poster num. 42

Radiation tolerance test with 10 MeV protons and performance evaluation of pnCCD for future satellite mission *HiZ-GUNDAM*

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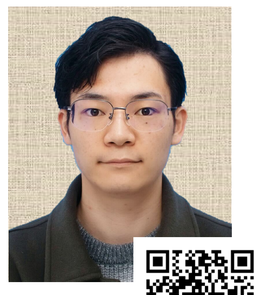


Please email me with any questions or inquiries. →

S. Takahashi et al., NIM-A, 2024, Volume 1064, pages 169413

1. *HiZ-GUNDAM*

Launch target is in early 2030s

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

■ Key Sciences

1. Exploration of early universe (at z > 7) with GRB
2. Exploration of electromagnetic counterparts of gravitational wave or neutrino sources.

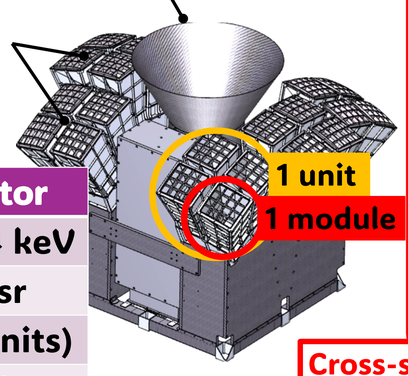
■ Instruments

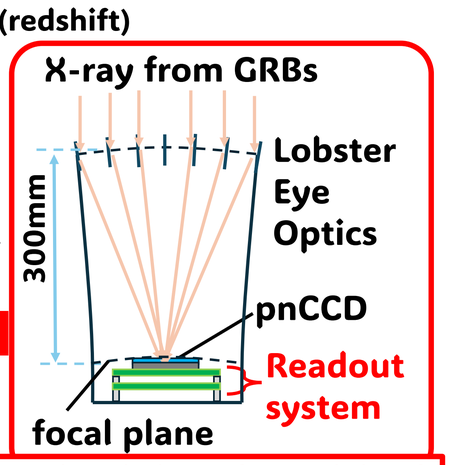
Near Infrared Telescope

Measurement of the distance (redshift)

Wide Field X-ray Monitor

Discovering and direction determination of the gamma-ray bursts (GRBs)





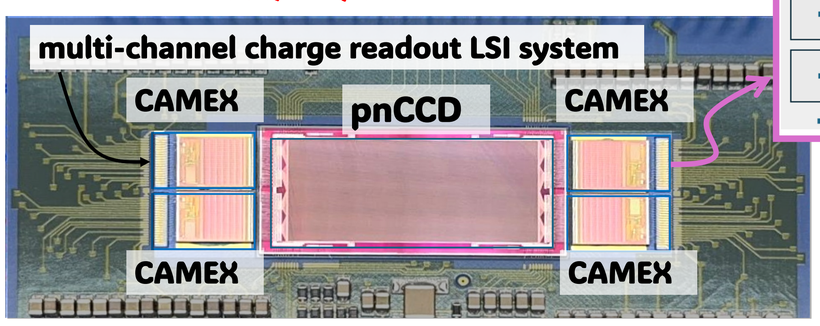
Cross-sectional view of 1 module of Wide Field X-ray Monitor

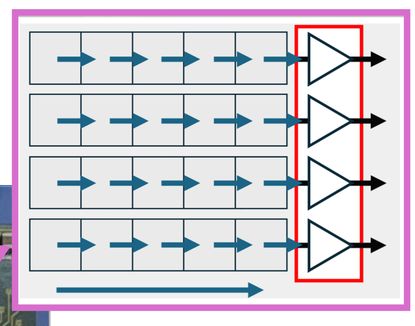
Wide Field X-ray Monitor	
energy range	0.4 – 4 keV
field of view	0.5 sr
num. of pnCCD	16 (4 units)
time resolution	< 0.1 s

■ pnCCD Image Sensor

pnCCD system manufactured by PNsensor GmbH

- Multi-Channel Readout
- High frame rate (up to 1000 frames/second !)
- Onboard multiple spacecraft
  XMM-Newton, SRG/eRSITA, SVOM/MXT, Einstein Probe/FXT, etc.





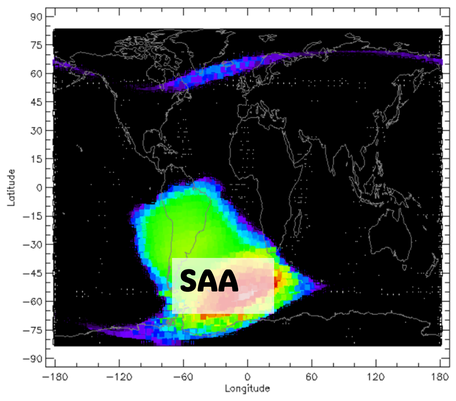
The image of typical pnCCD-LSI electrical board system and the diagram multi-channel readout with the LSI,CAMEX.

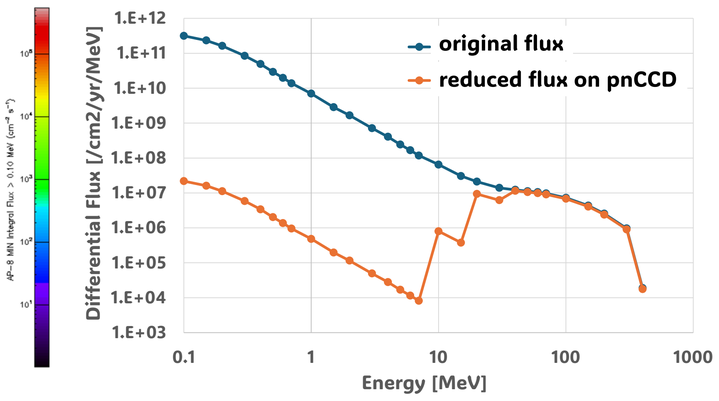
2. Radiation and its Effects in Orbit

■ *HiZ-GUNDAM* orbit(TBD)

sun synchronous dawn-dusk orbit(altitude: 500 – 600 km, 98.1°)
mission term: 3 – 5 years

■ Captured Proton Flux for *HiZ-GUNDAM*





Left: Simulated captured proton flux map by SPENVIS (AP-8).
Right: Estimated flux of protons incident on a pnCCD in one module in orbit.

■ Radiation Damage Effects on pnCCD

Increase in dark current
→ Worsen lower detectable energy

Lower limit of the energy range in which the signal can be sufficiently distinguished from noise to be detectable

▶ Requirement for focal plane detector: 0.4 – 4 keV may no longer be satisfied.

We must test radiation tolerance to various irradiation doses.

3. Purpose

To quantify the degrade in soft X-ray detection performance of pnCCDs in response to changes in irradiation dose.

Investigate in the parameter space of framerate and temperature.

pnCCD operating range before irradiation

Items	Parameter
lower detectable energy	0.1 keV
framerate	any
temperature	any

▶

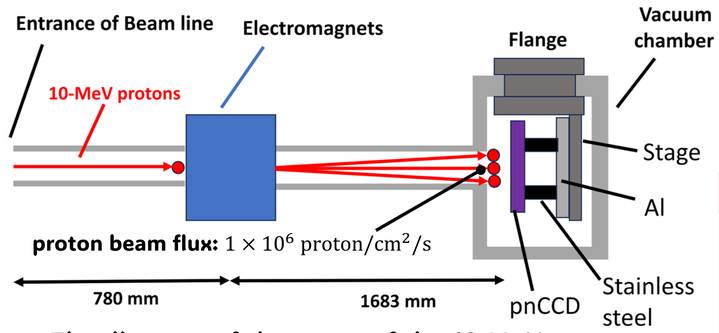
pnCCD operating range after irradiation

Items	Parameter
lower detectable energy	≤ 0.4 keV
framerate	≥ ??? frame/s
temperature	≤ ??? ℃

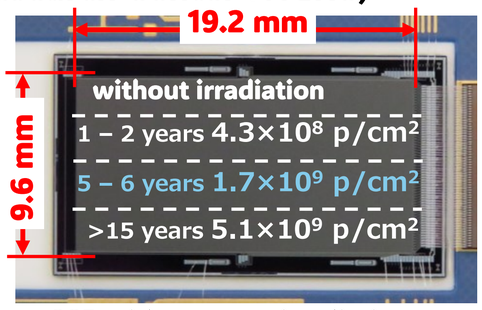
4. Radiation Tolerance Test

@ Wakasa-wan Energy Research Center (WERC)

- The dose in the orbit was represented by 10 MeV proton beams.
- The pnCCD was divided into four irradiated areas, each of which was irradiated with a different number of protons in 2023.



The diagram of the setup of the 10 MeV proton irradiation experiment



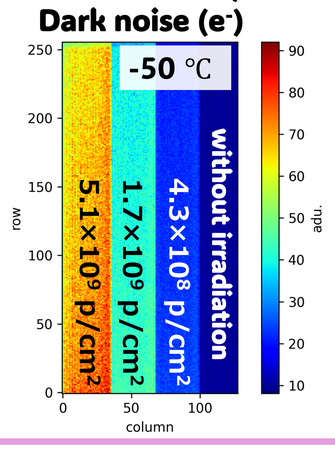
pnCCD with separate irradiation area
(number of years in orbit in the WORST case corresponding to the irradiation dose
→ Actual deterioration could be much less.)

Item	small-pnCCD
sensitive area	9.6 × 19.2 mm²
pixel size	75 um
pixel number	128 × 256
depletion thickness	450 um

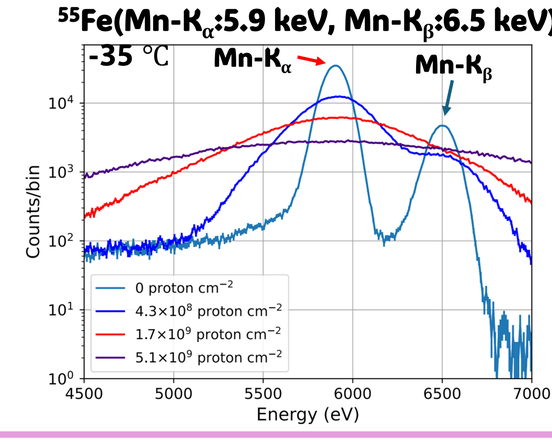
5. Image Data After Irradiation

frame rate: 33 frames/second
temperature: -20 ℃, -35 ℃, -50 ℃, -70 ℃, -90 ℃

Dark noise (e⁻)



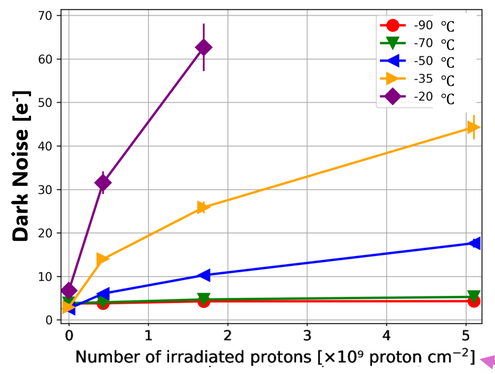
^{55}Fe(Mn-K$_\alpha$:5.9 keV, Mn-K$_\beta$:6.5 keV)



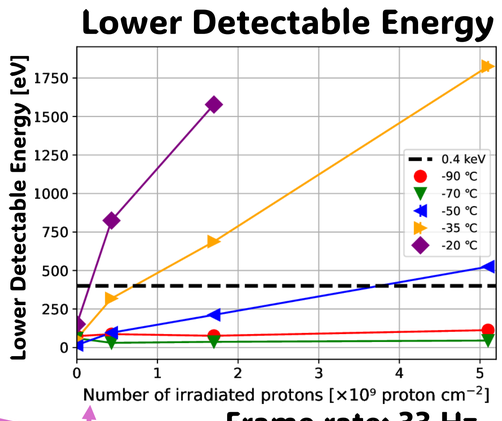
6. Analysis and Results

■ Dark Noise and Lower Detectable Energy

Dark Noise

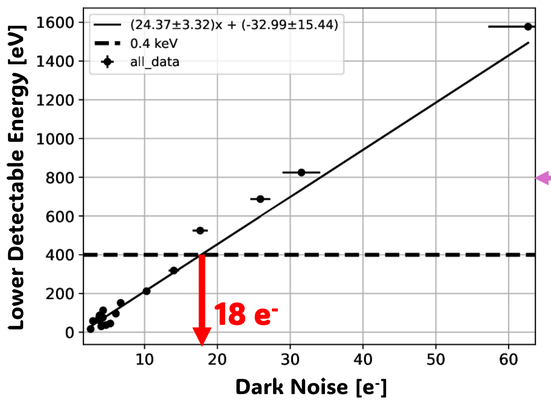


Lower Detectable Energy



Frame rate: 33 Hz

identical



the correlation between dark noise and lower detectable energy

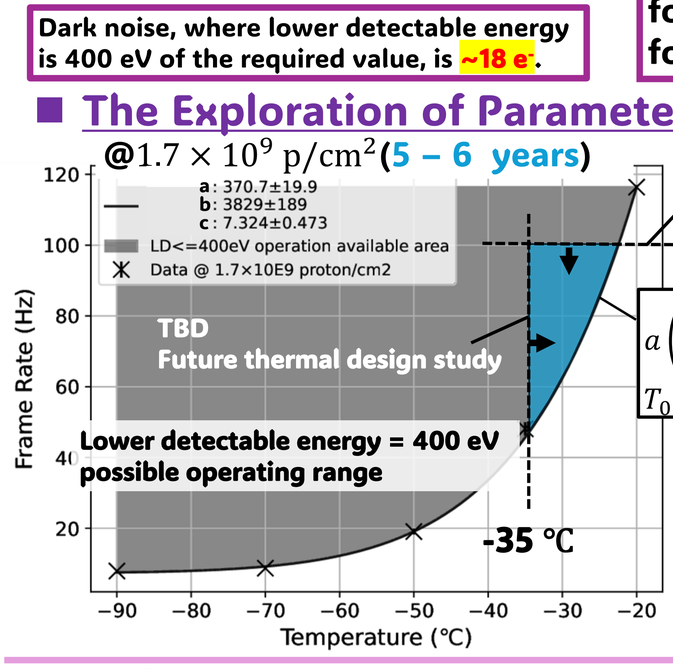
Dark noise, where lower detectable energy is 400 eV of the required value, is ~18 e⁻.

Assume the target value for the dark noise is 18 e⁻,

$$(\text{Dark noise}) \propto t_{\text{exposure}} \propto (\text{frame rate})^{-1}$$

Using this relationship, we searched for an acceptable parameter space for temperature and frame rate.

■ The Exploration of Parameter Space



TBD
Future elec. system study

100 [Hz]

$$a\left(\frac{T}{T_0}\right)^{3/2}\exp\left[-b\left(\frac{1}{T}-\frac{1}{T_0}\right)\right]+c$$
$$T_0 = 273\ \text{K}$$

(Derived by assuming a Boltzmann distribution.)

We can find this blue area with thermal design and elec. system study.
It can be said that the pnCCDs can tolerate radiation for the *HiZ-GUNDAM* mission term.

Next Step.

- ☐ Starting with thermal design and electrical system considerations, operating temperatures and frame rates will be discussed.
- ☐ Since it is possible to over-test the proton beam at 10 MeV to be representative of all proton energies, similar tests will be performed with proton beams of about 100 MeV for a comprehensive evaluation.

MAXI 15 Year Workshop for the Time Domain Astronomy on December 10-12, 2024, at Nihon university, Tokyo Japan