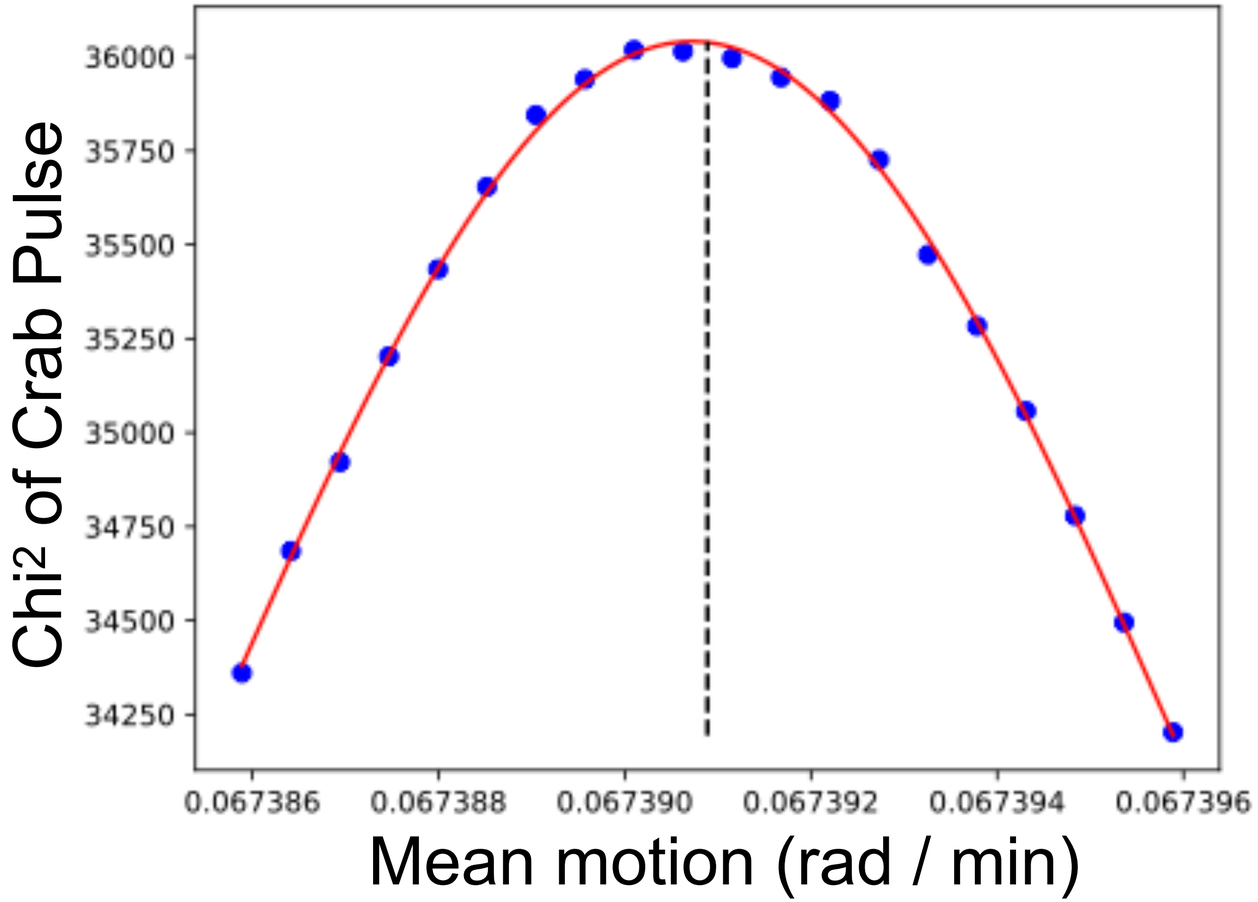
MAXI J1752−457 MAXI J1744 -294 Follow-up



Byproducts

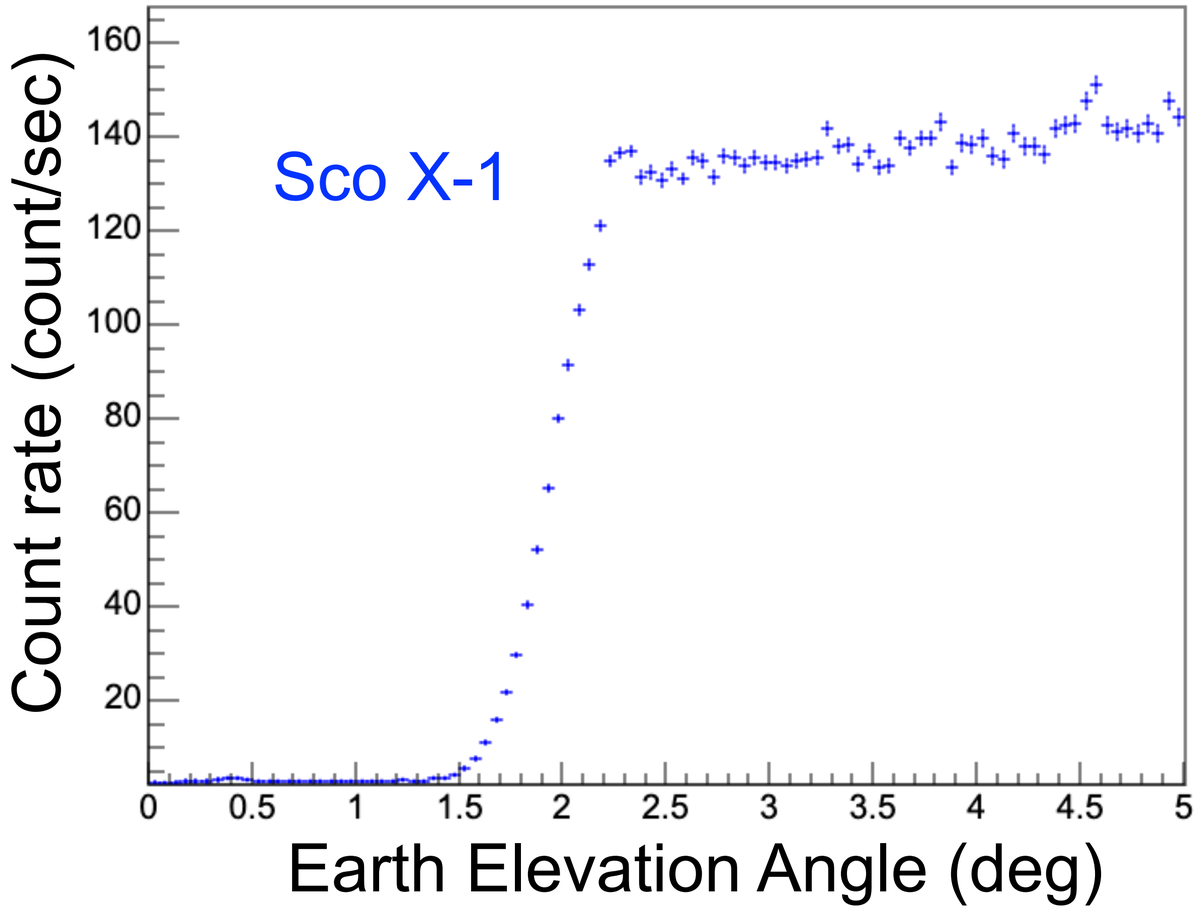
Pulsar-based navigation

Estimate satellite orbit based on significance of pulsar signal.
(Zheng et al. 2019)



Study of atmospheric structure

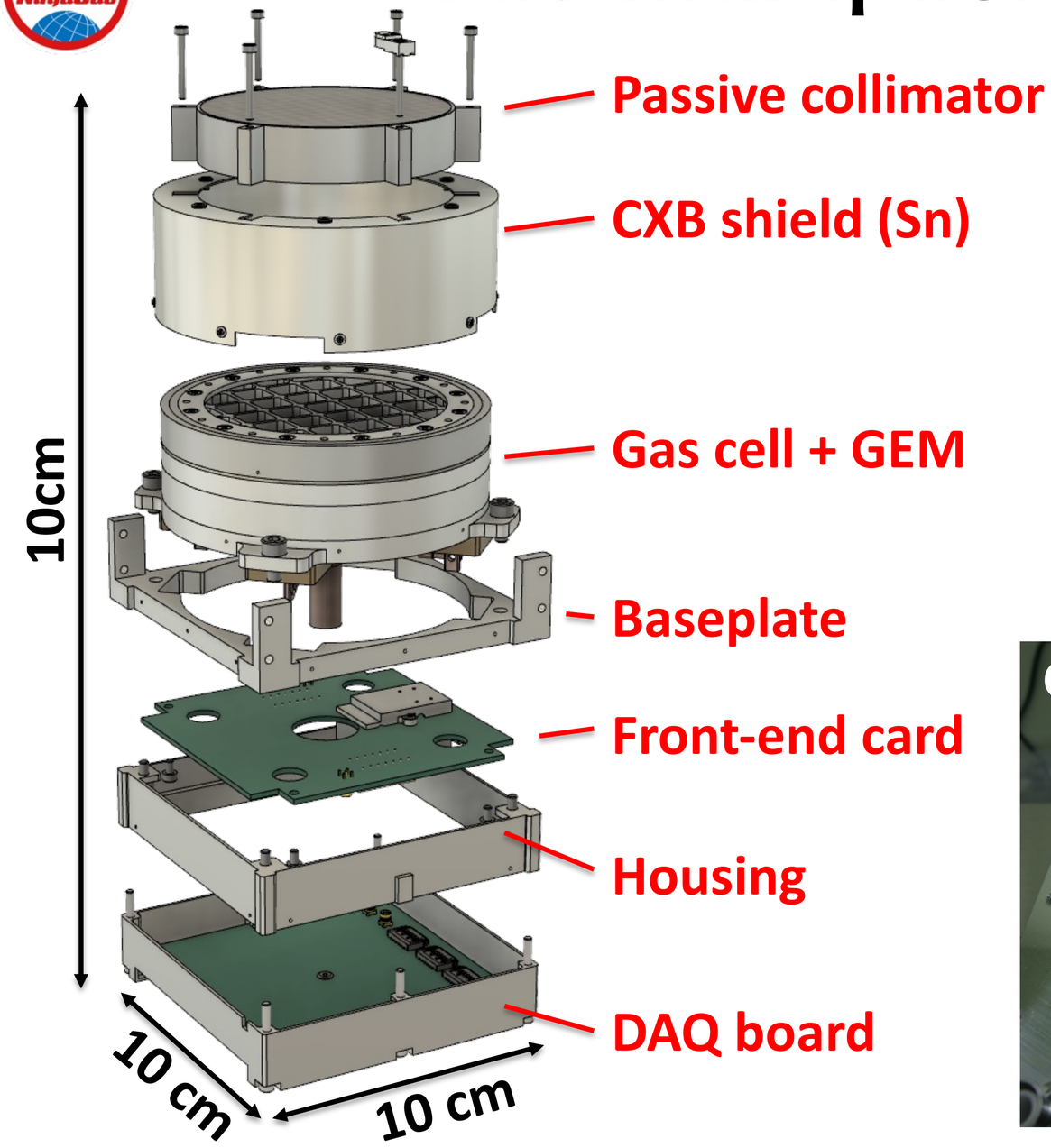
Observe x-ray source occultation / emergence to measure atmospheric density. (Katsuda et al. 2020)

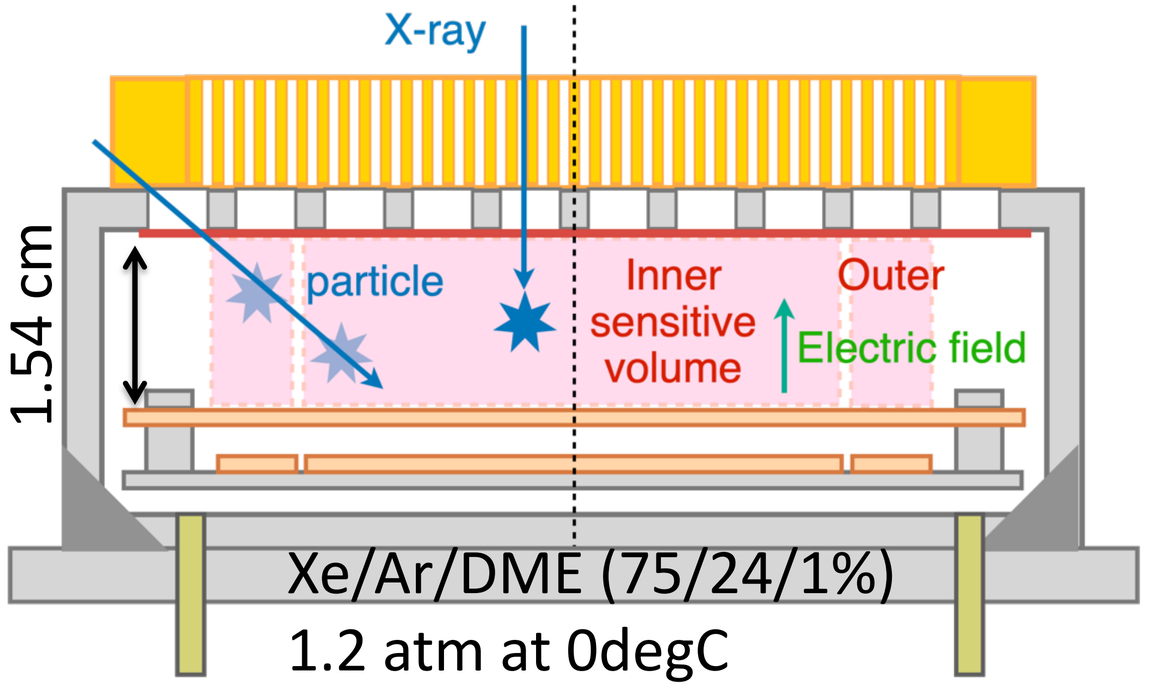


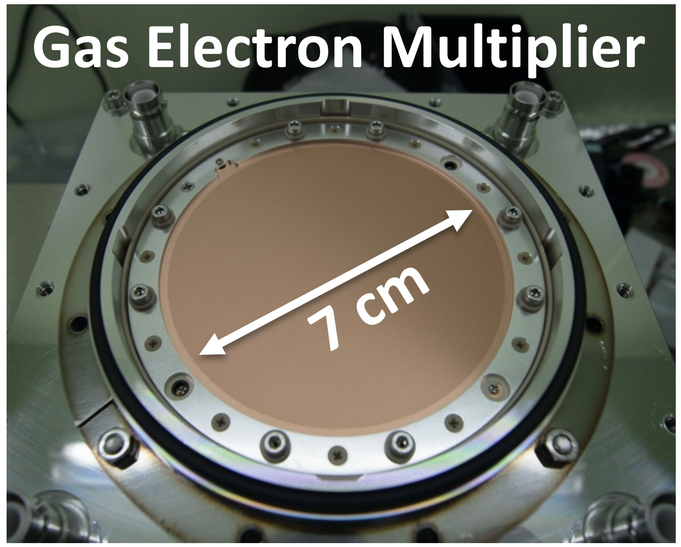
Summary

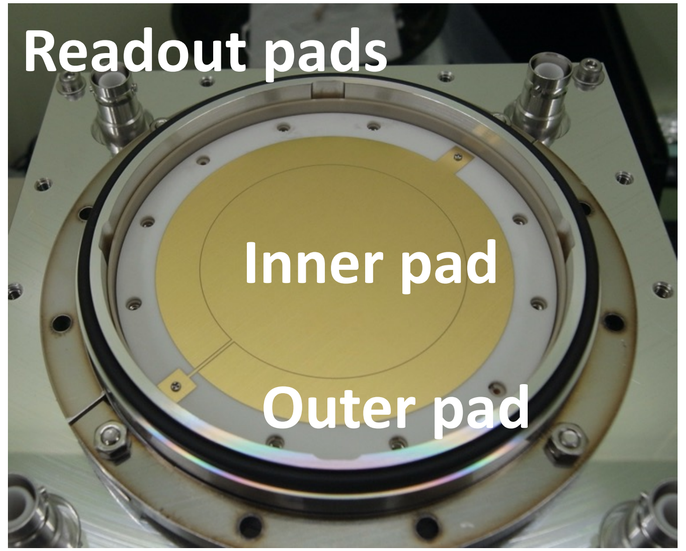
- We observed the Crab Nebula and calibrated timing, spectrum, and detector alignment.
- To increase observation time, a demonstration of observation at the polar regions was performed.
  - Pulse phase is consistent between polar and normal region. The observation data can be useable for timing measurement.
  - More background modeling is needed for spectrum analysis.
- NinjaSat mission succeeds in producing scientific results.
  - 28 sources are observed, 3 astronomical papers are written, and 4 Astronomer's Telegrams are announced.

Gas Multiplier Counters (GMCs)

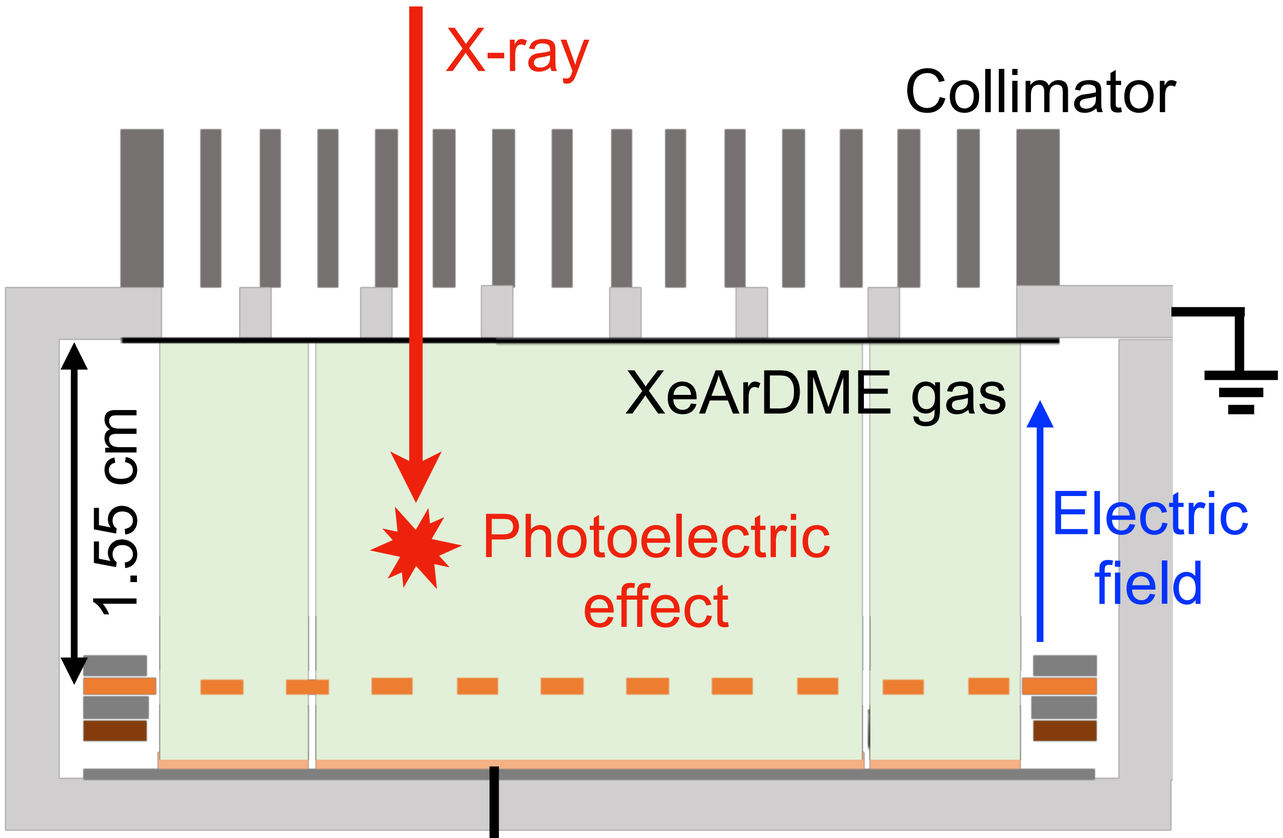


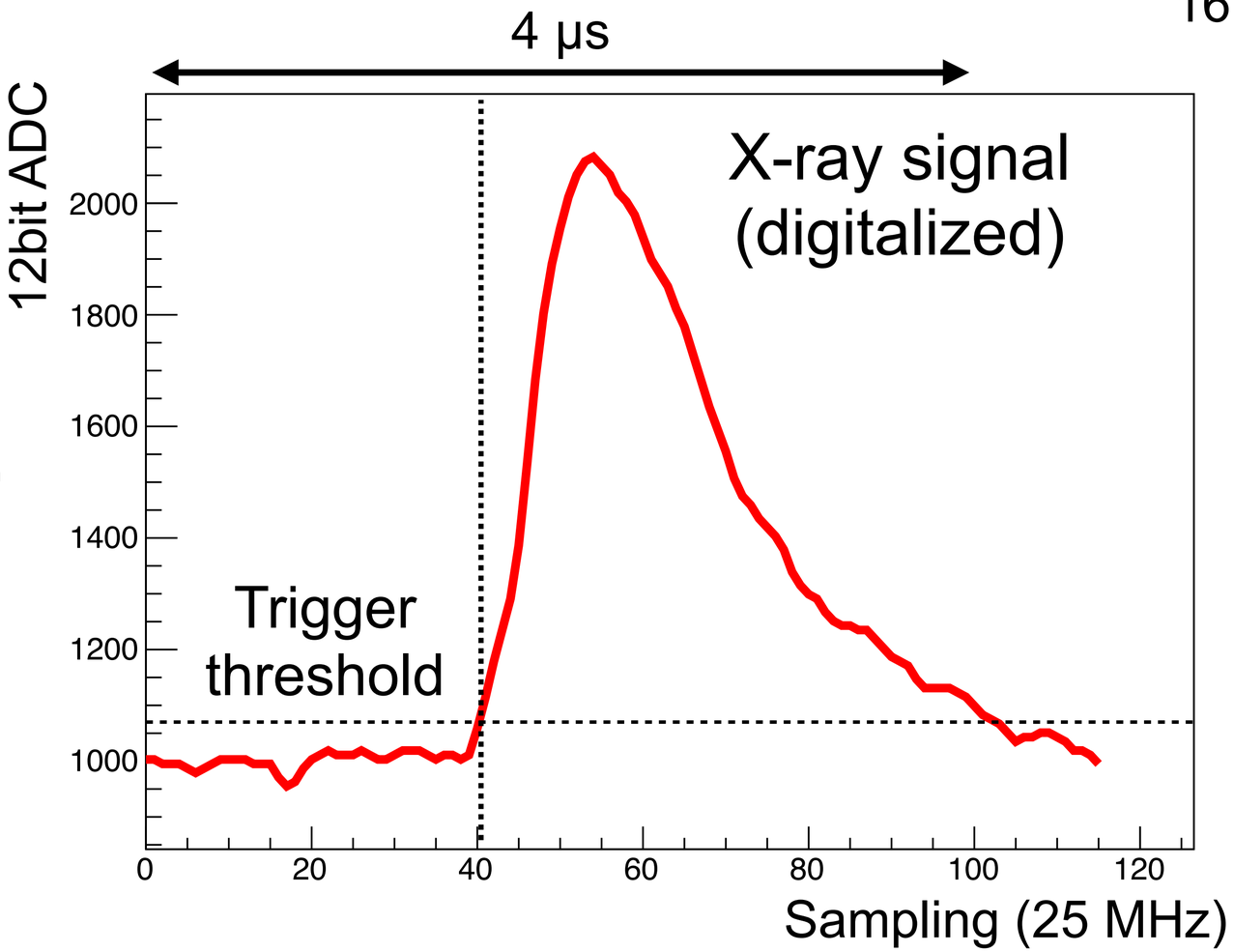


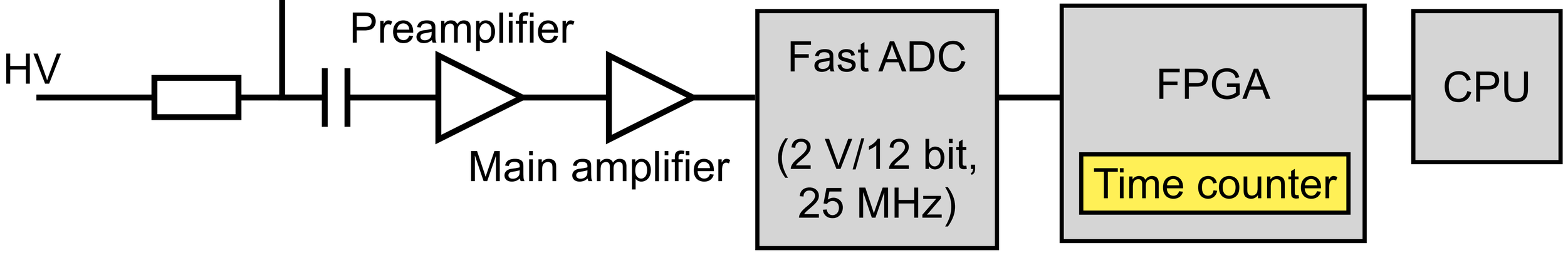




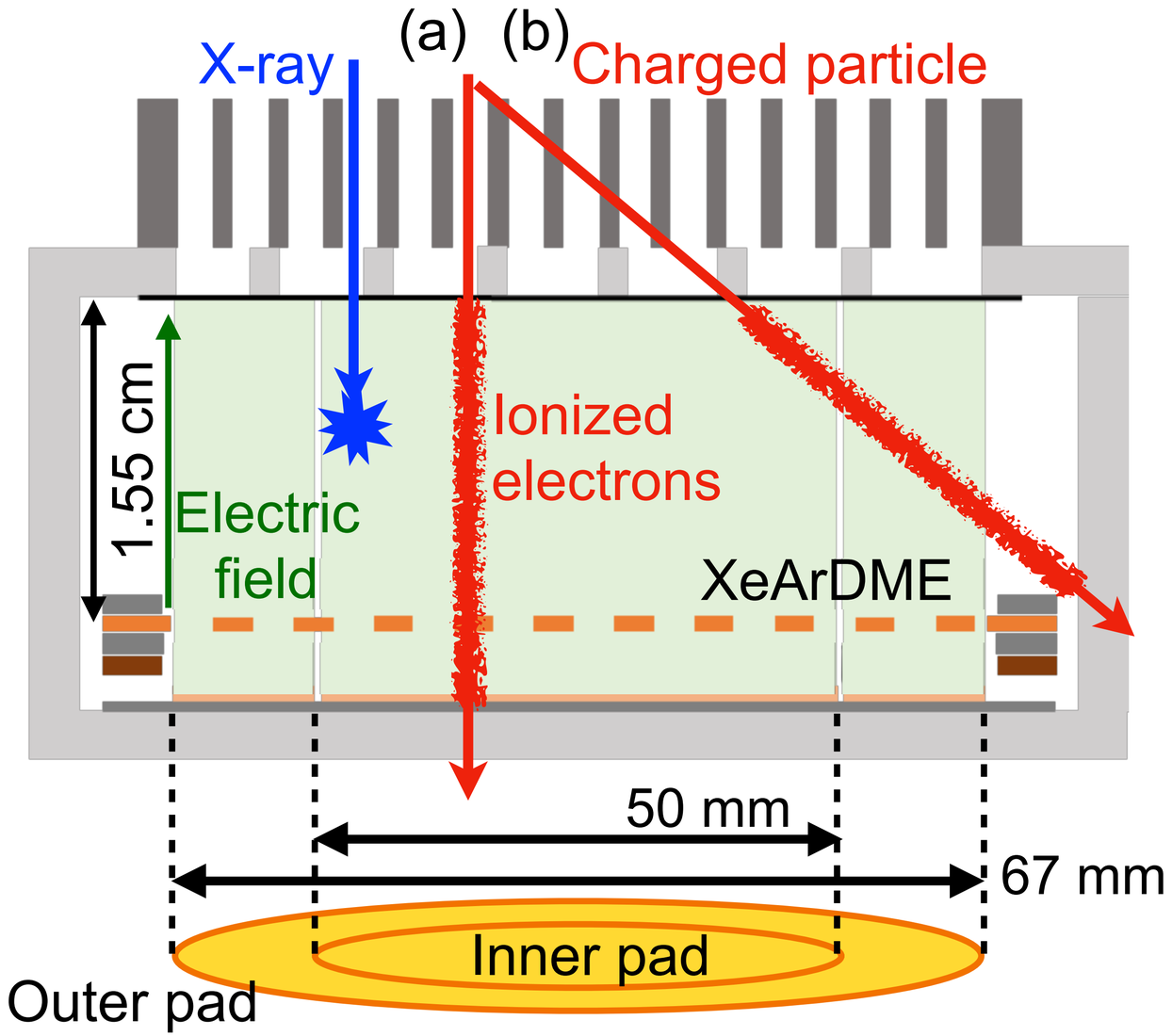
GMC X-ray detection flow





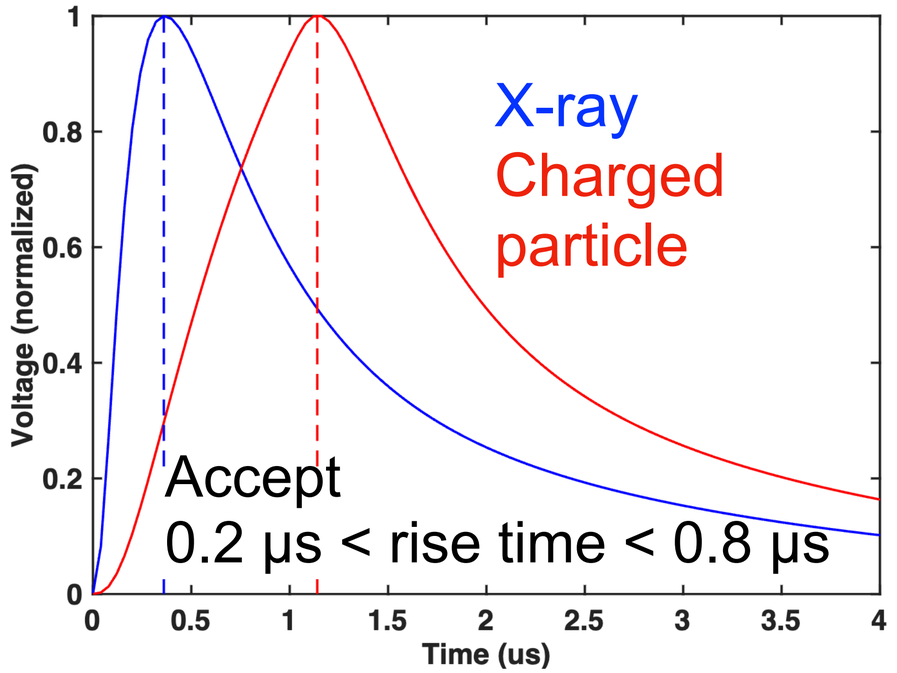


NXB rejection method

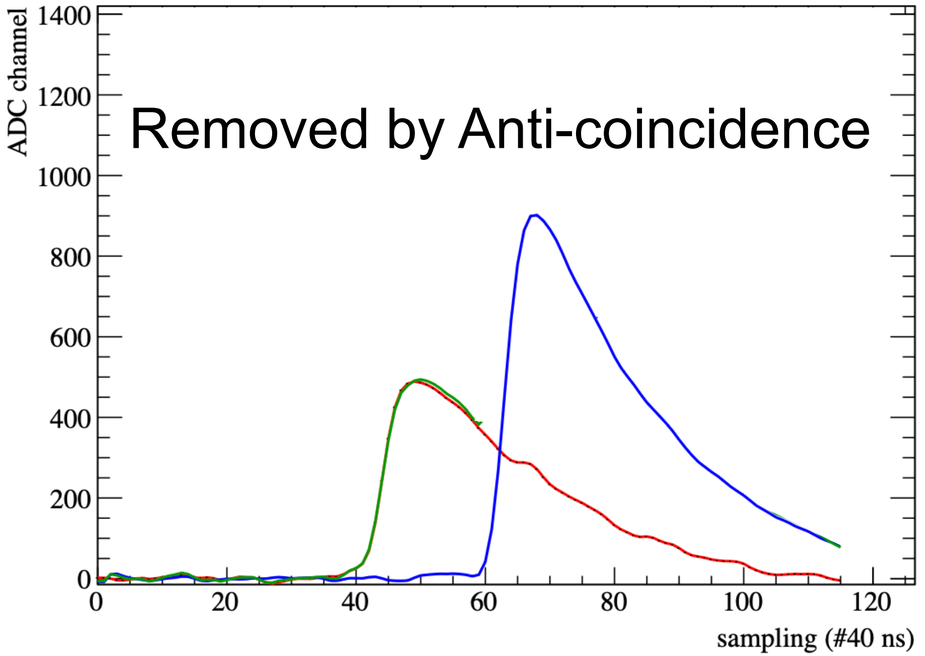


Drift velocity = 1.4 cm/μsec

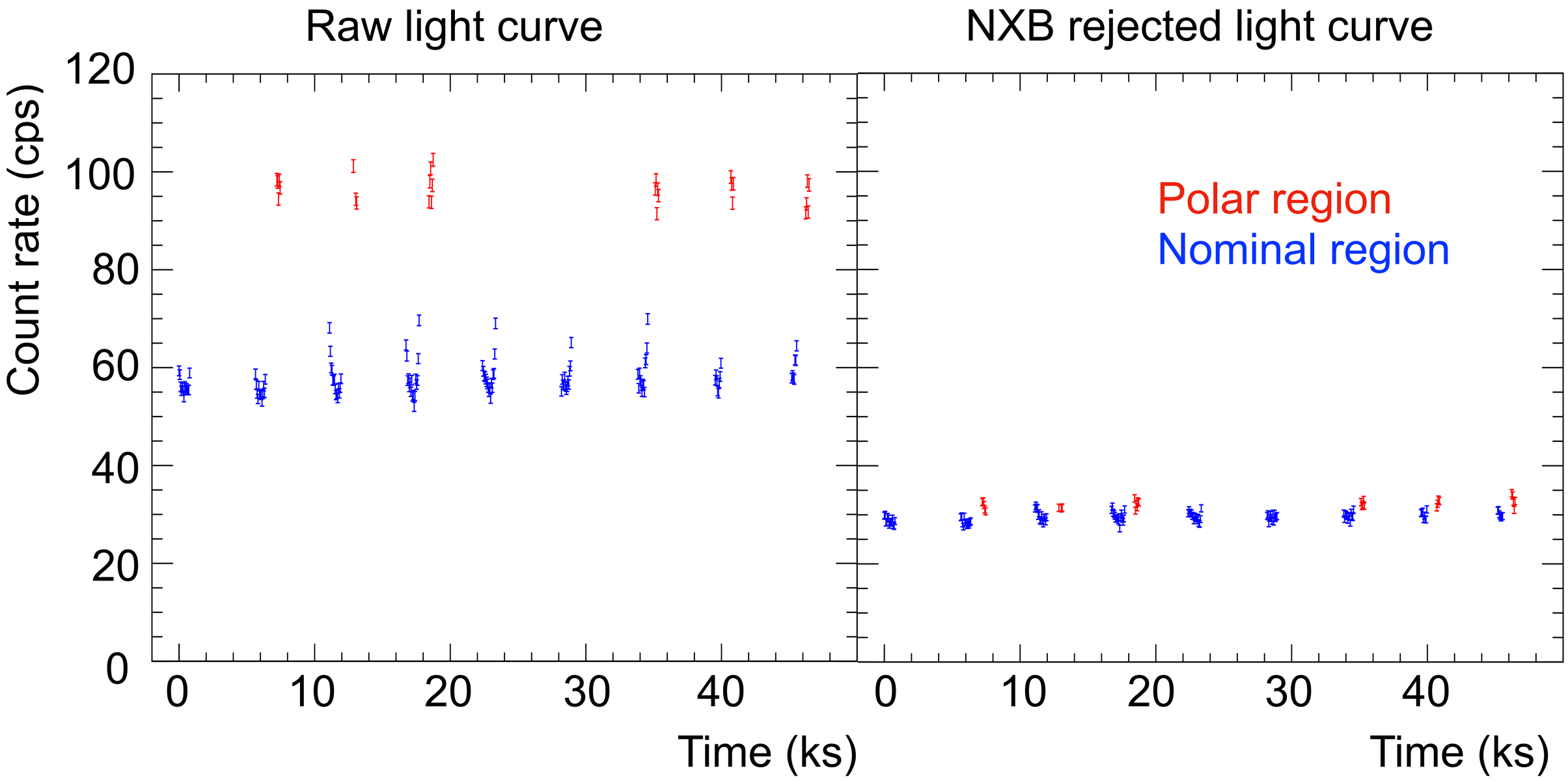
(a)



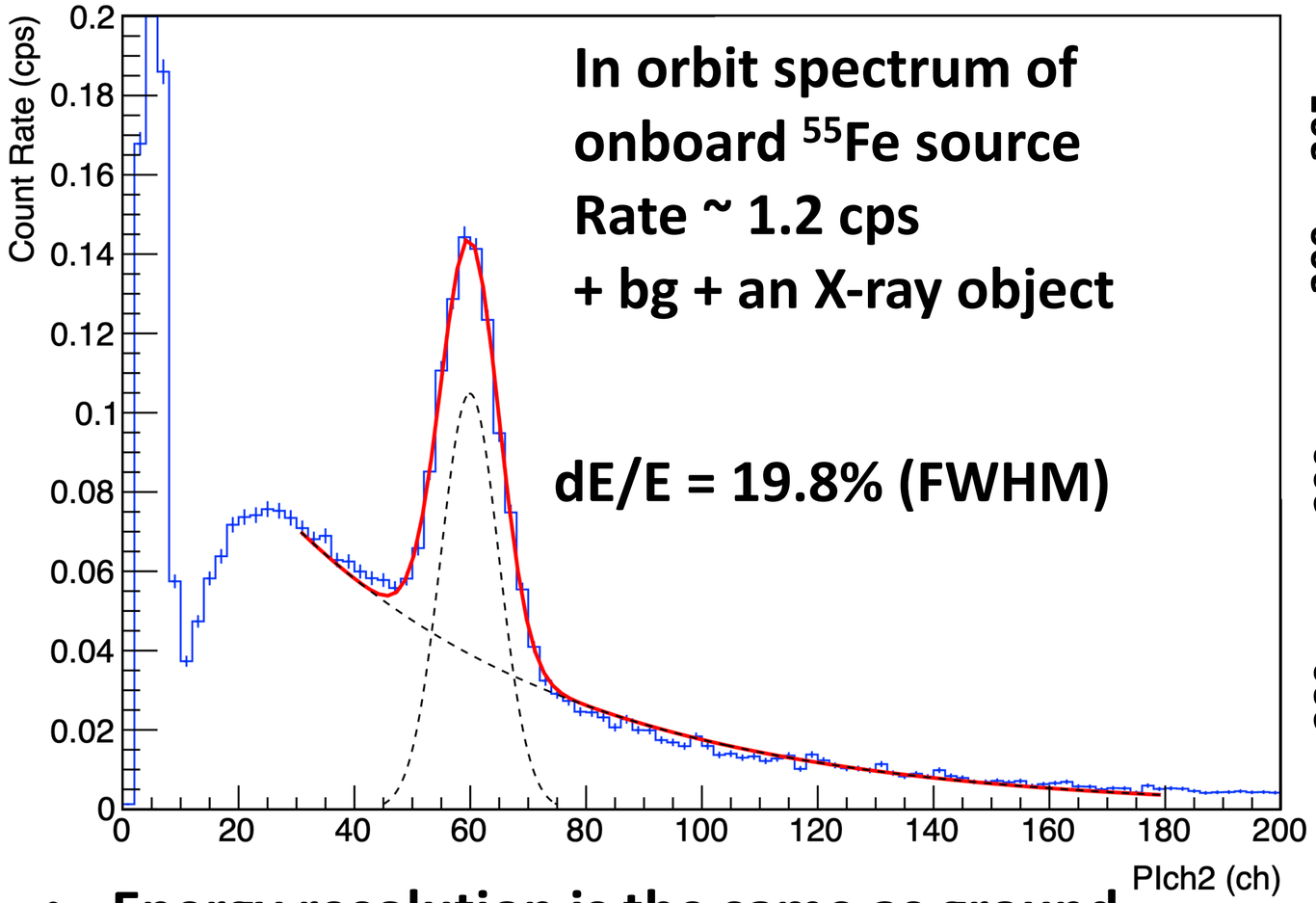
(b)

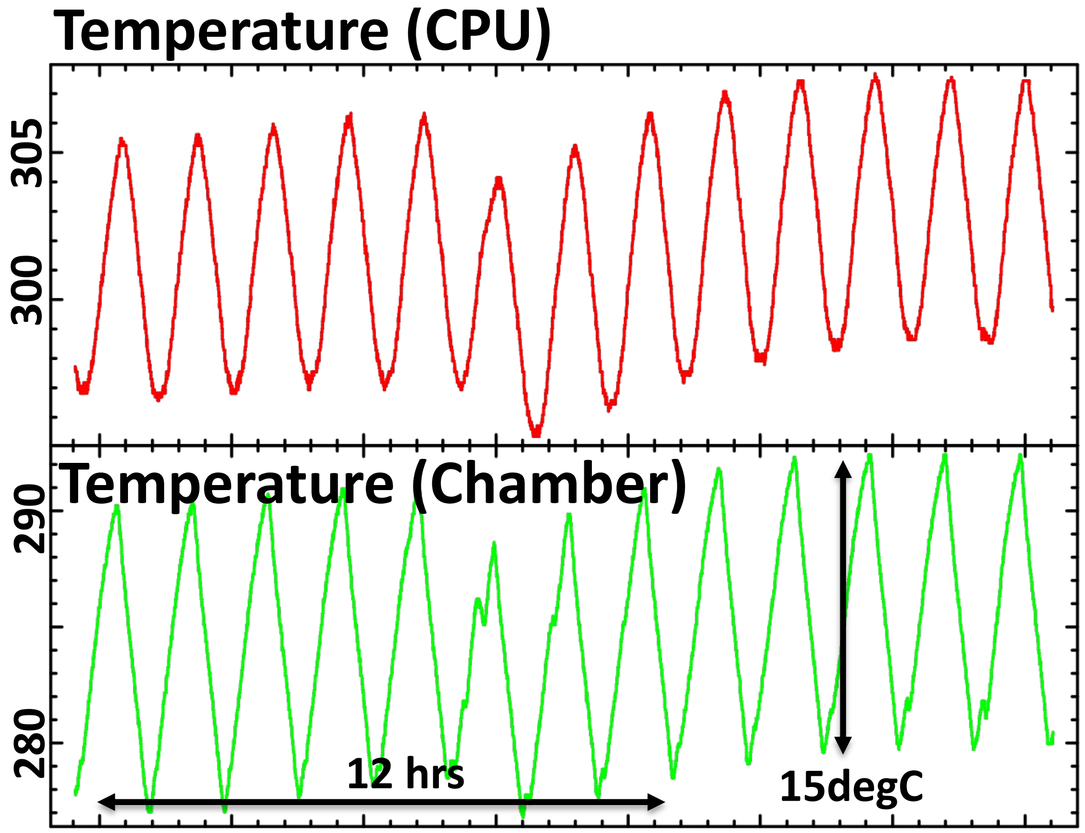


NXB rejection results; polar/normal region comparison



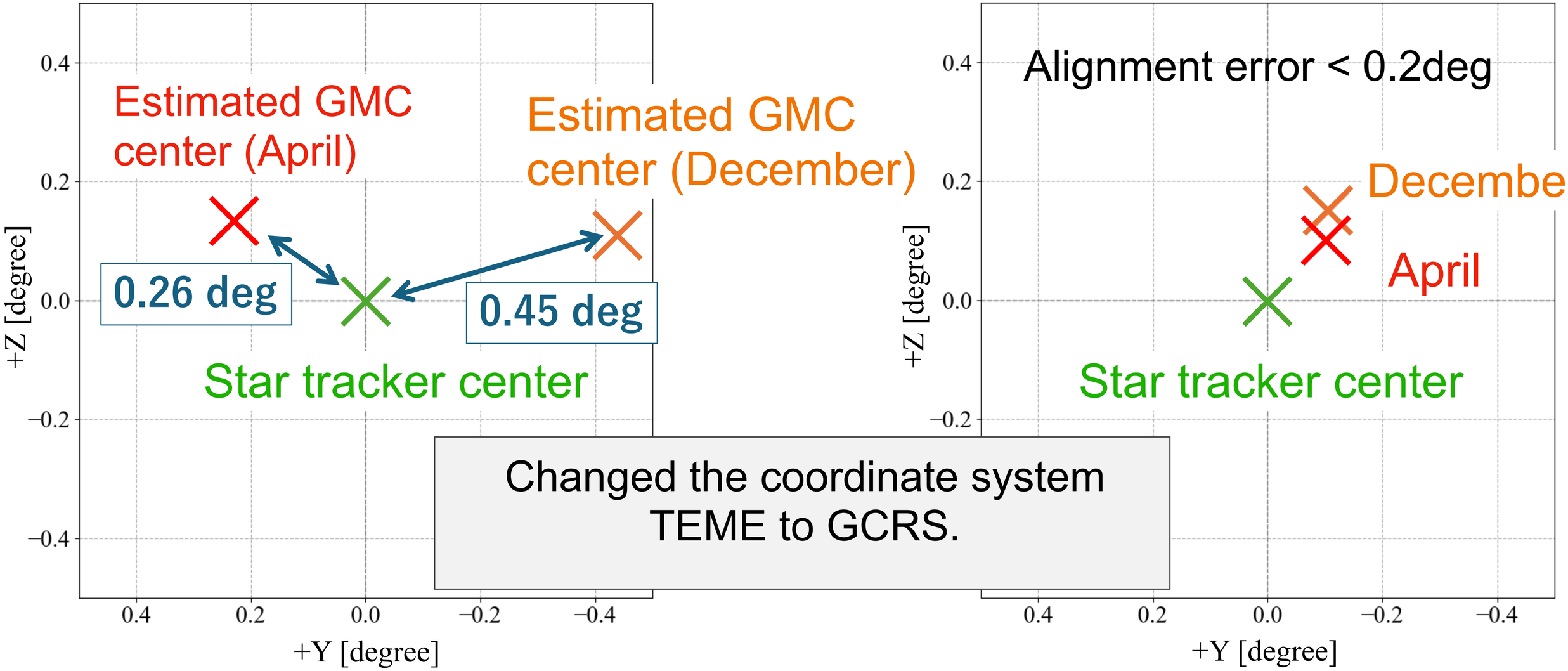
Onboard calibration source





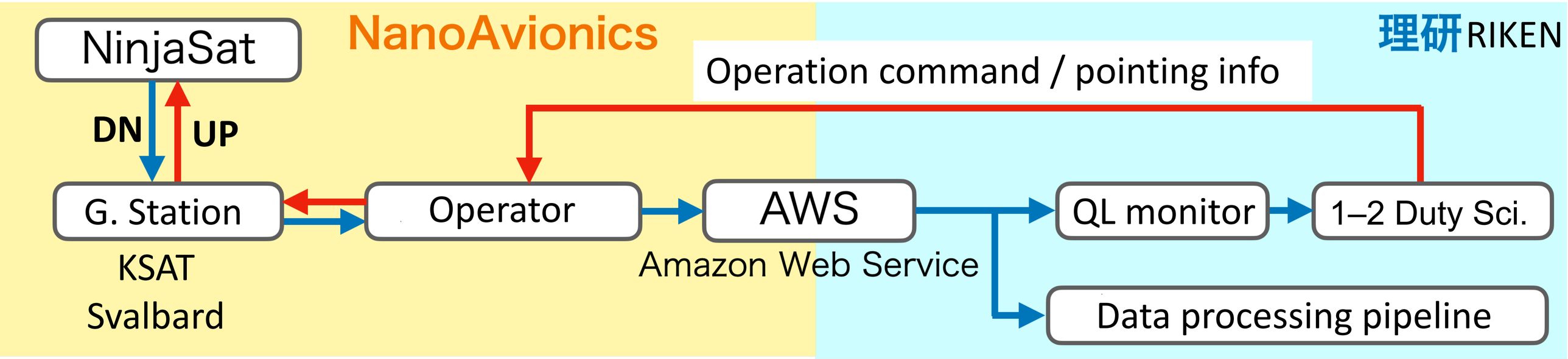
- Energy resolution is the same as ground measurement.
- 20% jump in gas gain from ground, but keep constant in orbit

Star tracker coordinate system issue



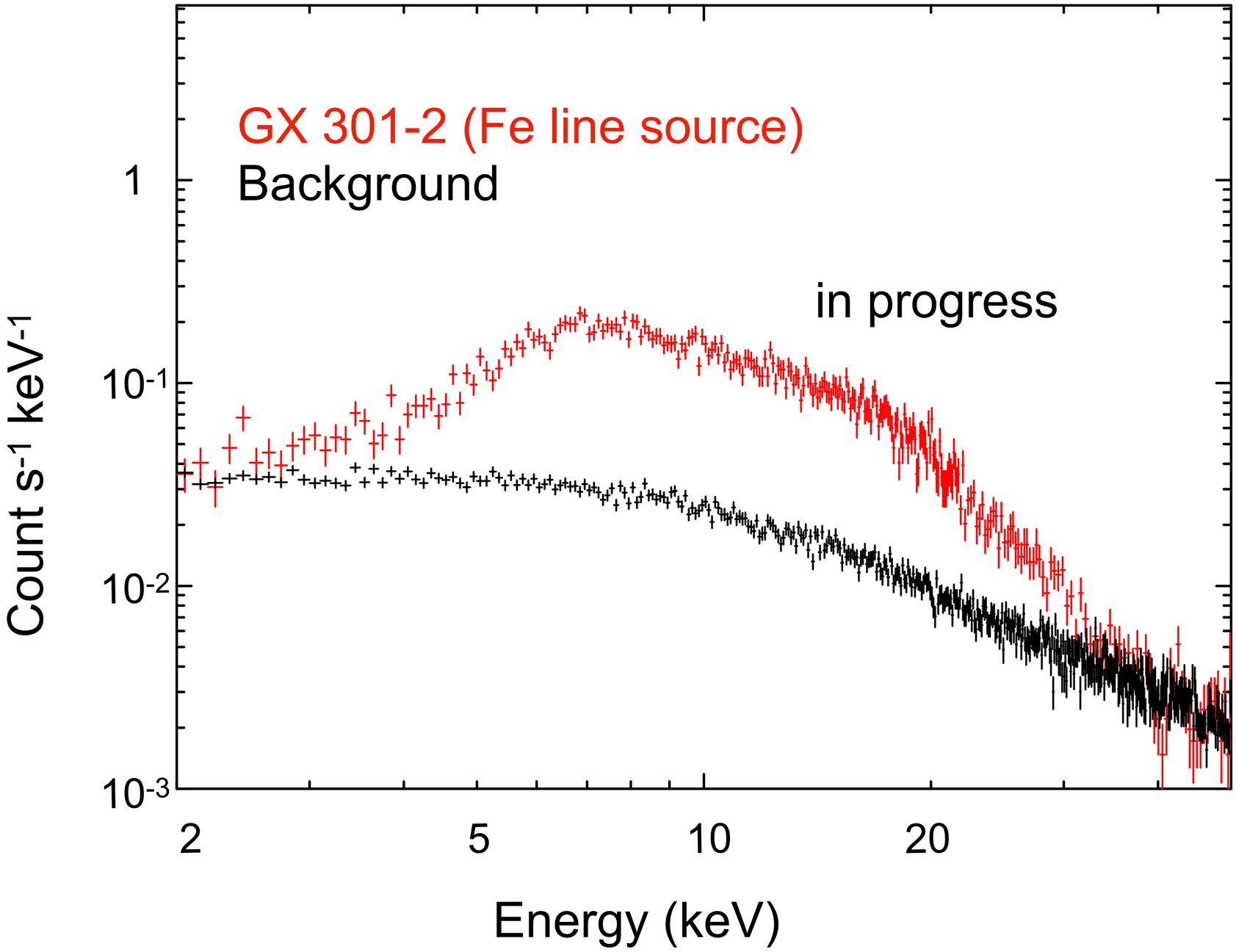
- We adjust the pointing direction of star tracker based on GCRS system.
- Crab flux increased to expected value.
  9.50 ± 0.27 cps → 11.72 ± 0.20 cps (inner readout electrode)

Operation

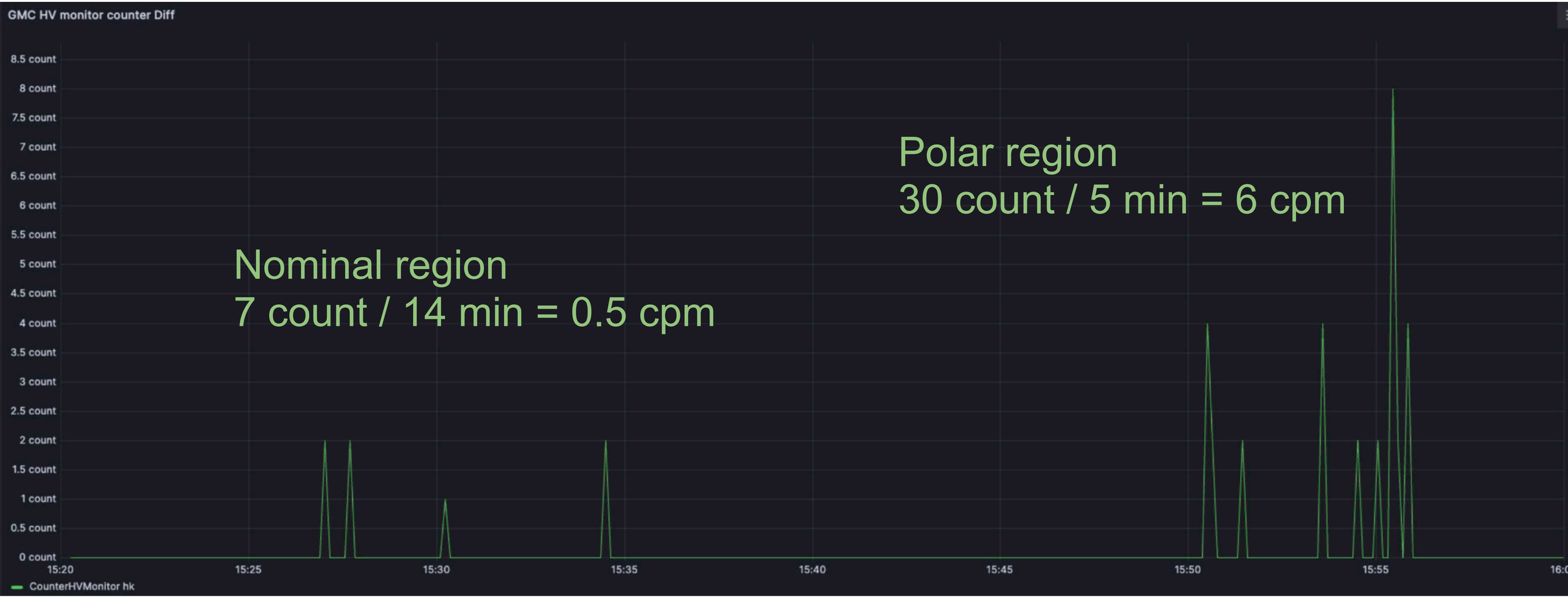


- 3 out of 12 contact passes at Svalbard used
- NanoAvionics is responsible for satellite ops.
- NinjaSat team is responsible for science ops.
- Send ops command (2-3 hrs before uplink), pointing list (one day before uplink)
- Data can be analyzed with a standard method.

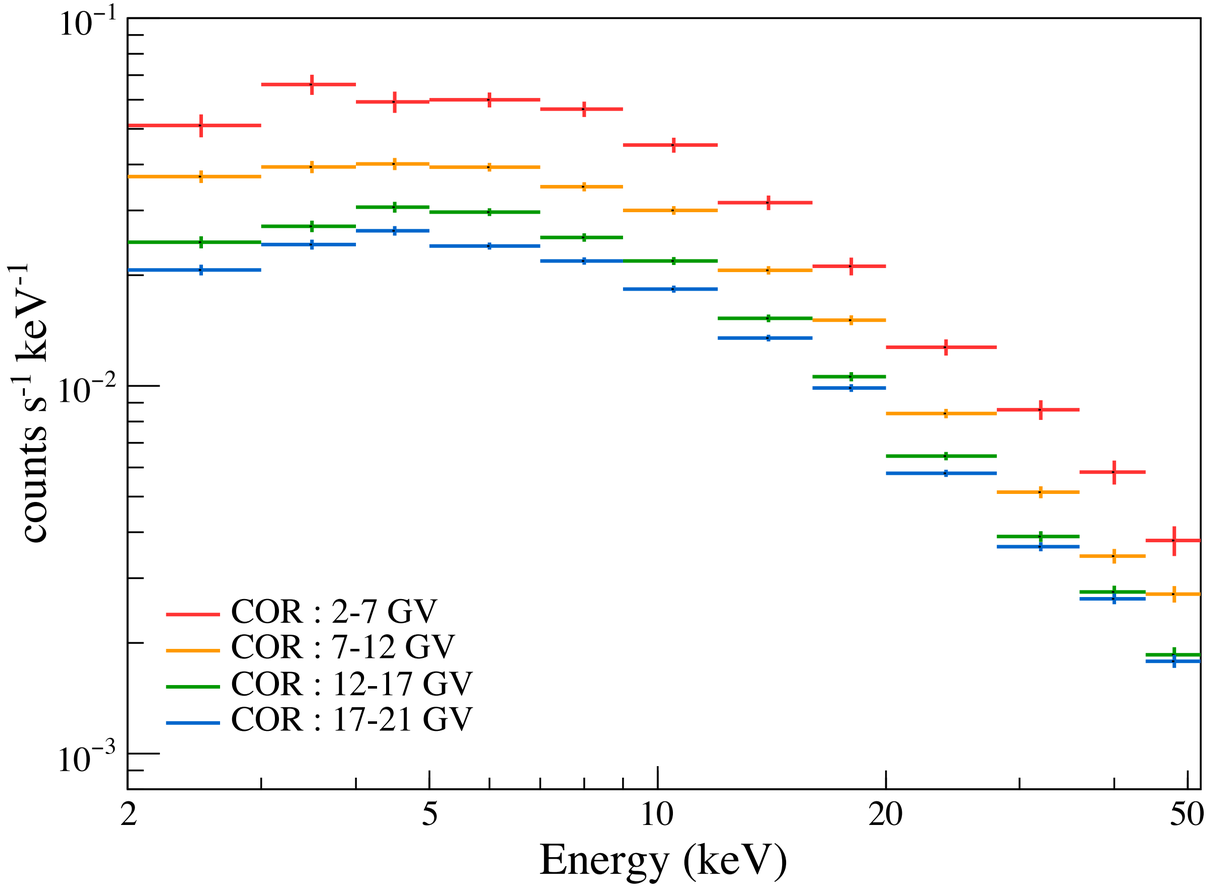
GX 301-2

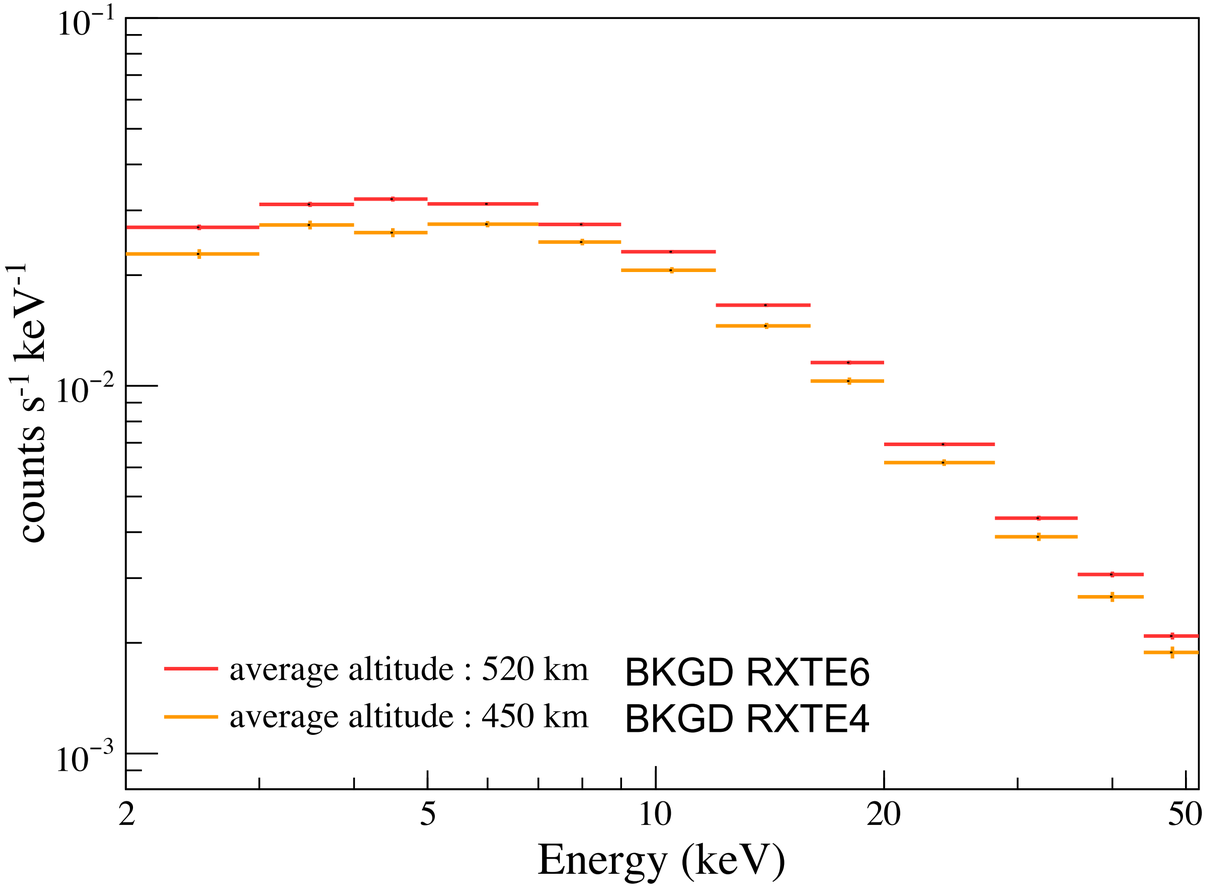

GX 301-2 (Fe line source)
Background
in progress
Count s-1 keV-1
1
10-1
10-2
10-3
2
5
10
20
Energy (keV)

Discharge at polar region



Background status



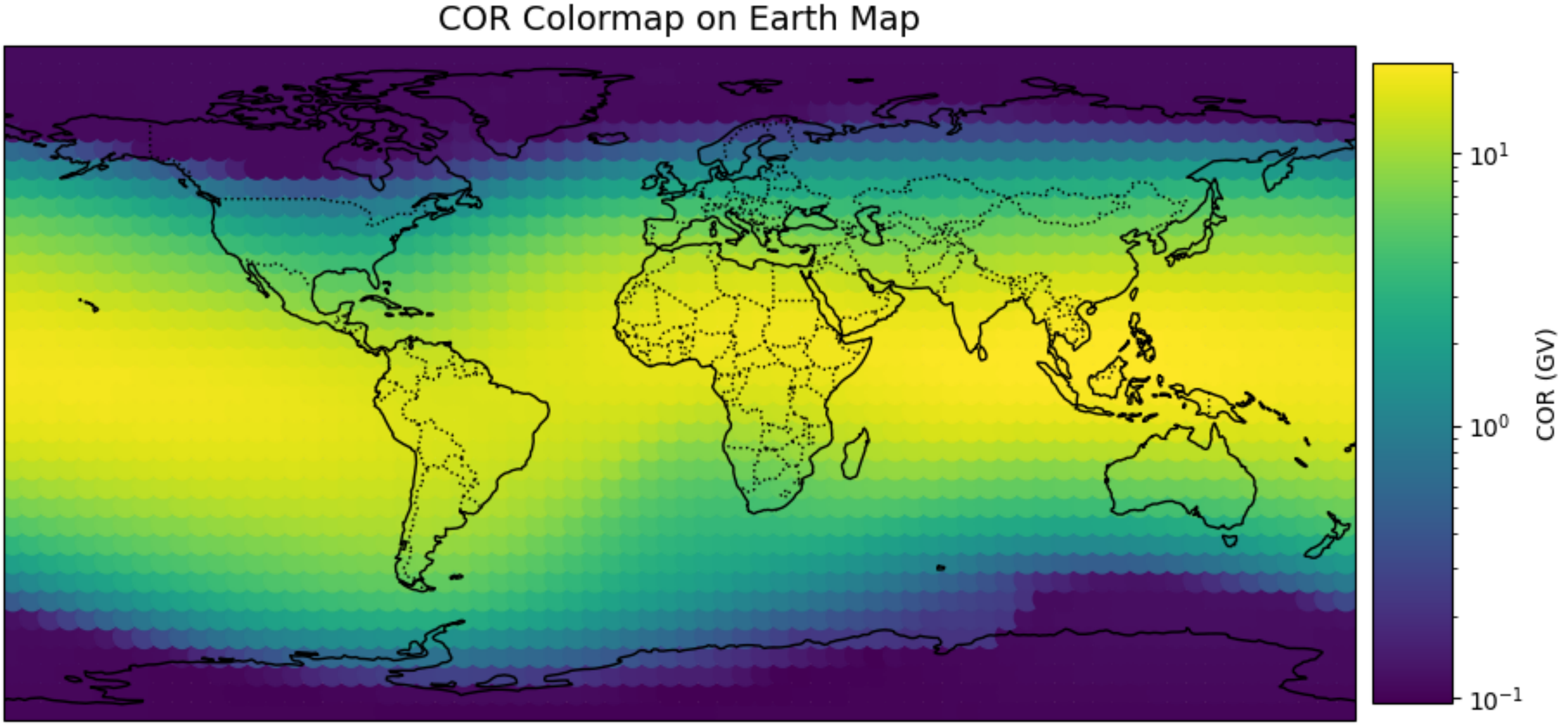


COR (GV)	2–50 keV rate (cps)	1 σ error (cps)
2–7	1.00	0.02
7–12	0.648	0.006
12–17	0.477	0.004
17–21	0.418	0.003

Altitude (km)	2–50 keV rate (cps)	1 σ error (cps)
520	0.516	0.002
450	0.456	0.003

※ Inner readout electrode

Cut Off Rigidity



Current altitude

May 13th (UTC)