X-ray Irradiation Tests of pnCCD for GRB Observation in the HiZ-GUNDAM

Gamma-ray bursts are the brightest explosions in the universe. HiZ-GUNDAM uses a wide-field X-ray monitor with pnCCD to study the early universe. We developed its drive/readout system and evaluated pnCCD through gain correction and multi-energy X-ray detection.

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Introduction

Credit: NASA Goddard Space Flight Center

GRB : Gamma-Ray Burst

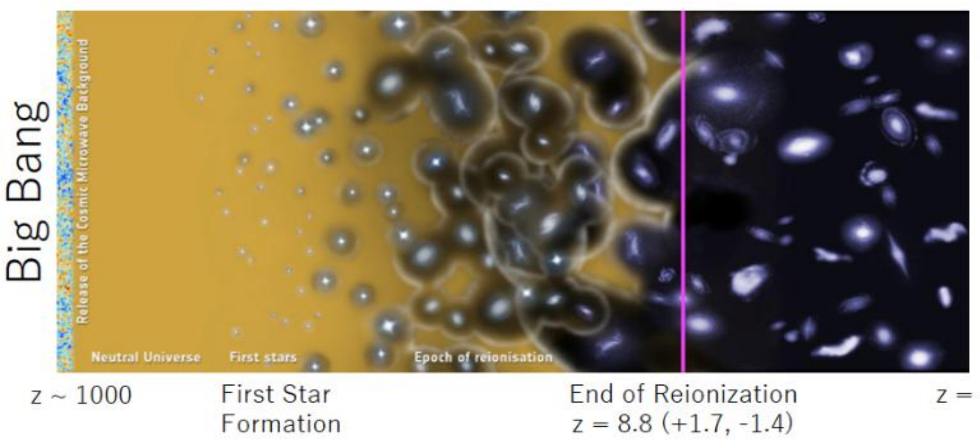
- An astronomical phenomenon that releases an energy of 10^{52}–10^{54} erg
  — the brightest explosion in the universe.
- Bright prompt emission
- Fading afterglow over several days
- Observed up to $z = 8.2$ [1]

Expected to be a probe of the early universe

High-z Gamma-ray bursts for Unraveling the Dark Ages Mission [2]

Mission: Detect GRBs with a wide field of view, identify their redshifts, and promptly alert large ground-based telescopes worldwide.

Key Science 1: Probing the early universe(z > 7) with GRBs



Credit: ESA / Planck Collaboration

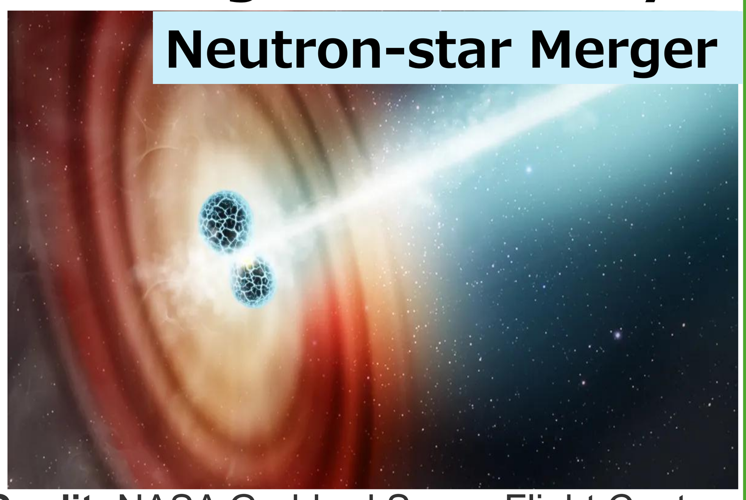
Main target
(1) GRB occurrence rate at z > 7
(2) History of cosmic reionization
(3) History of heavy element synthesis
(4) Population III (first-generation) GRBs

Key Science 2: Contribution to Multi-messenger Astronomy

Observations in **GW170817/GRB170817A**[3]

- **Compact-object mergers** (neutron-star / black-hole systems) emit **gravitational waves**.
- The same events launch relativistic jets, producing **short gamma-ray bursts**

Observed as **electromagnetic signals**



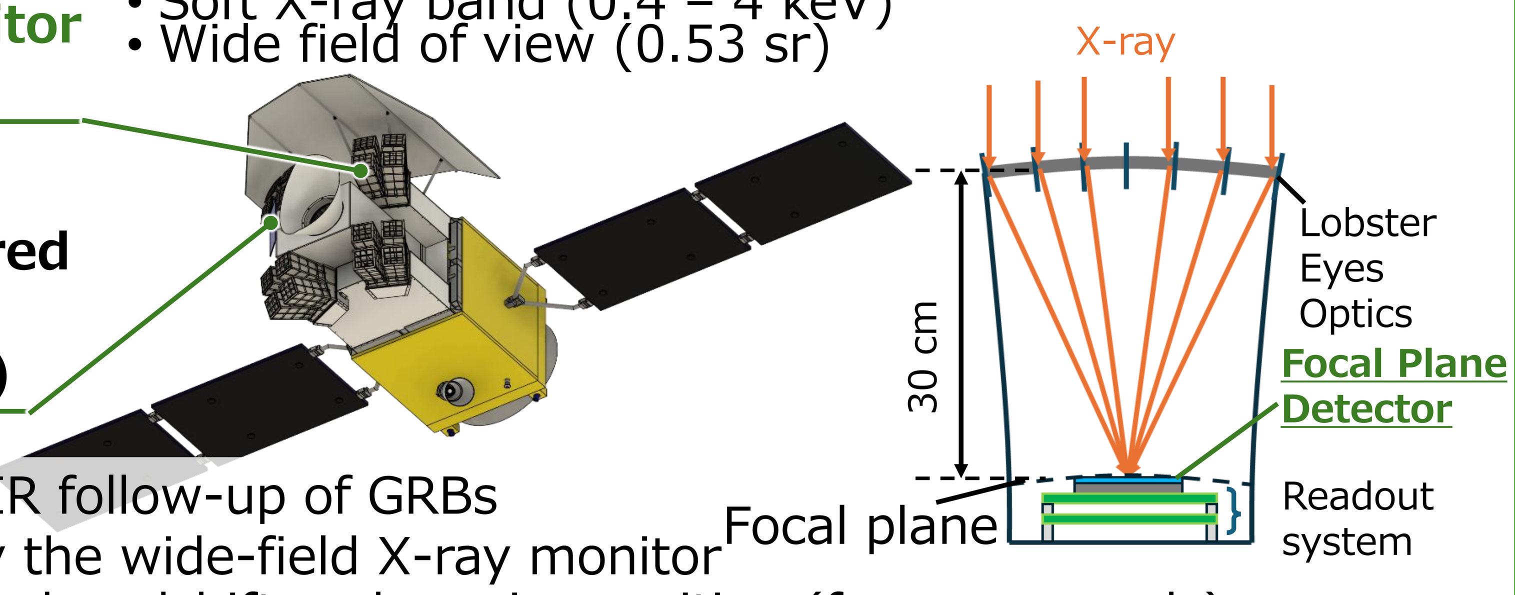
Credit: NASA Goddard Space Flight Center

HiZ-GUNDAM observes X-ray and NIR emissions to uncover black hole formation and energy-release mechanisms.

Mission Instruments of HiZ-GUNDAM [2]

Wide-field X-ray Monitor (EAGLE)
- Localization of about 1.5 arcmin (1σ one-side)
- Soft X-ray band (0.4 – 4 keV)
- Wide field of view (0.53 sr)

Optical and Near-Infrared Telescope (MONSTER)



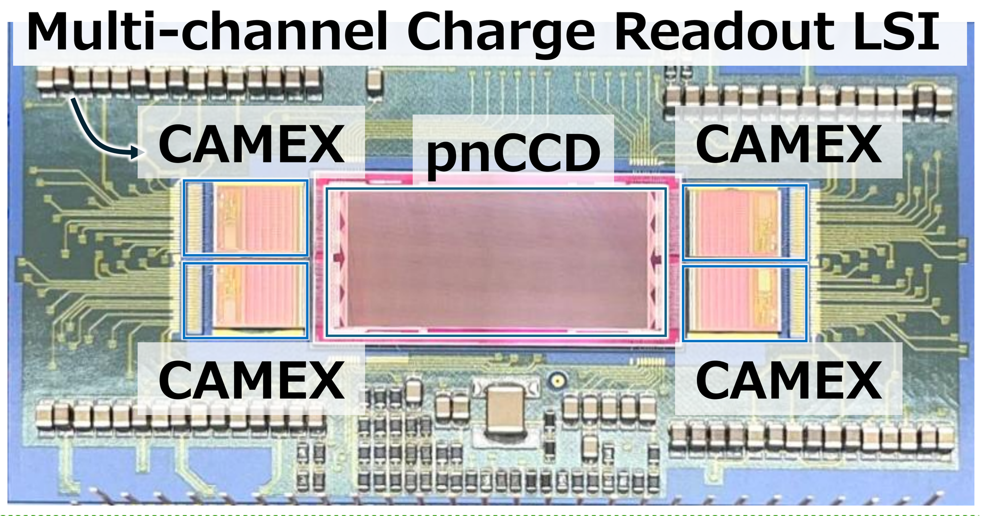
- Optical / NIR follow-up of GRBs detected by the wide-field X-ray monitor
- Measure rough redshift and precise position (few arcseconds)

Focal Plane Detector : pnCCD

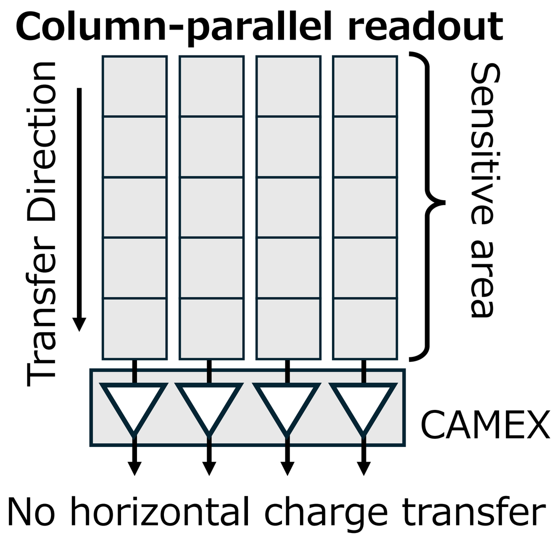
pnCCD Image Sensor by PNSensor GmbH

- Fully depleted structure
  → High detection efficiency
- Back-illuminated type
  → Sensitive to soft X-rays
- Large sensitive area
- High frame rate (max 1000 fps)

Multi-channel Charge Readout LSI



Column-parallel readout



Research Objective

To obtain **a comparable spectrum** using our own system

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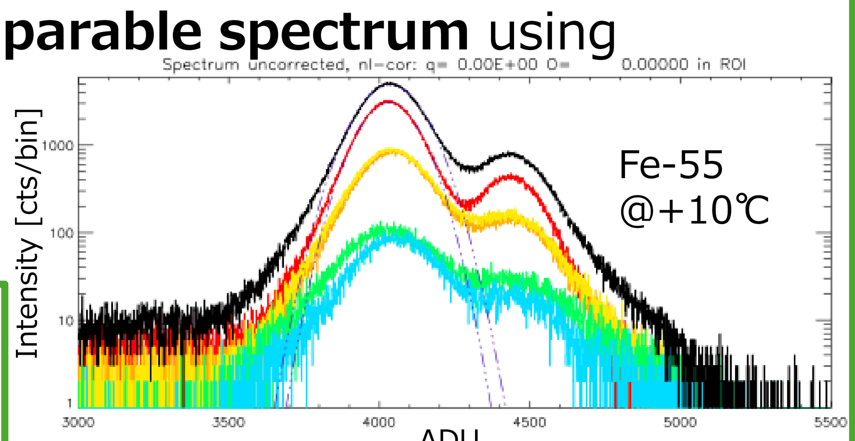
Performance at PNSensor

Energy Resolution: FWHM 330 eV



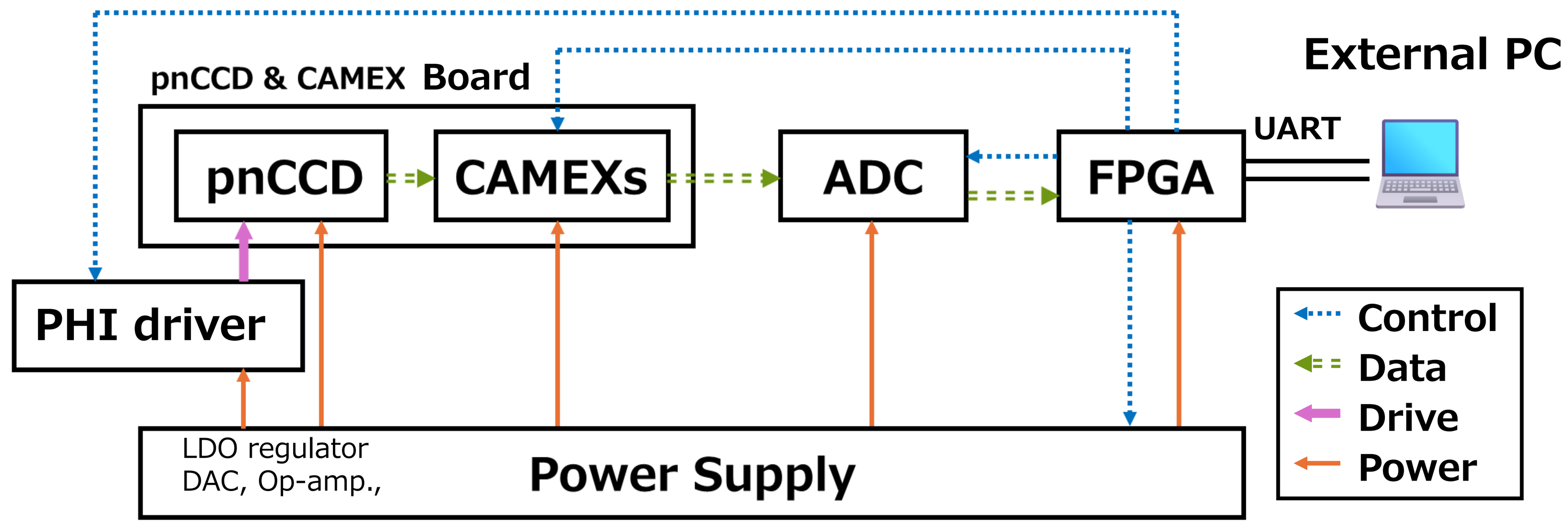
Spectrum Shape Provided by PNSensor

Items	Peformance Requirements	Parameters for Satellite Application	Small pnCCD Used in This Study
Energy	0.4 – 4 keV	0.3 – 11 keV	0.3 – 11 keV
Sensitive area	≥ 55 × 55 mm²	55 × 55 mm² (TBD)	12.7 × 25.3 mm²
Pixel size	75 – 100 μm	~ 100 μm (TBD)	132 μm
Frame rate	≥ 10 fps	max. 1000 fps	max.1000 fps

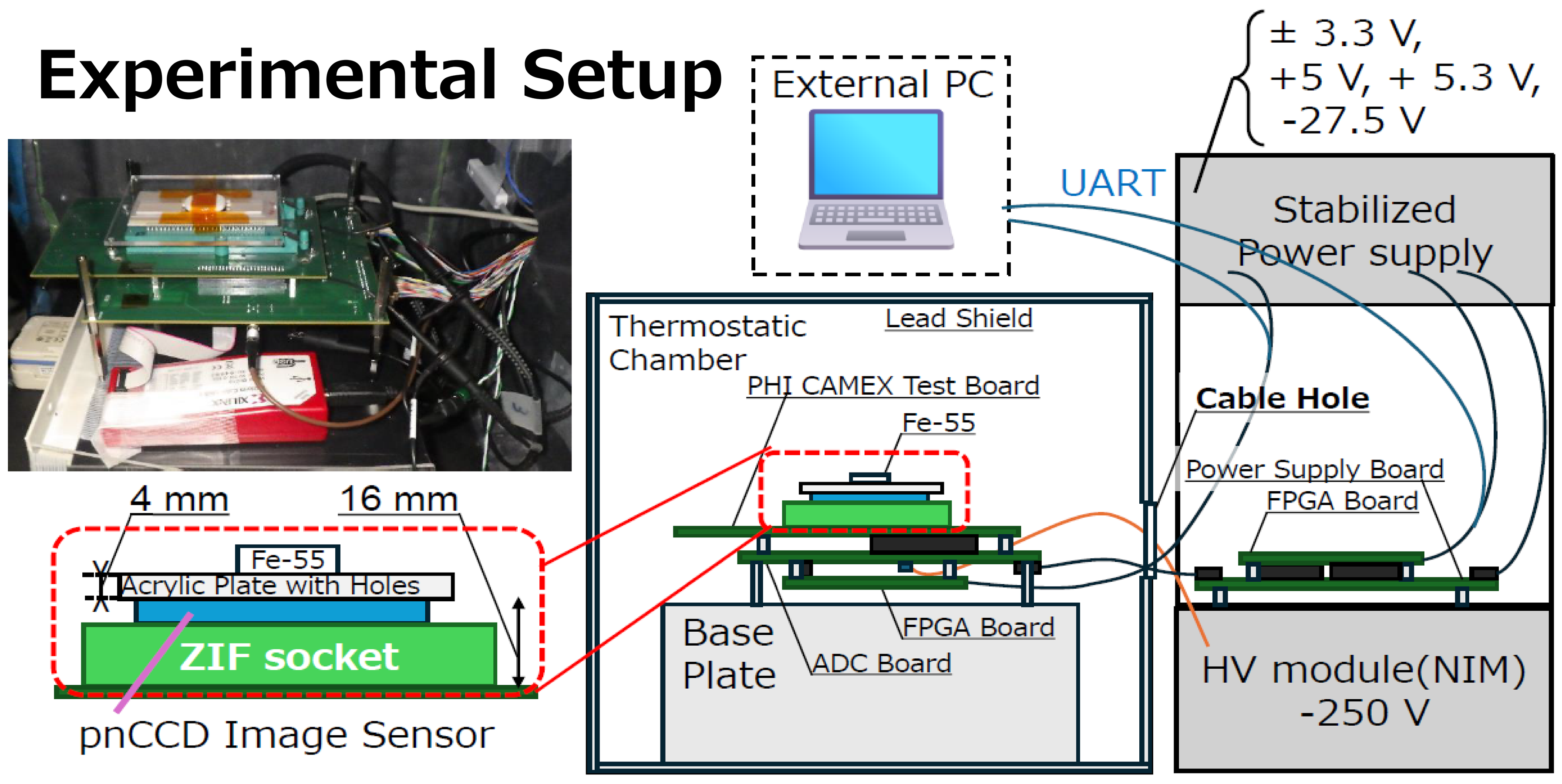
➡ **Meeting the Performance Requirements of HiZ-GUNDAM**

pnCCD Driving and Readout System

We have been developing a pnCCD driving and readout system to meet the performance requirements of HiZ-GUNDAM.[4][5]

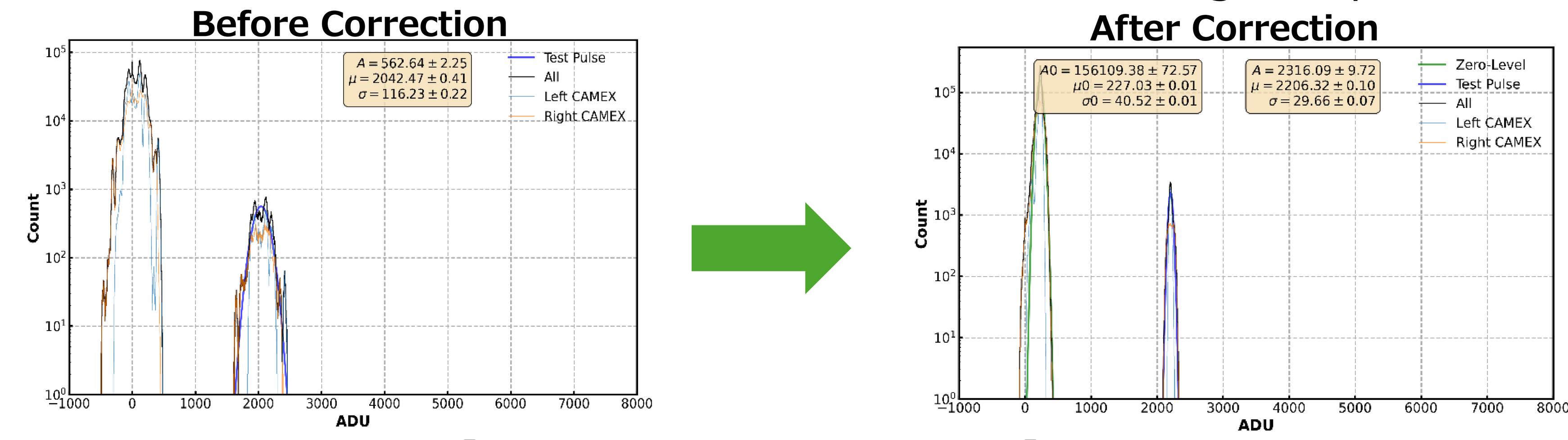


Experimental Setup

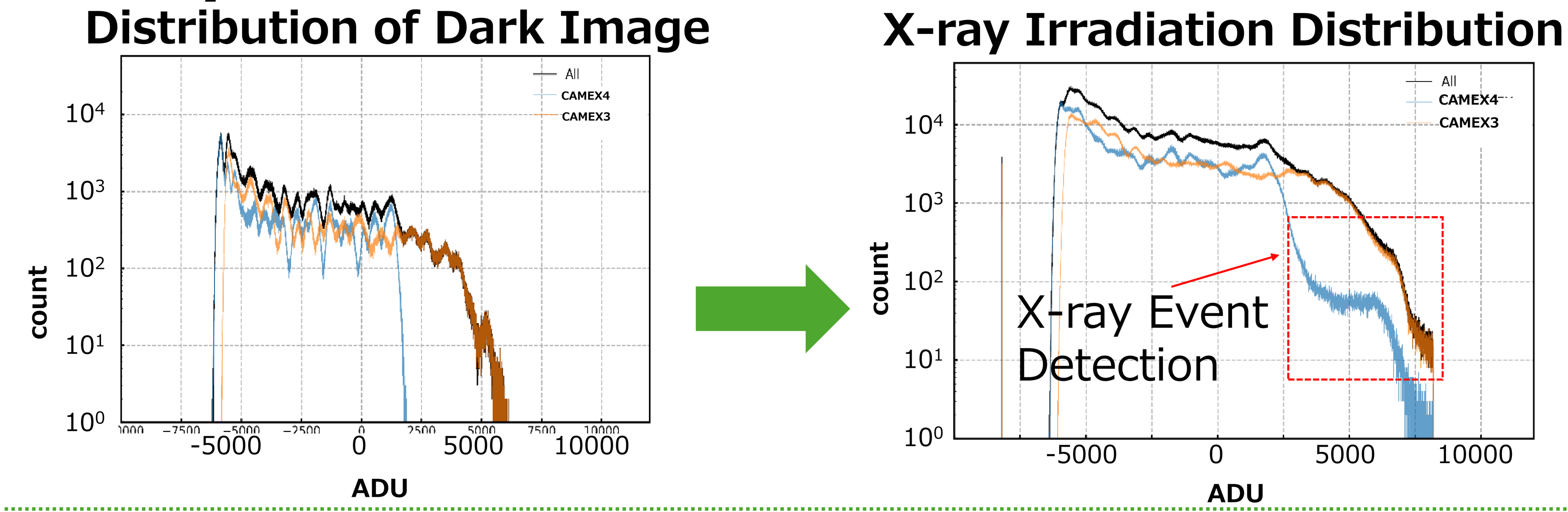


Gain Correction

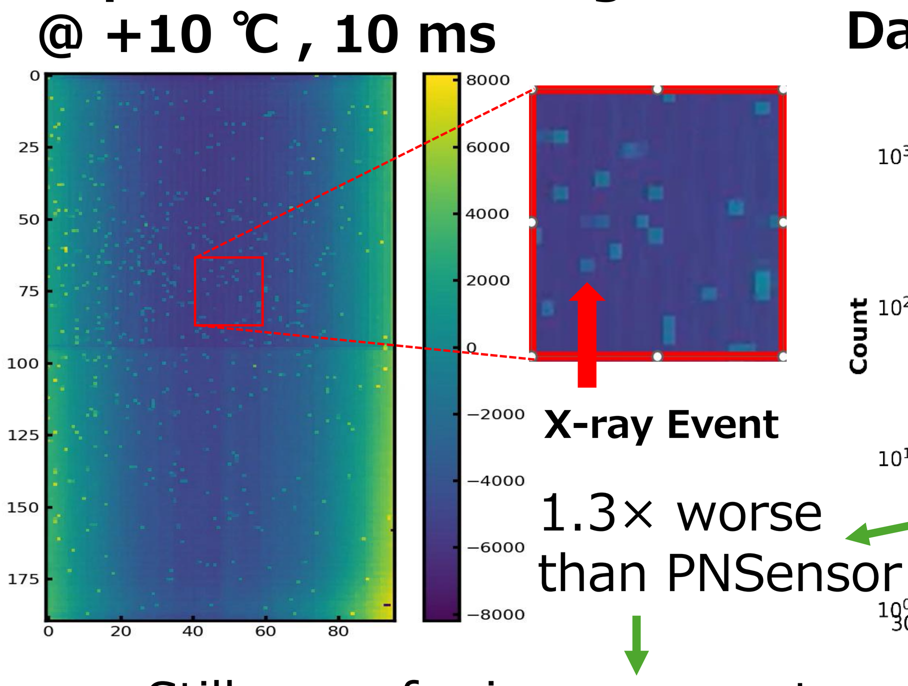
Gain variation correction for each CAMEX channel using test pulse



X-ray Detection Demonstration Test



Captured Frame Image @ +10 ℃ , 10 ms



1.3× worse than PNSensor

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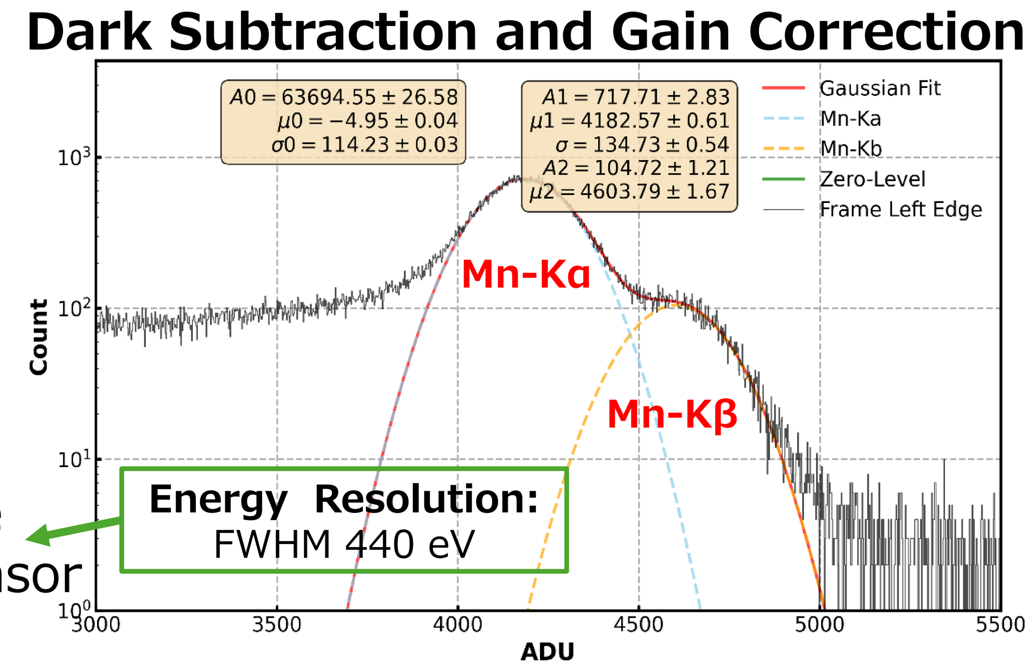
Still room for improvement

ADU Distribution after Dark Subtraction and Gain Correction



Possible cause: common-mode noise

✓ Achieved **energy resolution comparable to PNSensor** at +10 °C
✓ Confirmed **the Mn-Kα and Mn-Kβ structures**

Summary and Future task

- Constructed the pnCCD drive and readout system.
- Investigated the gain of each LSI channel and applied correction
- Performed X-ray detection test using Fe-55
- Achieved energy resolution nearly equivalent to the performance guaranteed by PNSensor GmbH at +10 °C.
- Successfully identified the structure of Mn-Kα and Mn-Kβ lines.

→**Plan to conduct** energy calibration using X-ray peaks of various energies

→**Plan to review** the measurement system and setup to improve energy resolution.

Reference
[1] Tanvir, N. R. et al. *Nature*, 461:1254–1257, 2009.
[2] D. Yonetoku et al., J. Astron. Telesc. Instrum. Syst., 11:044002, 2025.
[3] B. P. Abbott et al. (LIGO/Virgo Collaborations), ApJL, 848:L12, 2017.
[4] H.-C. Shen et al., Proc. SPIE 13093:130936C ,2024.
[5] R. Kondo et al. Proc. SPIE 13093:130936D ,2024.