KANAZAWA UNIVERSITY

Development of an Electric System for pnCCD onboard HiZ-GUNDAM with Integrated Charged-Particle Event Removal Algorithms

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The 14th international "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors (HSTD-14) on November 16 - 21, 2025 at the Activity center of Academia Sinica , Taipei, Taiwan.

Gamma-Ray Burst (GRB)

Gamma-Ray Burst

- The **most luminous explosions** in the Universe, releasing of energy on the order of 10^{52-54} erg lasting from 10 msec to 100 sec.
- Observed even in the early universe !

They are **expected to serve as luminous probes of the early Universe.**

Credit: NASA Goddard Space Flight Center

Key Science

Credit: ESA/ Planck

Main Targets

(1)History of Star Formation

(2)History of heavy element

(3)First-generation stars

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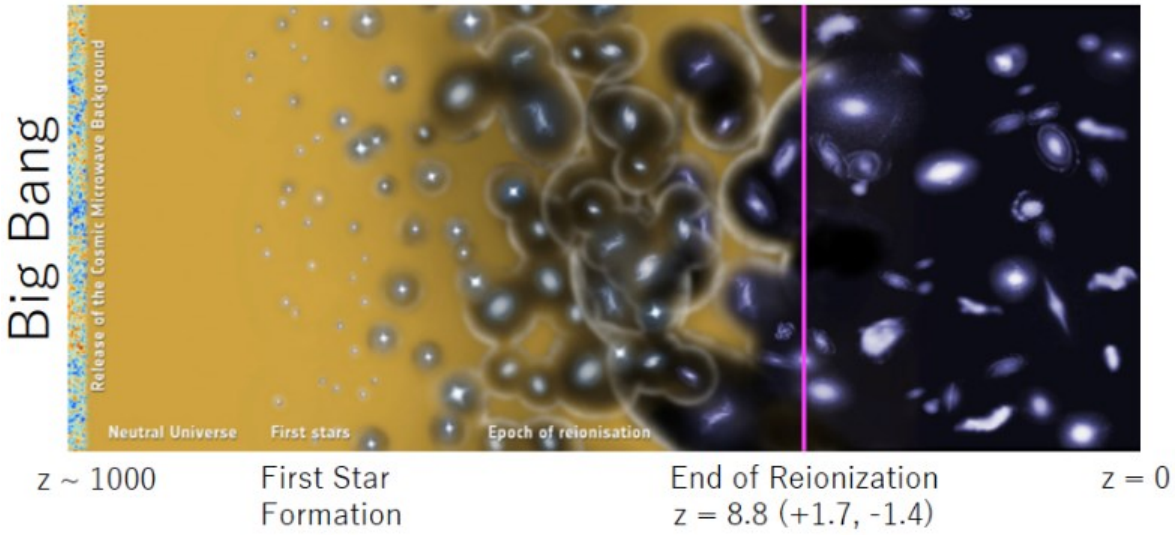

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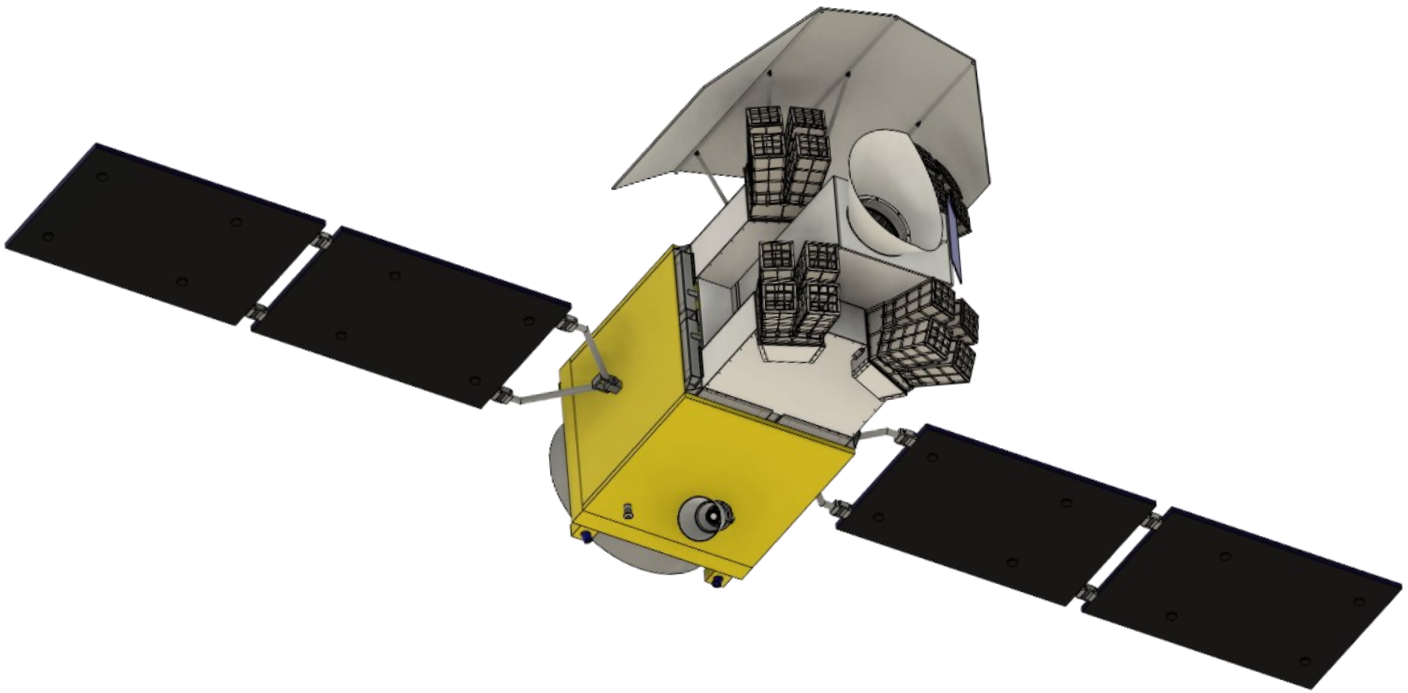
HiZ-GUNDAM

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



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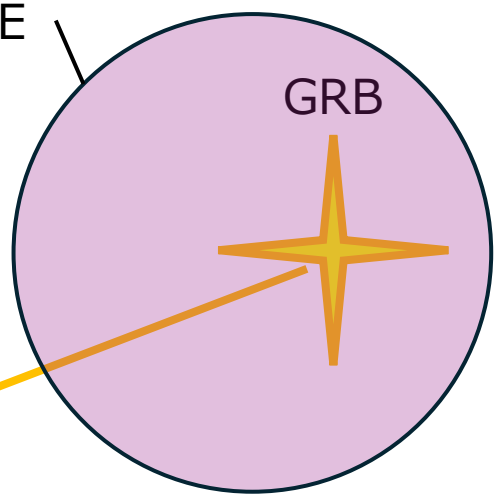
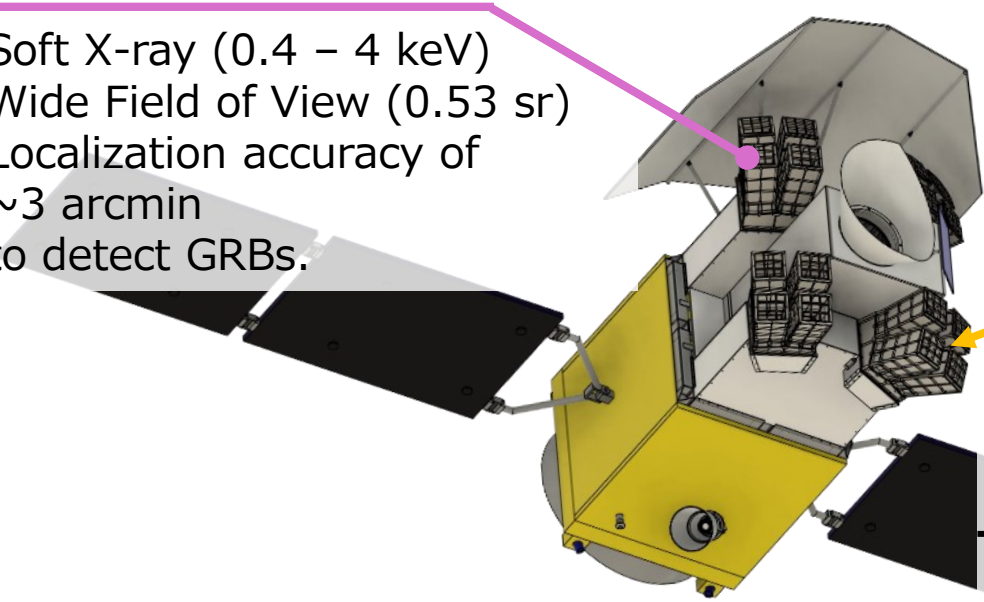
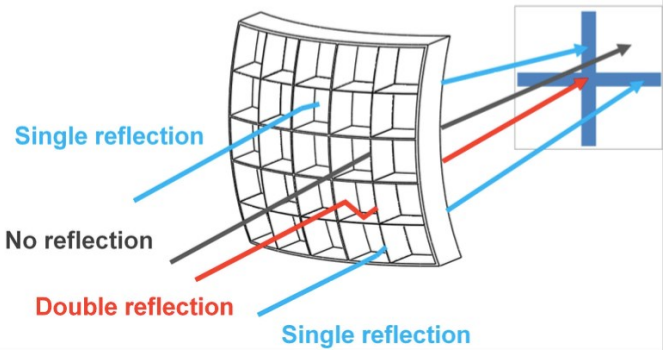
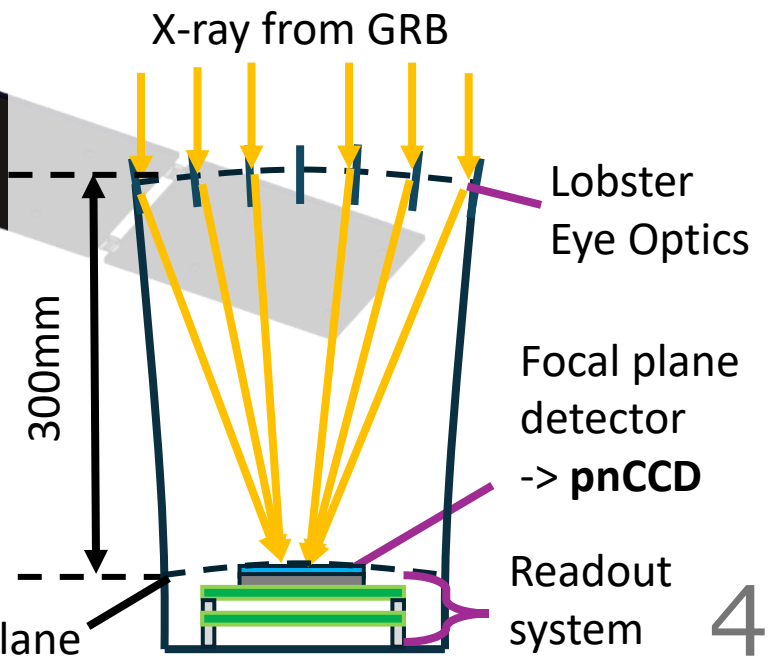
Exploration of Ancient GRBs with Lobster Eye (EAGLE)

- Soft X-ray (0.4 – 4 keV)
- Wide Field of View (0.53 sr)
- Localization accuracy of ~3 arcmin to detect GRBs.









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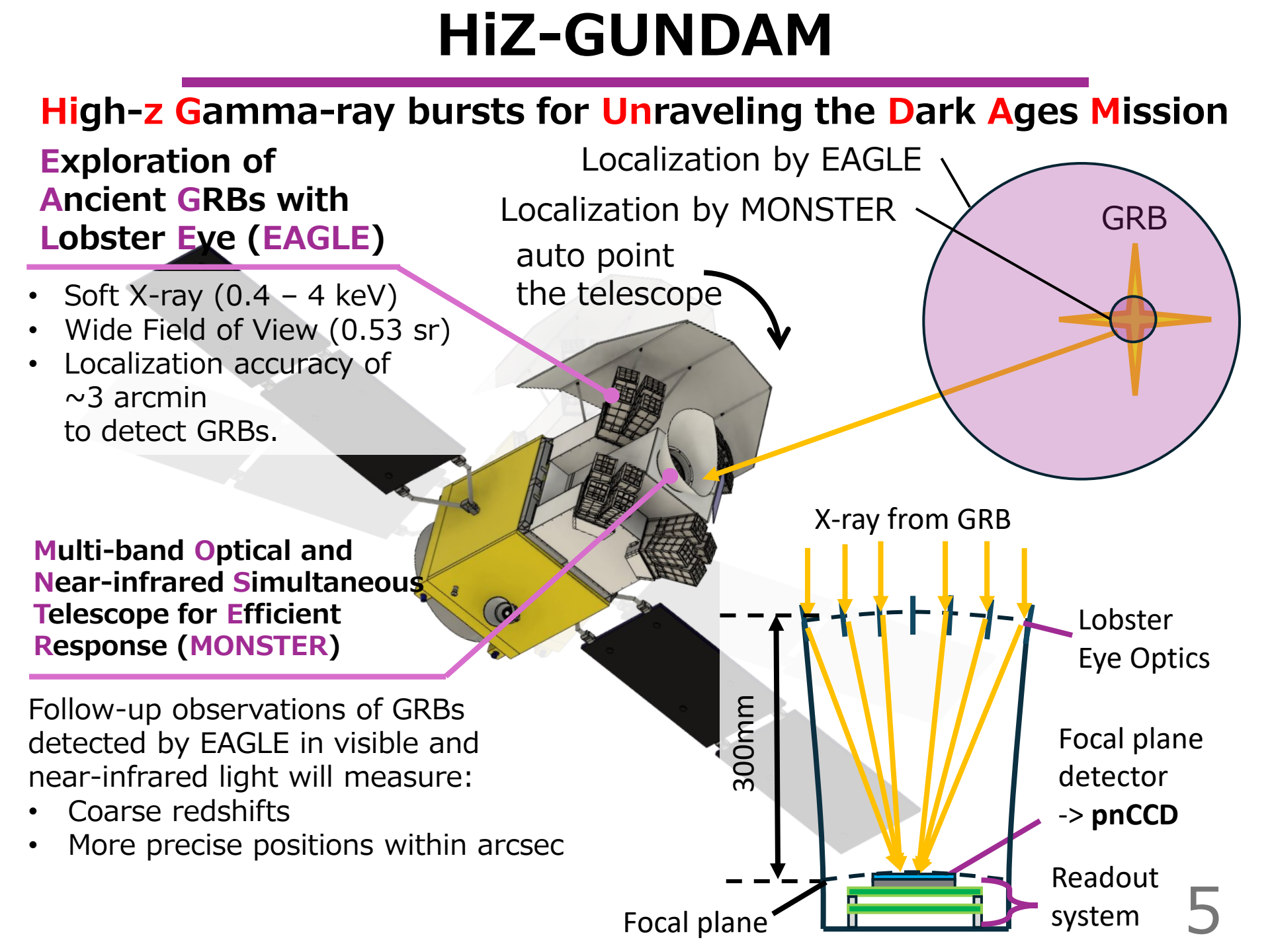
Multi-band Optical and Near-infrared Simultaneous Telescope for Efficient Response (MONSTER)

Follow-up observations of GRBs detected by EAGLE in visible and near-infrared light will measure:

- Coarse redshifts
- More precise positions within arcsec



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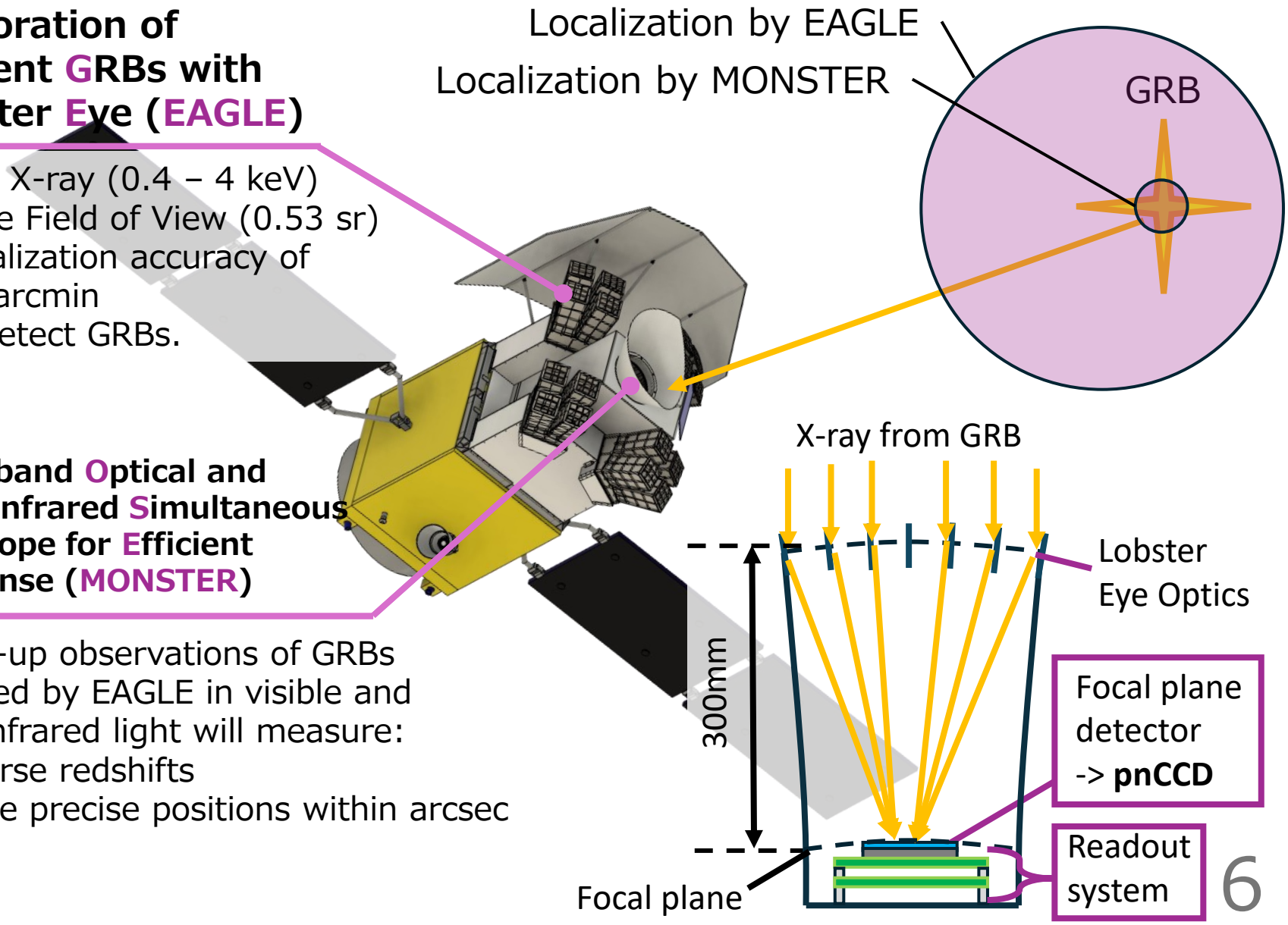


Charged Particle Problem

The HiZ-GUNDAM satellite repeatedly passes through the South Atlantic Anomaly (SAA) and high-latitude regions, exposing it to high-dose charged particles multiple times per day.

HiZ-GUNDAM orbit:

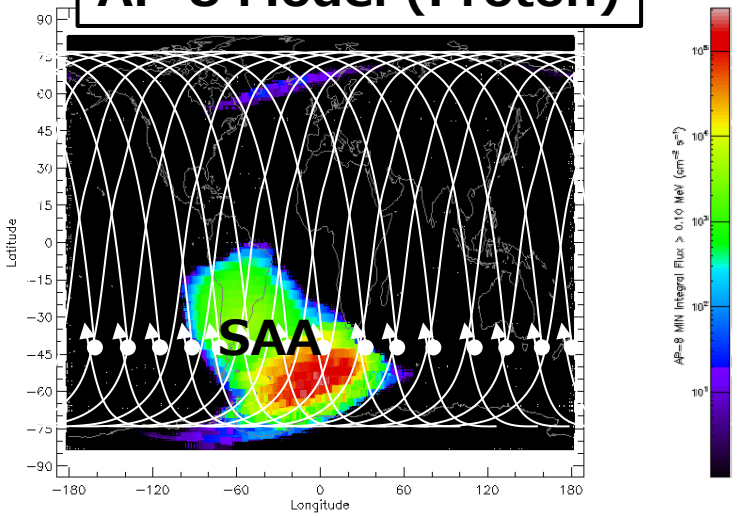
sun-synchronous polar orbit

Altitude: ~ 600 km

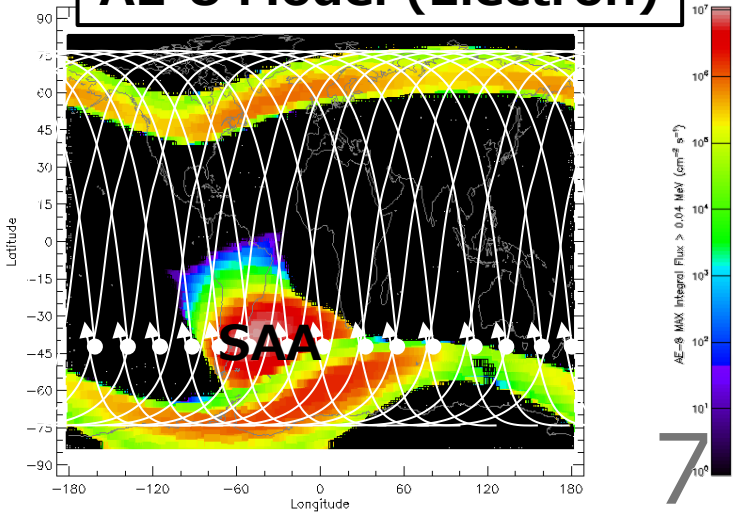
Inclination angle:~ 98°

Period: ~1.5 hours

AP-8 Model (Proton)



AE-8 Model (Electron)



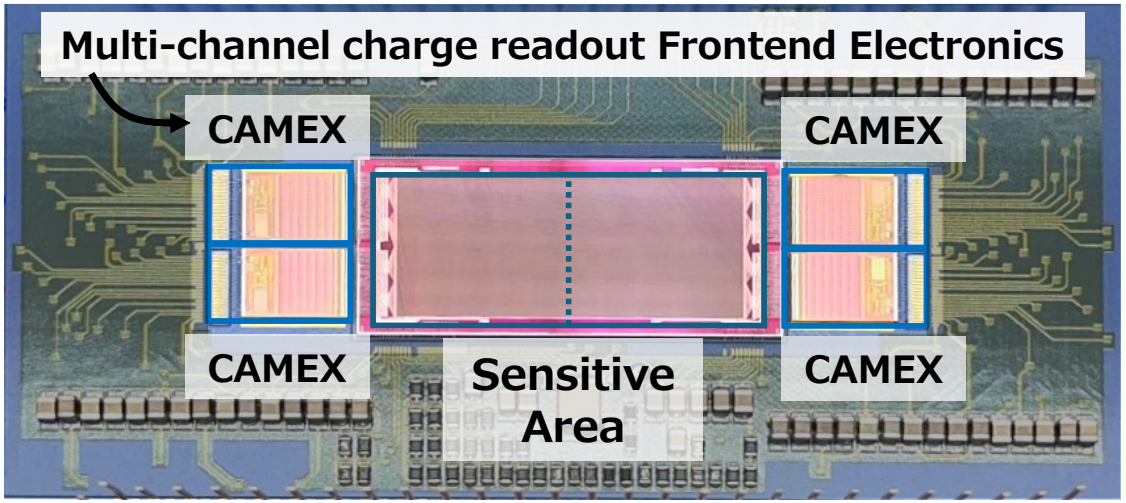
- **Charged particles events can cause False-GRB triggers.**
- **It is necessary to minimize charged particle events as much as possible on focal plane detector.**

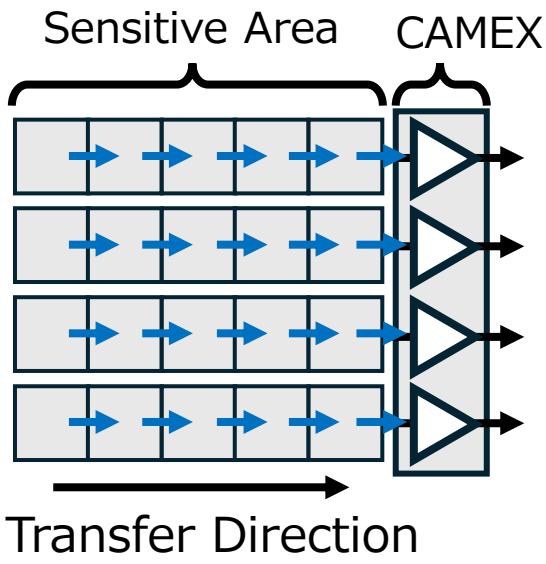
Focal Plane Detector: pnCCD Image Sensor

manufactured by PNSensor GmbH.

Features

- Silicon pixel sensor
- Fully depleted ~ 450 um
- Back-illuminated for Soft X-ray.
- Large sensitive area
- High frame rate!

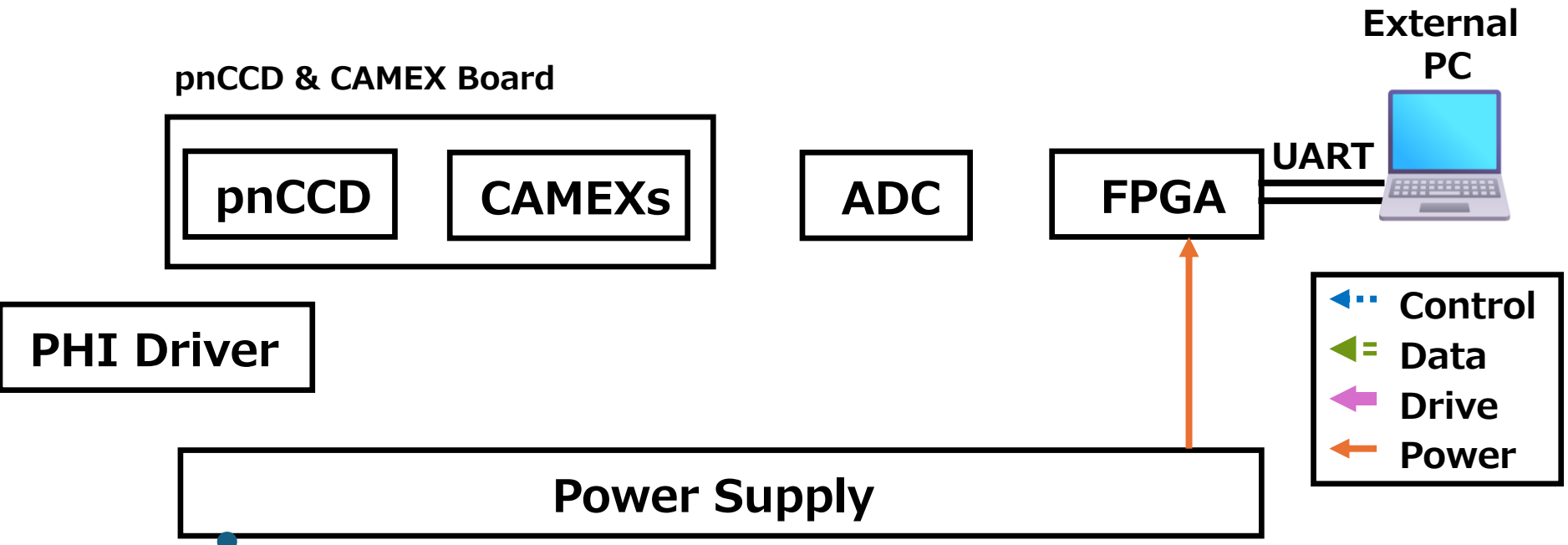


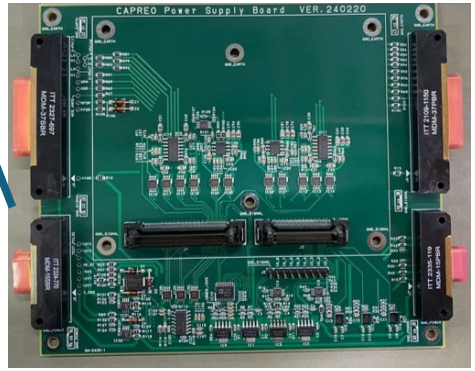


Items	Requirement	pnCCD for satellite
Energy Range	0.4 – 4 keV	0.3 – 11 keV (quantum eff. >90 %)
Sensitive Area	≥ 55 × 55 mm^2	55 × 55 mm^2
Pixel Size	~100 um	107 um
Frame Rate	≥ **10 fps**	**up to 1000 fps**

- **The pnCCD specifications fully meet the requirements!**
- **Onboard processing must be sufficiently faster than the frame rate, with 1 msec per frame being adequate.**

pnCCD Drive & Readout Electric System

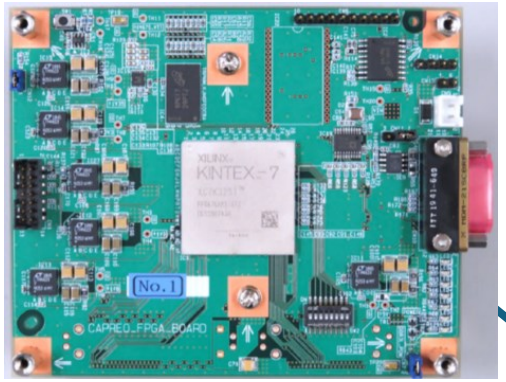




Power Supply Board

- **Digitally controllable voltage**
- Features DAC, Op-Amp, and LDO regulator

pnCCD Drive & Readout Electric System



FPGA Board

- Command Center
- CCD Data Acquisition
- **On-board X-ray Event Extraction**

pnCCD & CAMEX Board

pnCCD

CAMEXs

ADC

FPGA

UART

PHI Driver

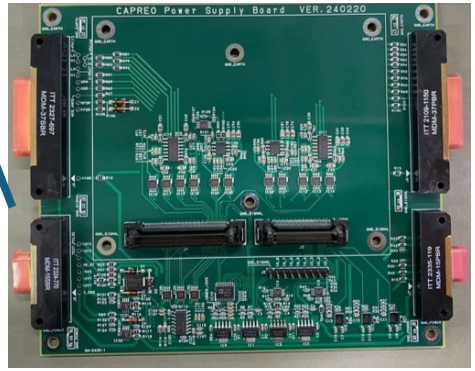
Control

Data

Drive

Power

Power Supply



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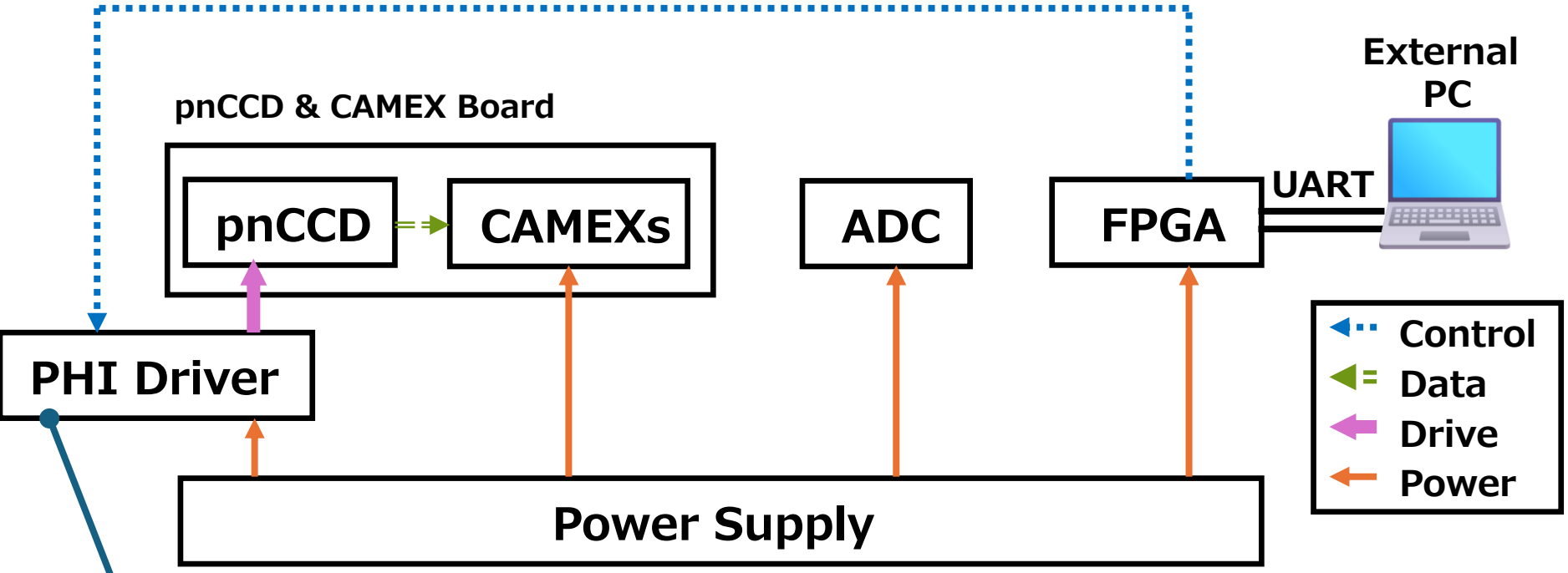
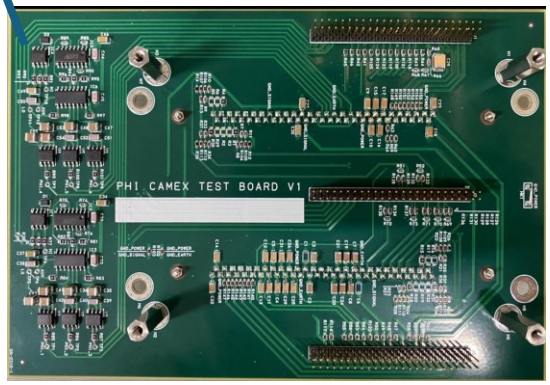
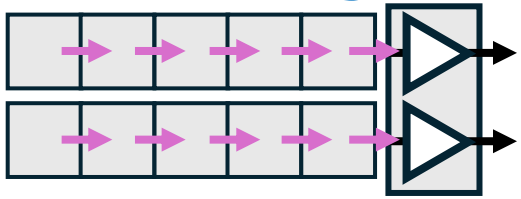




PHI Driver Board

- Generates **analog pulses for charge transfer** from **digital signals**.



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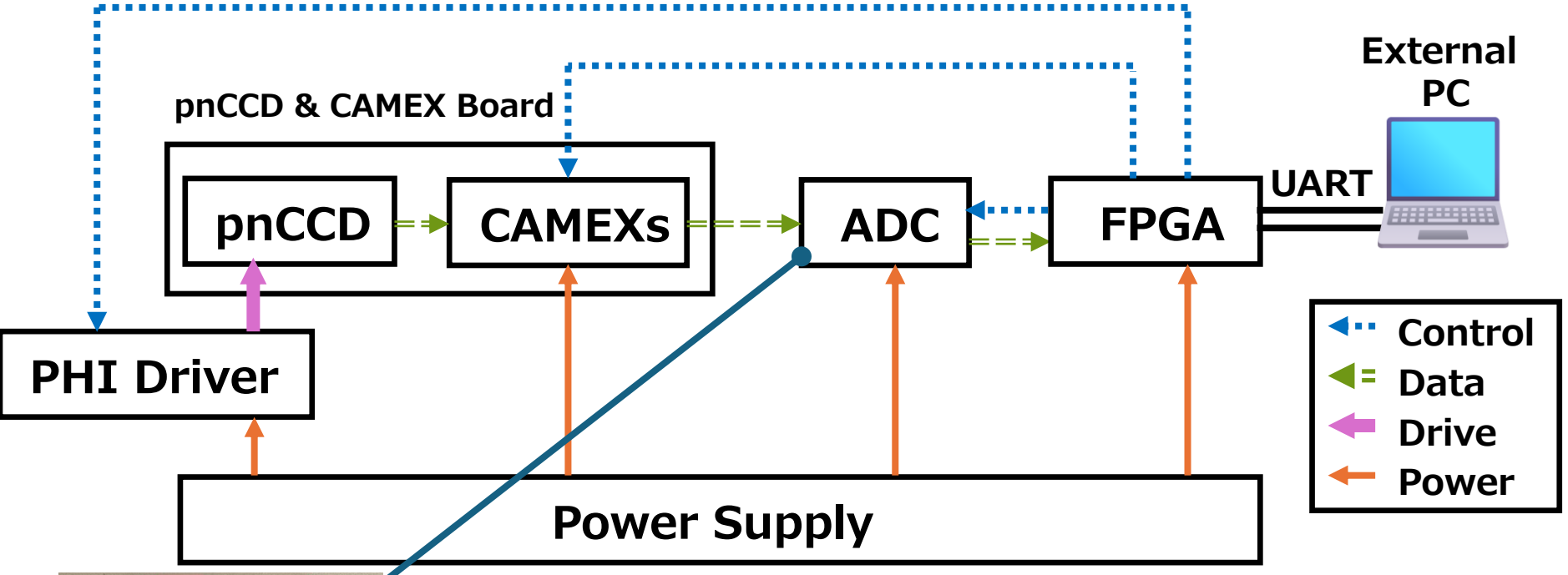
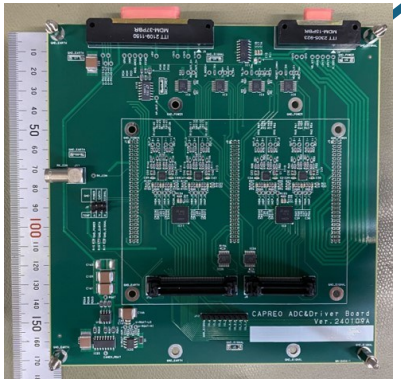
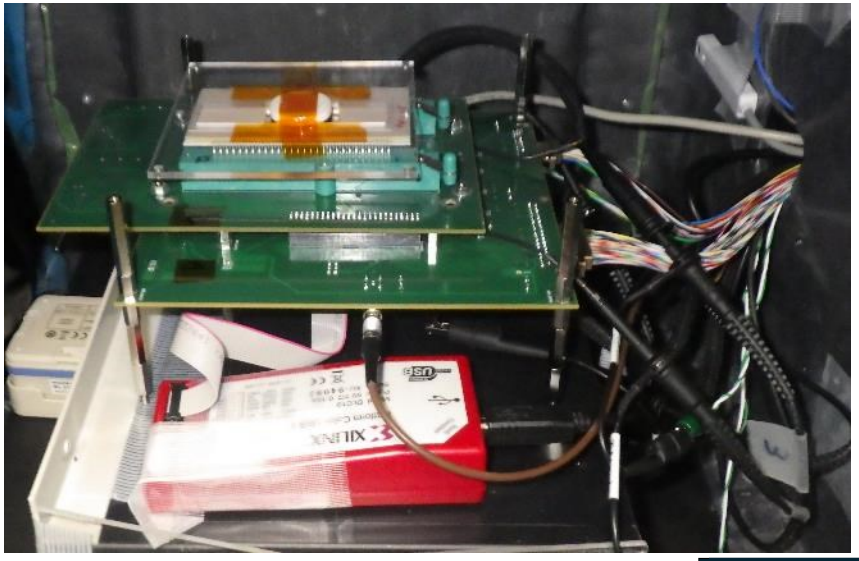


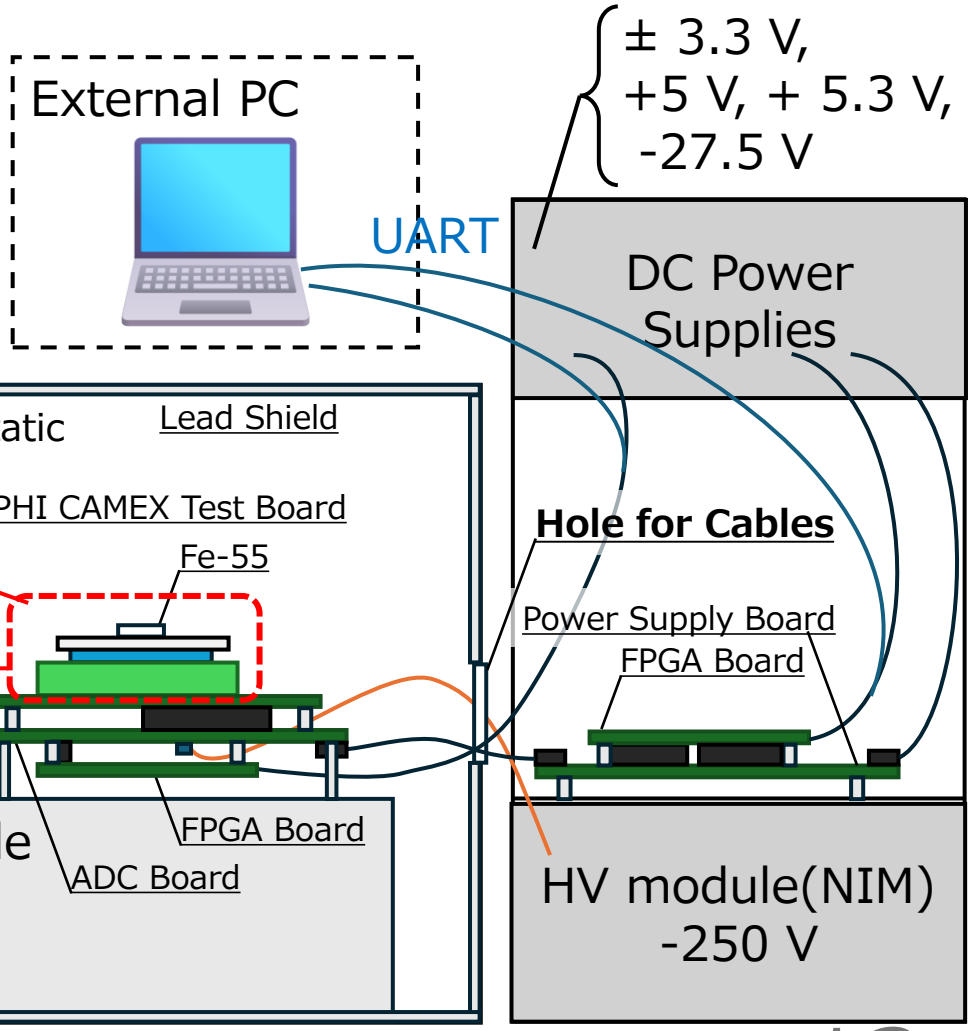


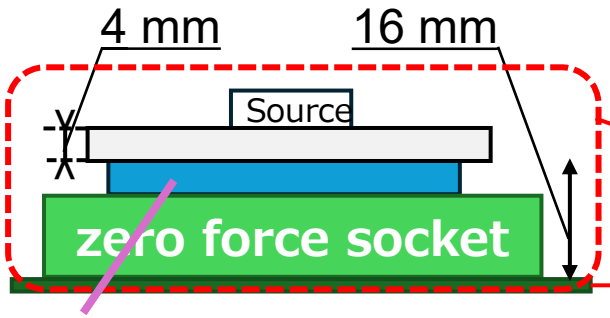
ADC Board

- Converts analog data output from CAMEX to digital data.
- Passes the data to the FPGA.

Our Experimental Setup







pnCCD image sensor

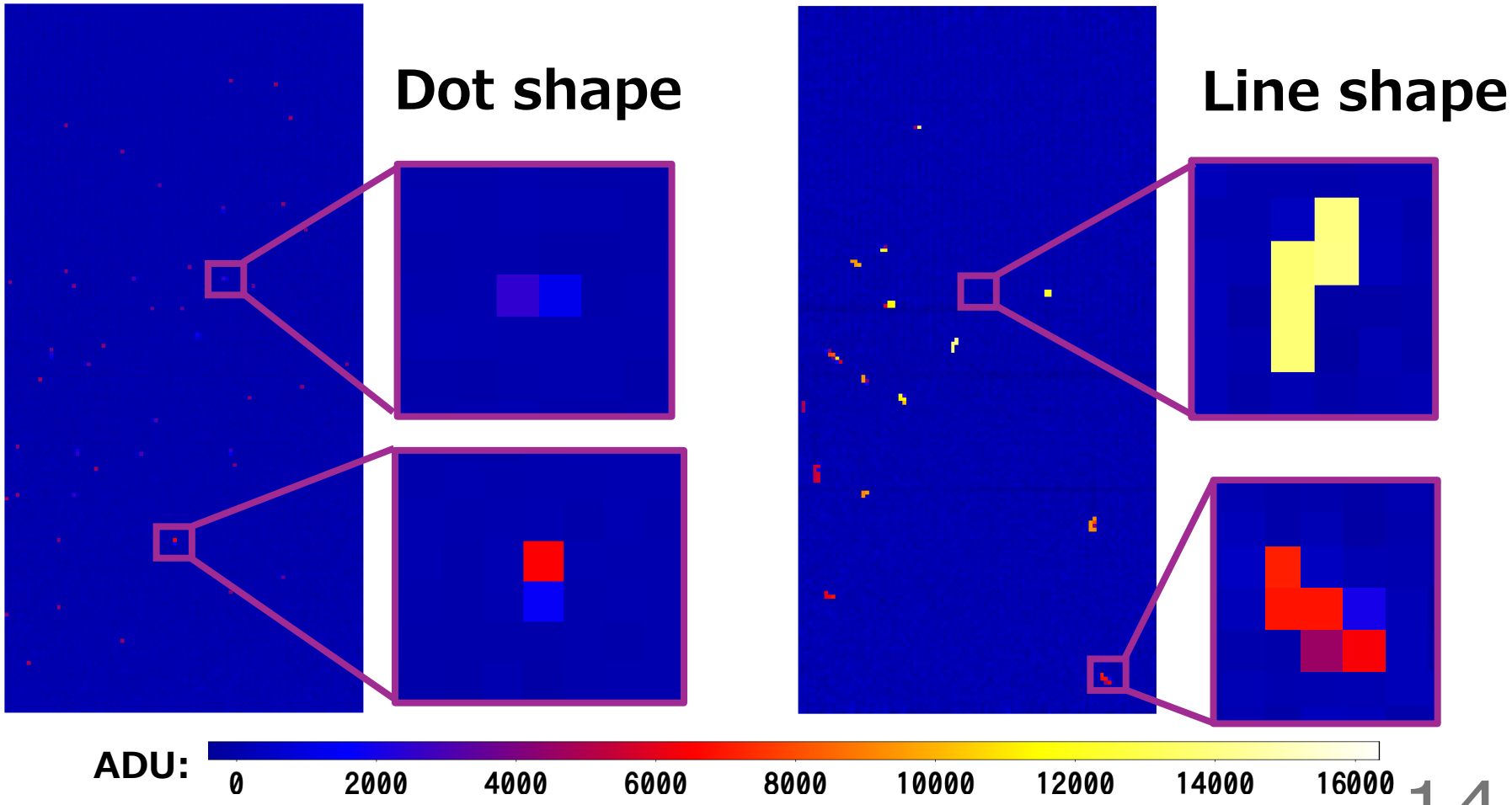
Sensitive Area	12.7 x 25.3 mm^2
pixel size	132 um
Depletion Layer	450 um
Bias	-250 V

sensor was put into the chamber. (0 ℃)

X-ray and β-ray Data

X-ray (Fe-55), Temperature = 0 ℃,
Integration Time = 20 ms
Data sets: 10 frames × 2,
100 frames × 1

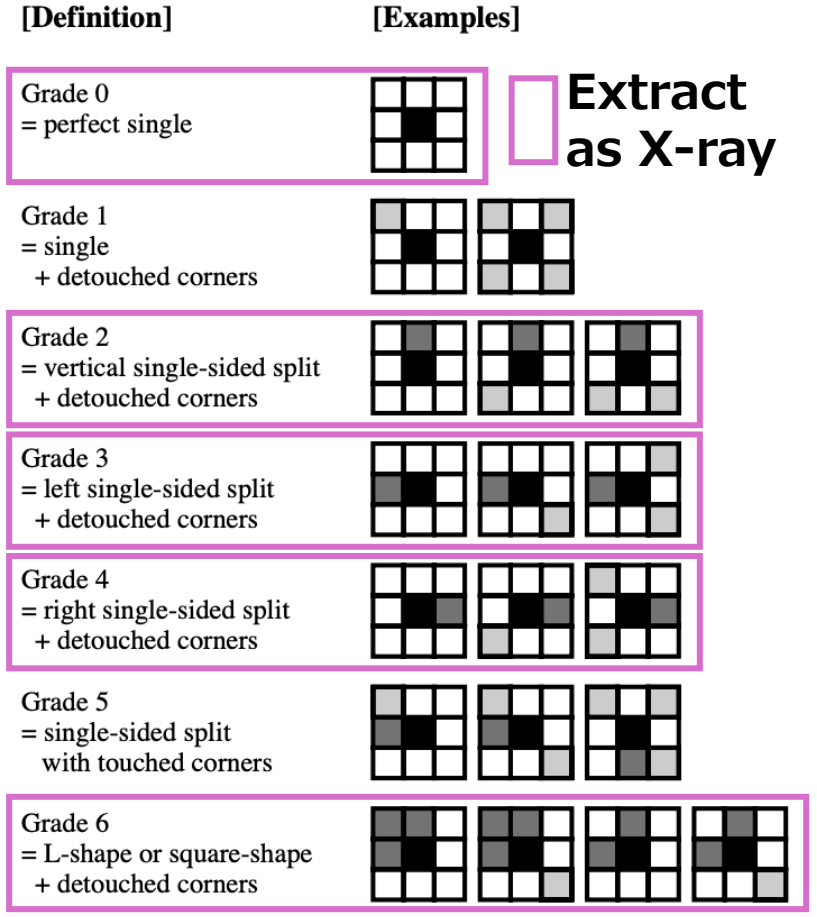
β-ray (Sr-90), Temperature = 0 ℃
Integration Time = 25 ms
Data sets: 100 frames × 2



Classical Method: X-ray Event Extraction

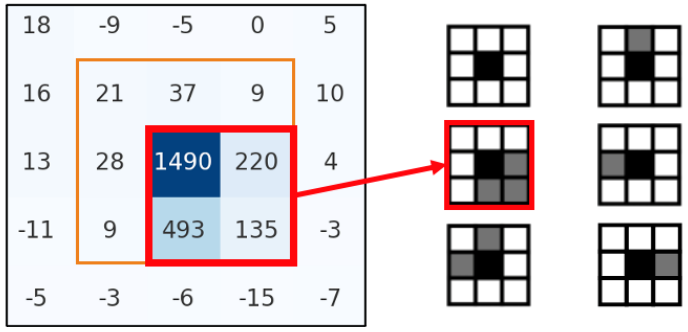
Grade Classification

- Classify and extract event propagation patterns using event thresholds (E_th) and split thresholds (S_th).
- Events exceeding the particle threshold (P_th) are removed as particle events.
- 3×3 pixels grade, 5×5 pixels grade
- **X-ray events are Grade 0, 2, 3, 4, 6**

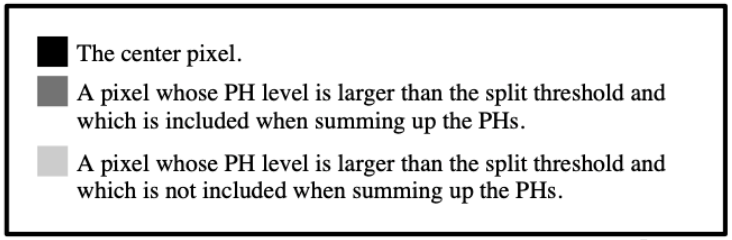


Example of event extraction

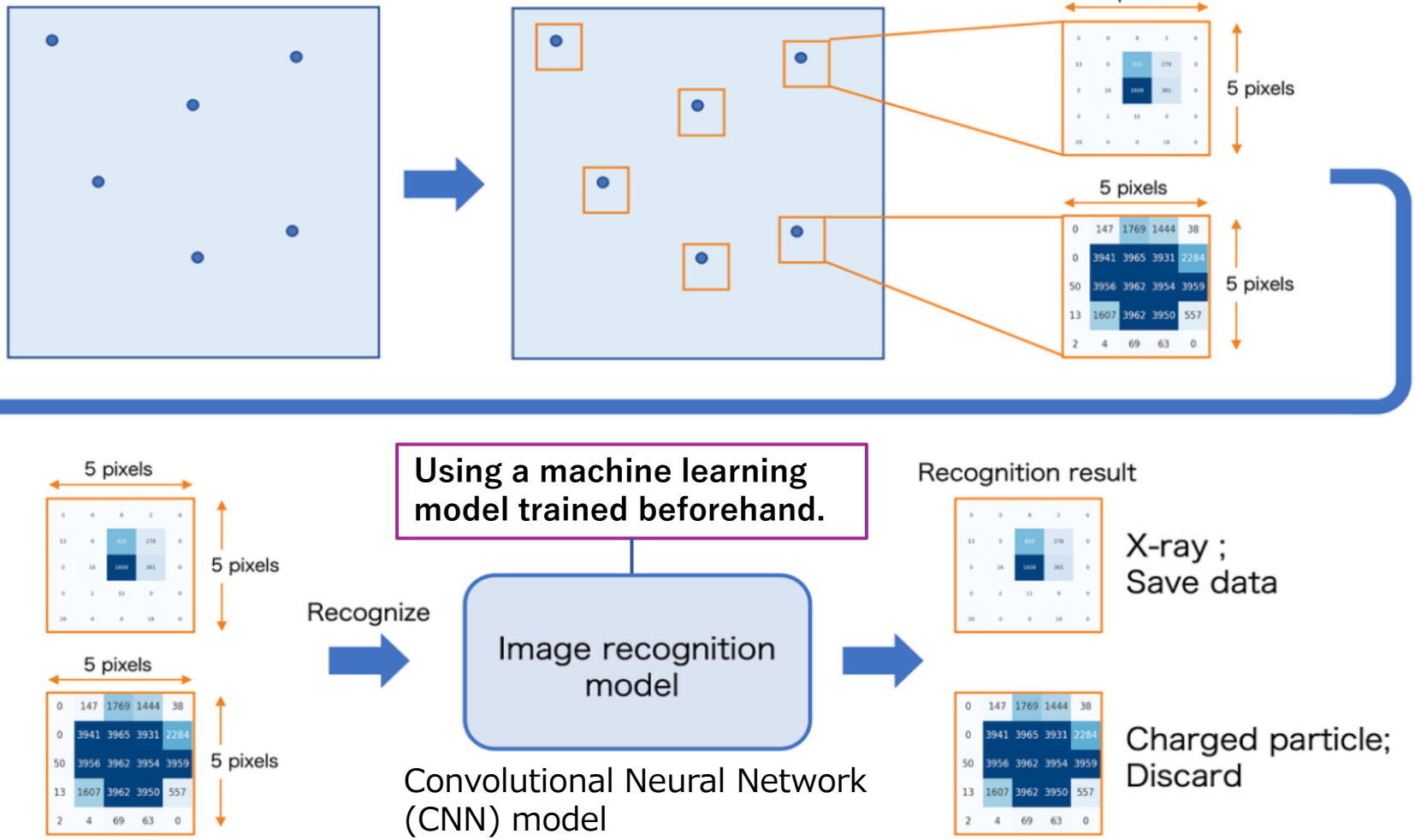
E_th = 200, S_th = 100



This X-ray event signal
=1490 + 220 + 493 + 135 = 2338



Machine Learning Method



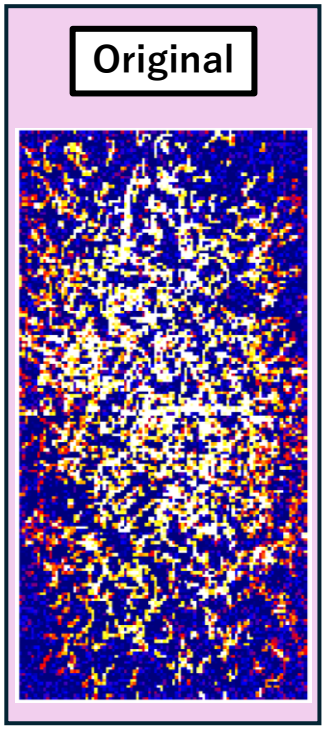
Crop the 5×5 pixels around the event

Data sets = 20 frames for X-ray, 100 frames for β-ray
Layer = 7, Num. of Epoch = 250, batch size = 32,
Train Data : Test Data = 7:3

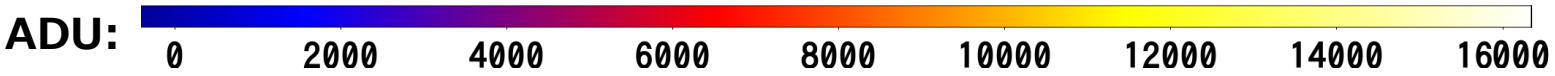
Comparison of β-ray Rejection

- Results from applying methods to Sr-90 data:

  Integration time = 25 msec, # of frames = 100 (separate from training data)



- This event map contains a large number of charged particle events.
- Among the 100 frames, a total of **1,893 β-ray events** were detected.



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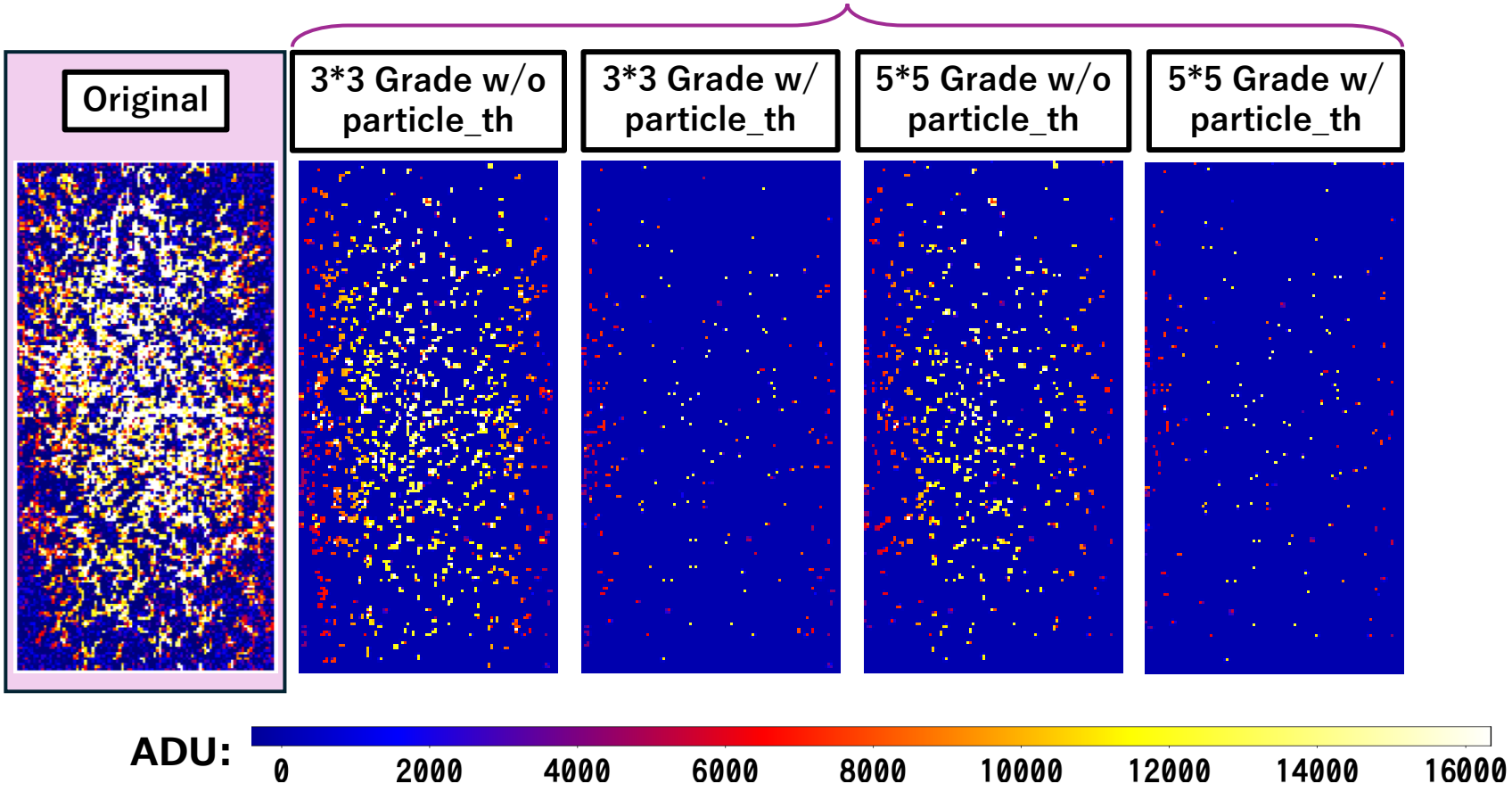
Charged particle events have been reasonably eliminated, but some still remain.



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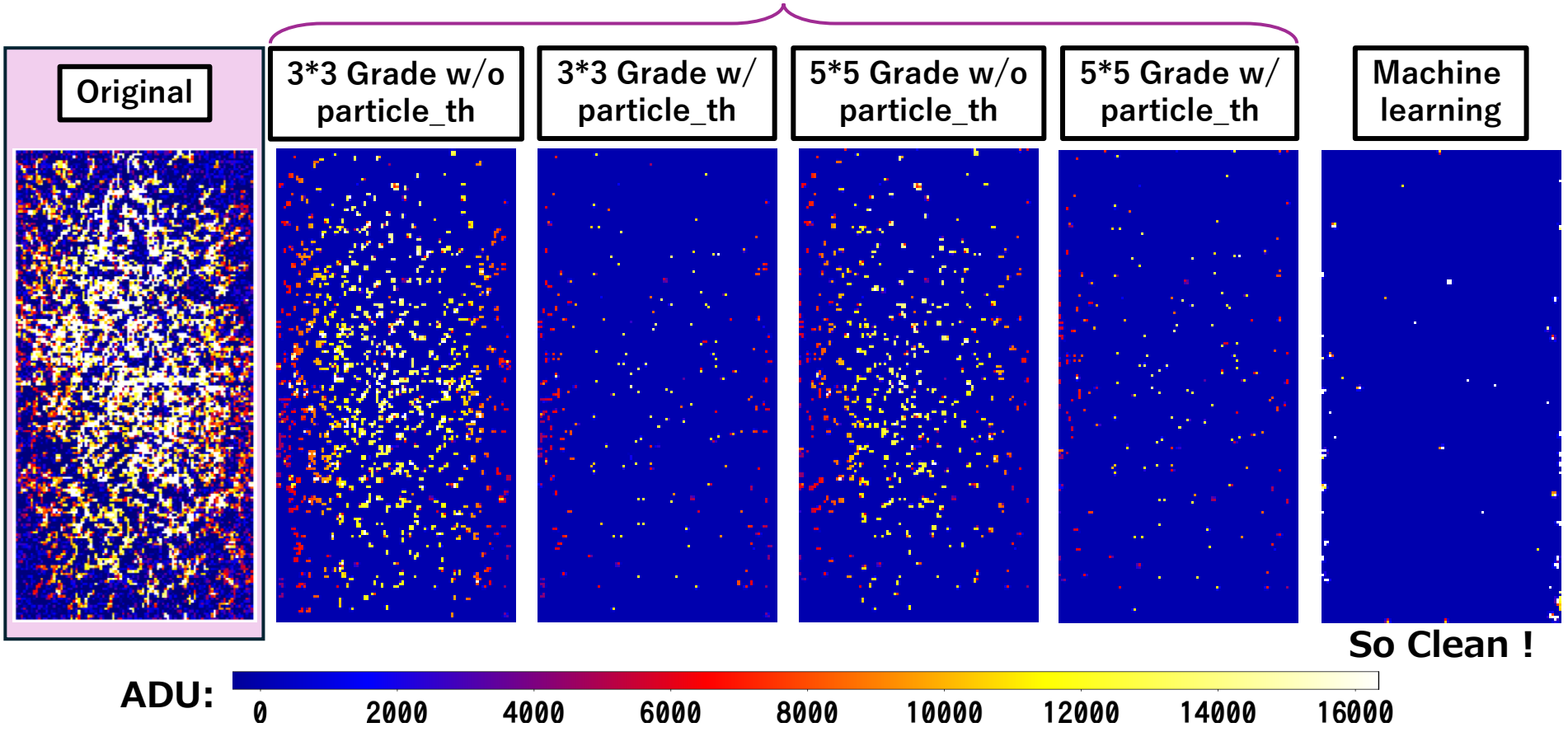

The Machine Learning (ML) method demonstrates visually superior charged particle rejection performance.

Comparison of X-ray Extraction

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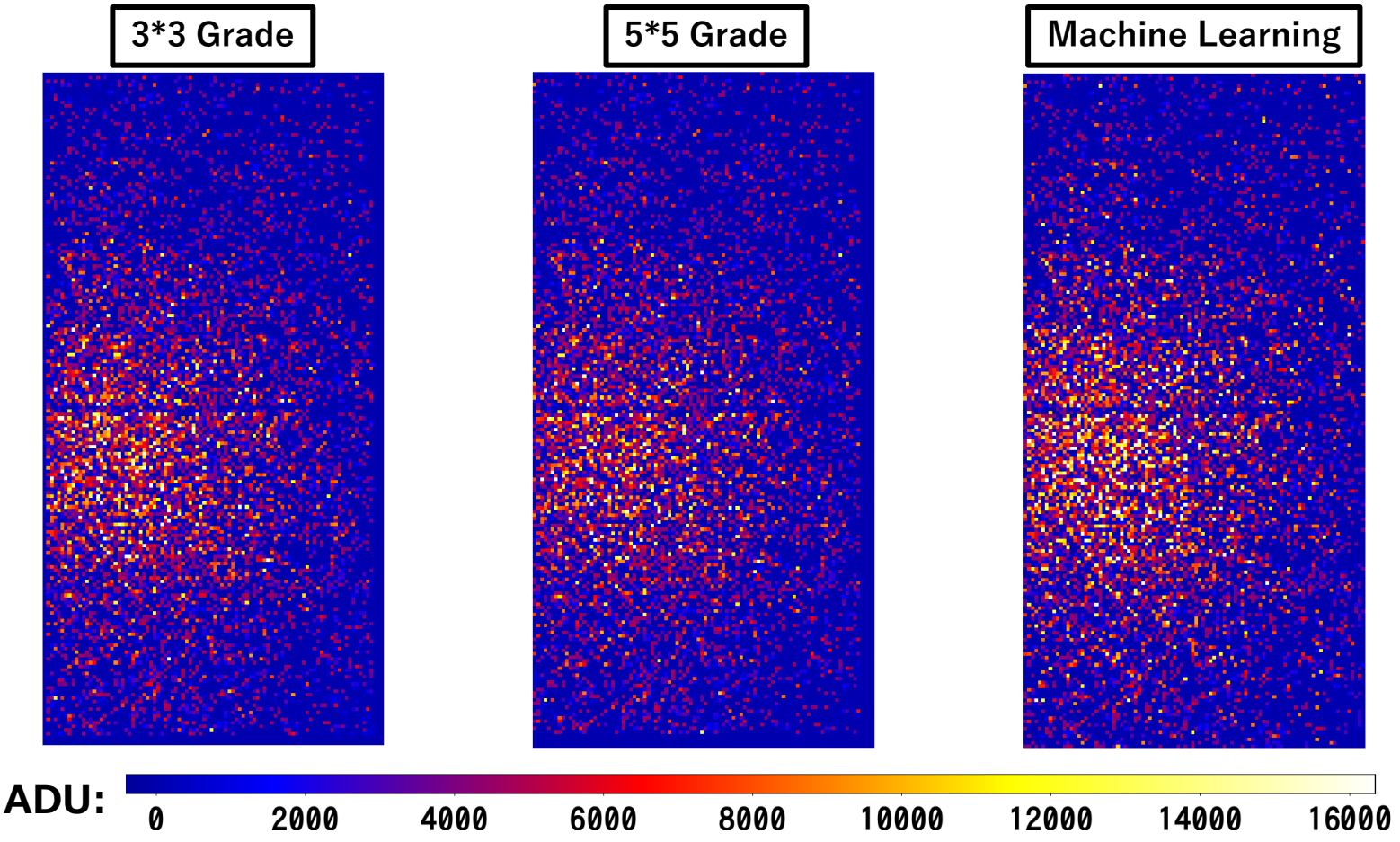


Visually, all methods are successfully extracting the X-ray events.

Comparison of Results

- ✓ While the grade method achieves only 10% removal efficiency, its processing is simple, requiring < 1 msec/frame.
- ✓ The machine learning method boasts an extremely low removal rate of 2.3%, but its processing time is 5-10 times slower than the grade method.

Methods	β-ray data set: False X-ray [count]	β-ray data set: "Misclassification Rate"* (as low as possible)	β-ray data set: Processing Time (CPU) [msec/frame] < 1 msec / frame is sufficient	X-ray data set: X-ray Extraction Rate (as high as possible)	X-ray data set: Particle Rejection Performance	X-ray data set: Feasibility on FPGAs
3×3 grade w/o p_th	999	52.8 %	0.739	99 %	○	◎
3×3 grade w/ p_th	226	11.9 %	0.366			
5×5 grade w/o p_th	499	26.3 %	0.848	95 %	○	○
5×5 grade w/ p_th	193	10.2 %	0.924			
Machine Learning	43	**2.3 %**	5.50	97 %	◎	△

Note1. Using **100 frames** of data.
Note2. Among the 100 frames, a total of 1,893 beta-ray events were detected.
The misclassification rate is defined as: **(Num. of false X-ray events) / 1,893**.

Summary

- **Onboard algorithm is essential for HiZ-GUNDAM** to prevent false GRB triggers from particle noise.
- Traditional Grade method has a relatively high misclassification rate (11.9%).
- Machine Learning method is superior, reducing the "**misclassification rate" to 2.3%** while maintaining 97% X-ray efficiency.
- Machine learning methods (with CNN model) are **5 to 10 times** slower than conventional methods.

Conclusion & Future Work

Conclusion

- For risk mitigation, the reliable "Grade method" will be implemented as the baseline system.
- The key result is that the ML method shows a clear path to achieving both high accuracy (2.3 %) and realistic processing speeds.

Future Work

- Currently, monochromatic X-ray sources are used.

→We will also use sources of other energies to validate the ML method model.

- To maximize the mission's observation efficiency, we also aim to implement the ML method.
- Investigate faster and lighter models with the goal of implementing them on FPGAs.

Thank you for your attention!

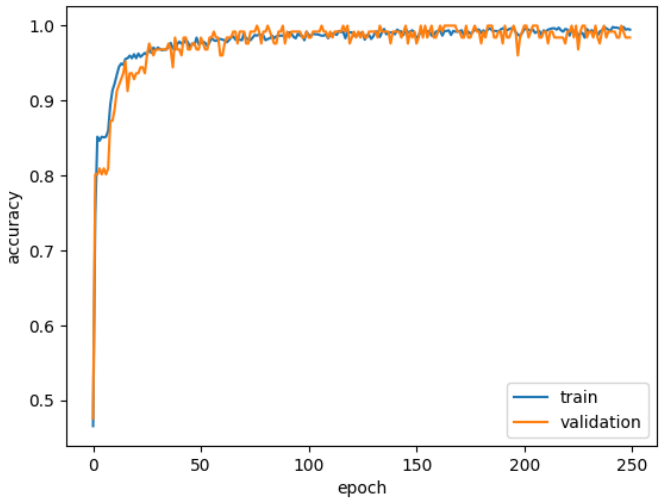
QR code:
You can send me an e-mail

ryuji_kondo07@stu.kanazawa-u.ac.jp

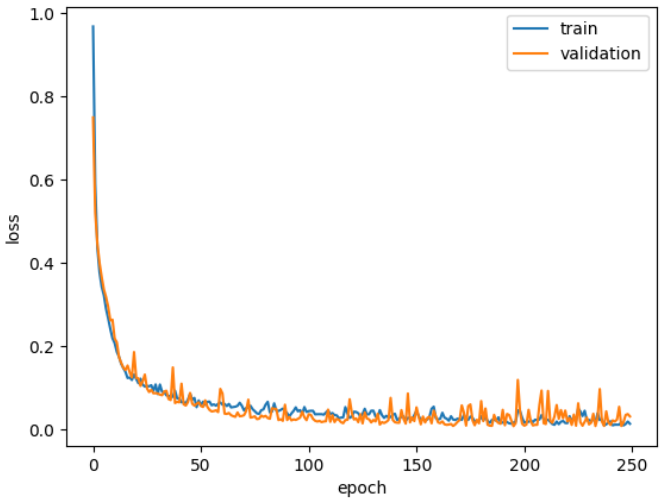
APPENDIX

Trained Model

Accuracy

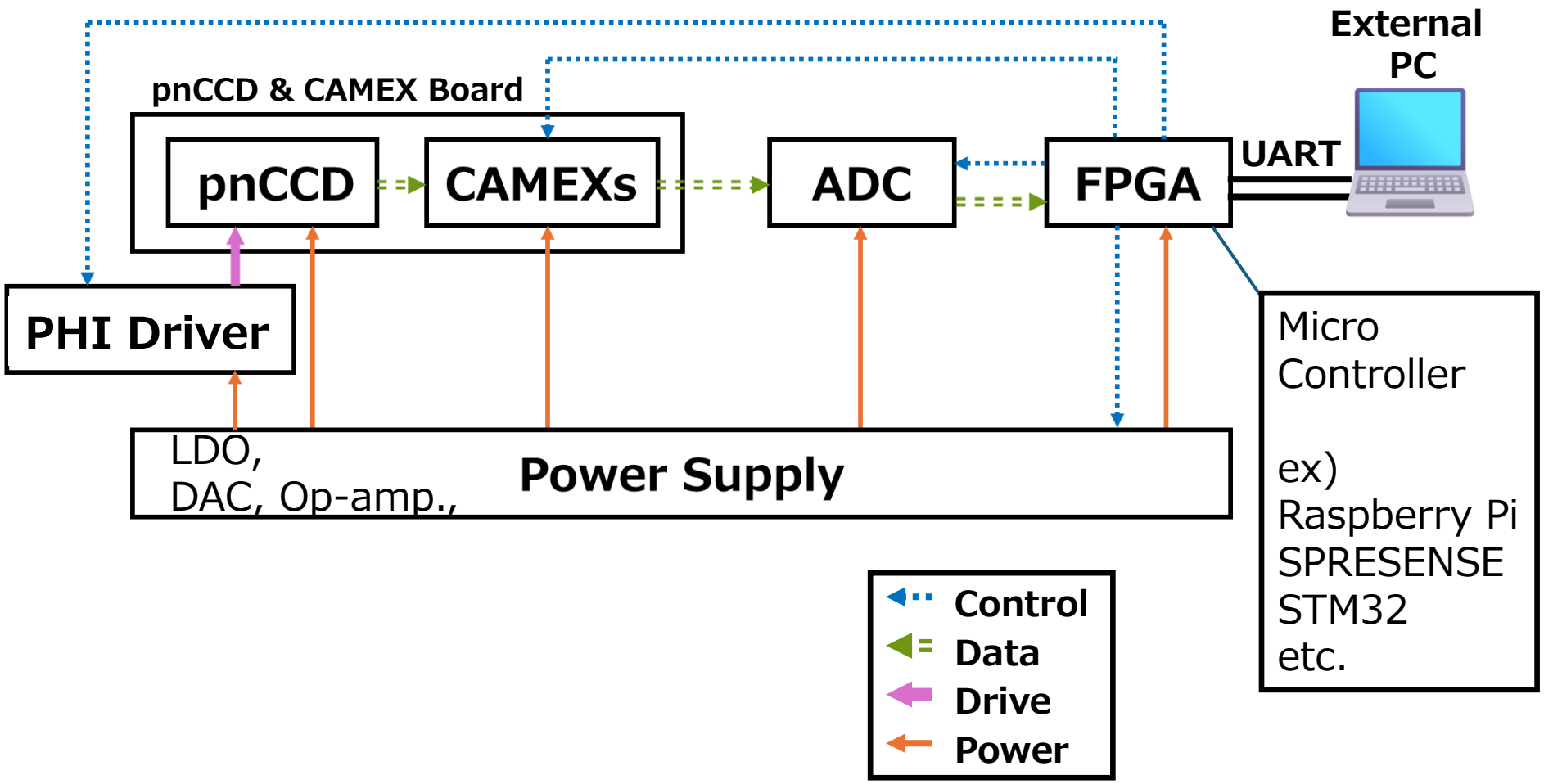


Loss



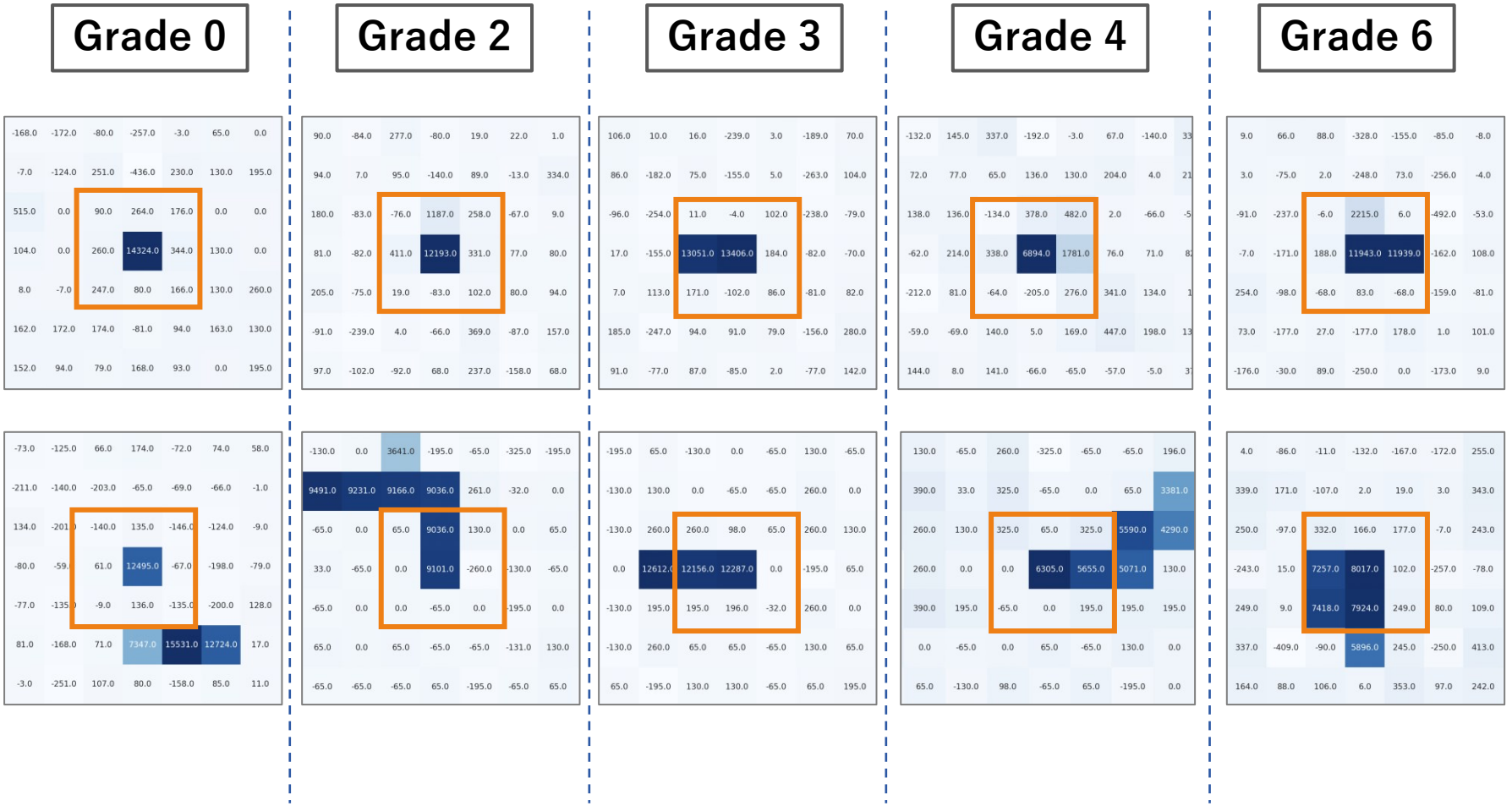
input_1: InputLayer	input:	(None, 5, 5, 1)
	output:	(None, 5, 5, 1)
conv2d_1: Conv2D (filters=16, kernel_size=3×3, relu)	input:	(None, 5, 5, 1)
	output:	(None, 3, 3, 16)
conv2d_2: Conv2D (filters=32, kernel_size=3×3, relu)	input:	(None, 3, 3, 16)
	output:	(None, 1, 1, 32)
dropout_1: Dropout (rate=0.25)	input:	(None, 1, 1, 32)
	output:	(None, 1, 1, 32)
flatten_1: Flatten	input:	(None, 1, 1, 32)
	output:	(None, 32)
dense_1: Dense (units=128, relu)	input:	(None, 32)
	output:	(None, 128)
dropout_2: Dropout (rate=0.5)	input:	(None, 128)
	output:	(None, 128)
preds: Dense (units=3, softmax)	input:	(None, 128)
	output:	(None, 3)

Next System


External PC
pnCCD & CAMEX Board
pnCCD
CAMEXs
ADC
FPGA
UART
PHI Driver
LDO,
DAC, Op-amp.,
Power Supply
Micro Controller
ex)
Raspberry Pi
SPRESENSE
STM32
etc.
Control
Data
Drive
Power

3×3 Pixel Grade False Classification

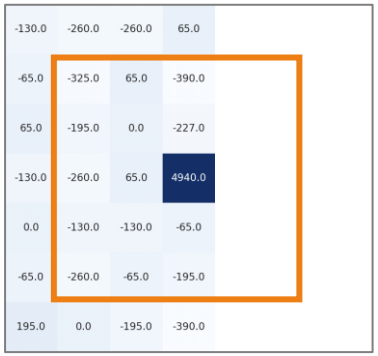
□ = Event Detection Area

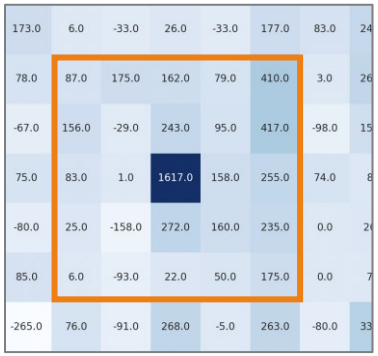


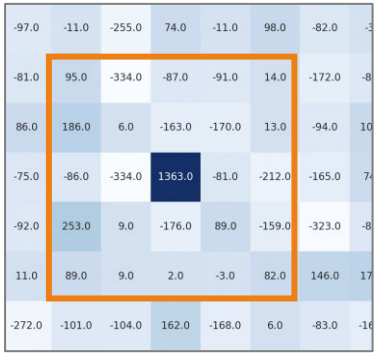
Machine learning

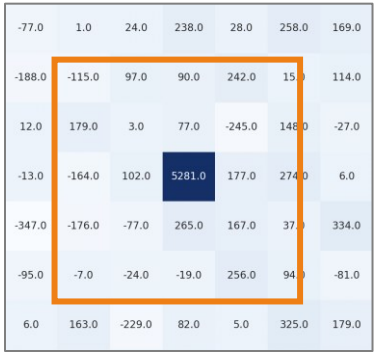
= Event Detection Area

Single pixel event

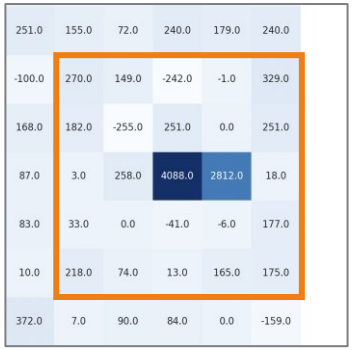


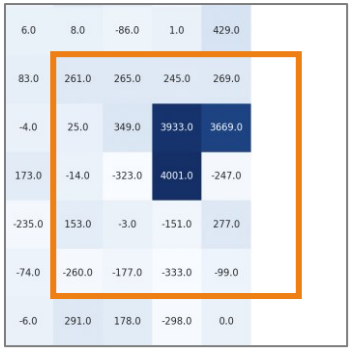


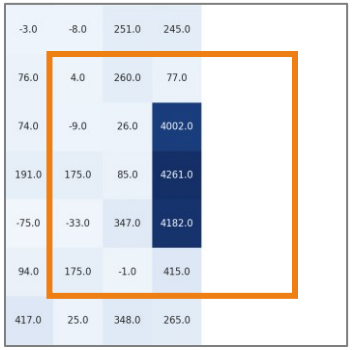




Multi Pixel Event







3×3 pixels Grade

= Event Detection Area

5×5 pixels Grade

= Event Detection Area