Design and evaluation of a MeV gamma-ray camera aboard a 50-kg class small satellite

R.Iwashita, J.Kataoka, K.Tanaka, R.Mori, T.Suga, S.Ogasawara (waseda U.)
Y.Yatsu, T.Chujo, K.Watanabe, H.Kobayashi, D.Kobayashi, Y.Amaki, K.Otubo,
A.Ohira , Y.Arai, M.Yasuda, K.Tashiro, Y.Ozeki, Y.Kawaguchi, D.Yoshimura, (Tokyo Tech)

WASEDA University Tokyo Tech

Abstract: Waseda University and Tokyo Tech are developing a 50-kg class small satellite, tentatively named **INSPIRE**, scheduled for launch in FY2026. The satellite's primary detector is a **BOX-type Compton Camera (CC-BOX)**. This camera covers a dynamic range spanning two orders of magnitude: it observes low energy (30 keV – 200 keV) in Pinhole mode and high energy (200 keV –3 MeV) in Compton mode. The CC-BOX comprises a pixelized **Ce:GAGG** scintillator array and an **MPPC array** operating at 40V. The absorber features a four-layer, 20mm thick depth-of-interaction (DOI) structure. Additionally, Ce:GAGG elements are positioned on the sides of the detector to enhance its sensitivity than traditional Compton Cameras. For the observation of low-energy gamma rays, the scatter has 5mm square holes to facilitate pinhole imaging. Furthermore, **BGO shields** are positioned on the side and bottom of the detector for efficient event rejection. In this poster, we begin by detailing the design of the CC-BOX, its data processing flow and power specifications. Next, we assessed the detector's anticipated performance through simulations, focusing on detection sensitivity, imaging resolution, energy resolution, and anticipated spectra when observing the Crab Nebula. Finally, we share the findings from a series of environmental tests in preparation for the FY2026 launch.

◆ Introduction

☐ MeV Gamma-ray Astronomy

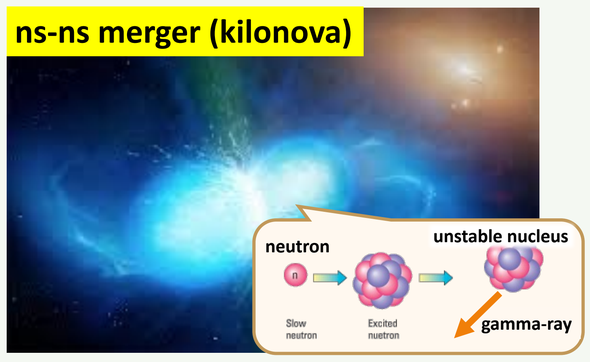
⇨ Nuclear gamma-rays are abundant

- ✓ The origin of rare metals (Pt, Au ++)
- ✓ Blackhole, Gravity waves, kilonova ...

But ...

- ✓ It is necessary to observe in space
- ✓ Background (CXB, Albedo) > Signal

MeV Gamma-ray is difficult to detect



e.g. $^{197}_{79}\mathrm{Au} + \mathrm{n} \rightarrow {}^{198}_{79}\mathrm{Au} + 412\ \mathrm{keV}$

Our Motivation

- ✓ **50-kg class satellite**: Low cost (~2M USD), Short-term development (~5yr)
- ✓ Performance comparable to COMPTEL

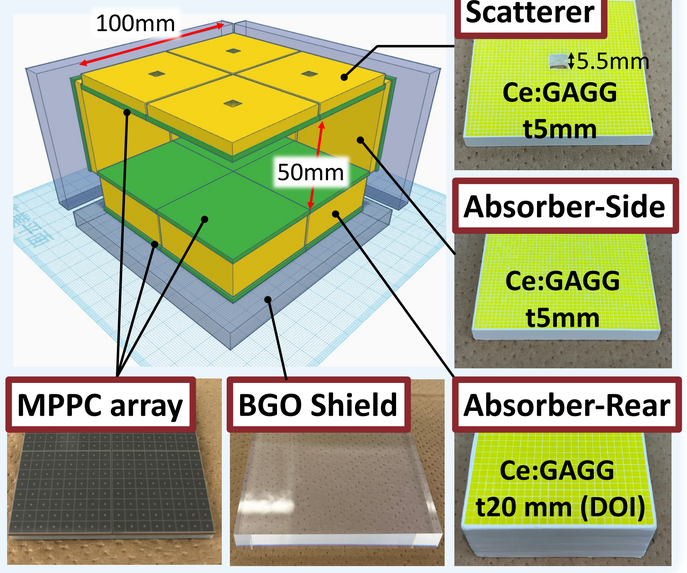
◆ Detector - INSPIRE -

☐ BOX-type Compton Camera (CC-BOX)

Scintillator: Ce:GAGG array
veto shield: BGO plate
photon detector: MPPC array

Spatial Resolution
Scatterer & Side: 1mm Rear: 2mm

Energy Resolution
Ce:GAGG: 9%(FWHM) @662keV
BGO: 16%(FWHM) @662keV



characteristic

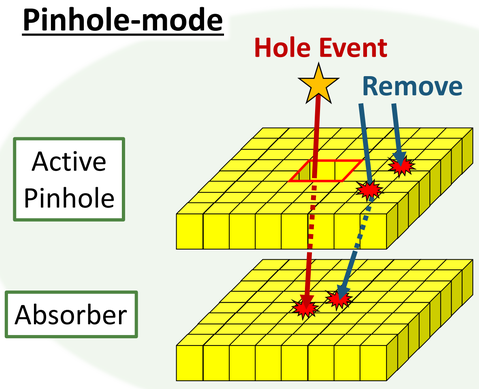
Active Pinhole: Low-Energy detection
Rear DOI: Sensitive to high-Energy
Absorber-side: Higher sensitivity
BGO shield: BKG/escape event removal

☐ Gamma-ray Detection Method

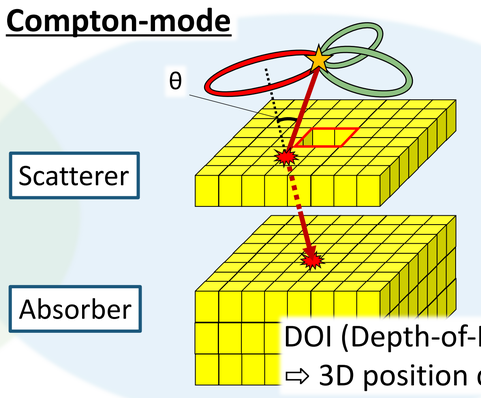
Low-Energy ~100keV High-Energy

photo absorption → Compton scattering

Pinhole-mode

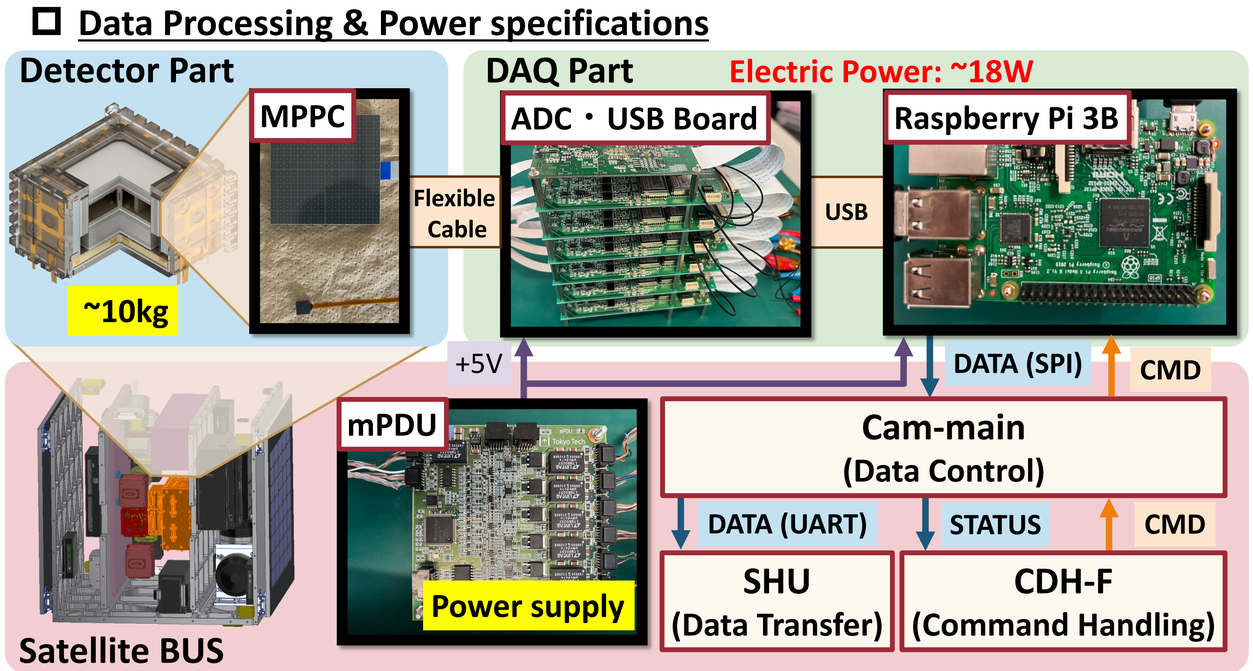


Compton-mode



DOI (Depth-of-Interaction)
⇨ 3D position detection

☐ Data Processing & Power specifications



◆ Performance - Geatn4 simulation -

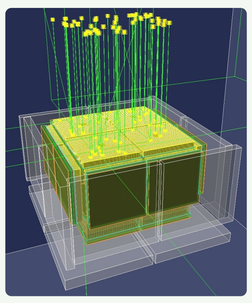
☐ Sensitivity

Continuum Sensitivity

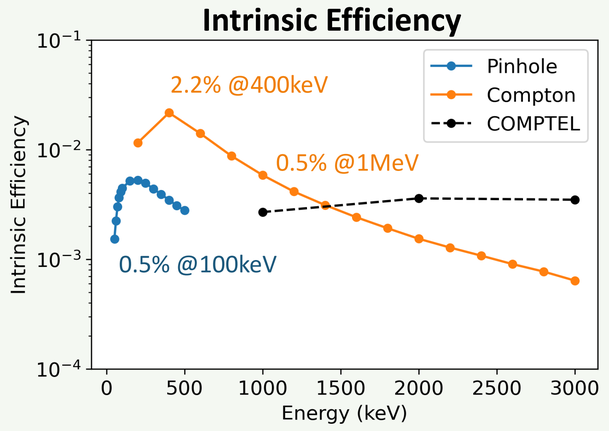
$$S(E) = \frac{f}{\eta(E)}\sqrt{\frac{b(E)}{A\,\Delta E\,T}}$$

Line Sensitivity

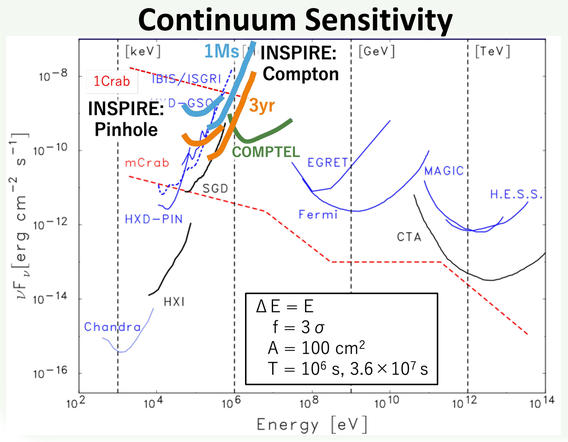
$$S(E) = \frac{f}{\eta(E)}\sqrt{\frac{2b(E)\delta E}{AT}}$$



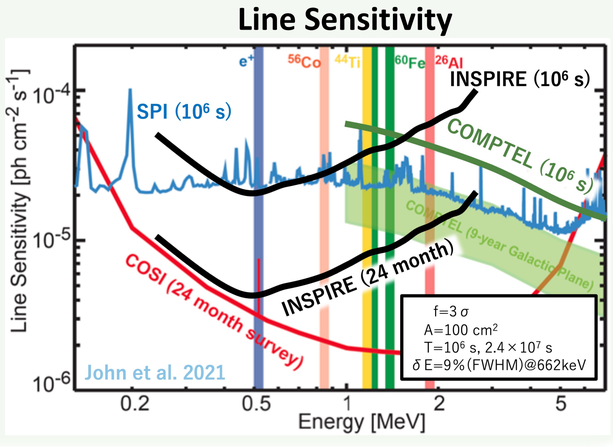
f: Lower limit of detection σ
$\eta(E)$: Intrinsic Efficiency
$b(E)$: Detected background (CXB, Albedo)
δE: Energy resolution (FWHM)



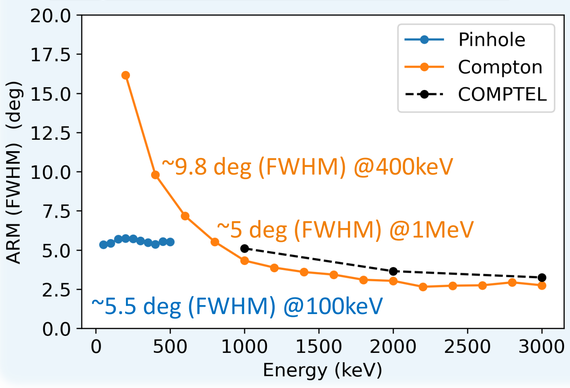
Continuum Sensitivity



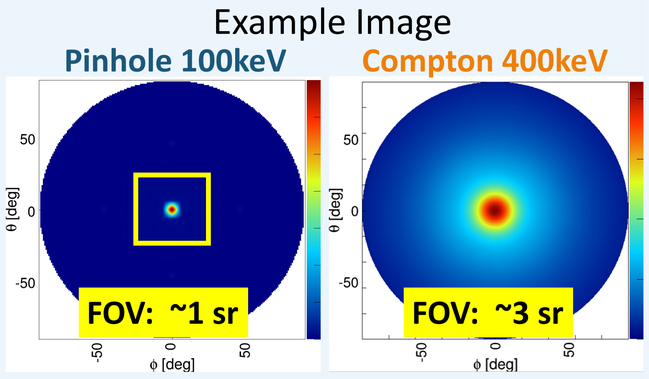
Line Sensitivity



☐ Angular Resolution Measure



Example Image

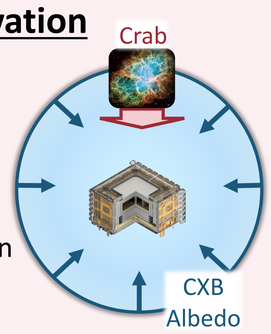


☐ Crab Observation

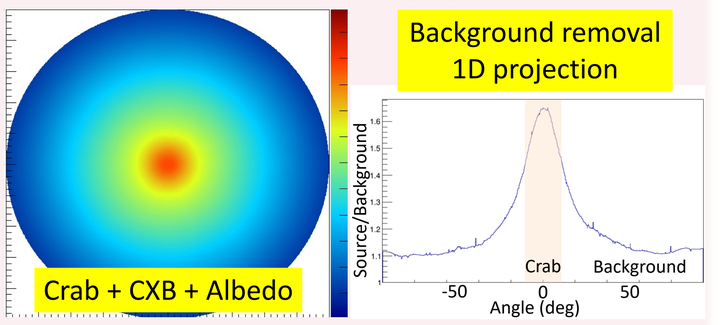
Assumption

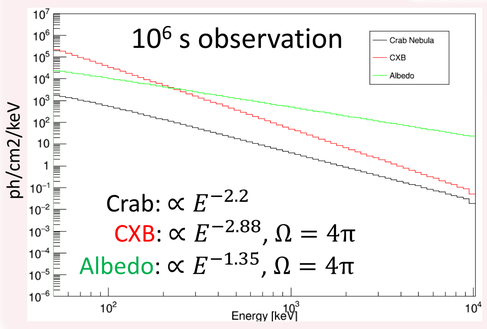
Crab: Center

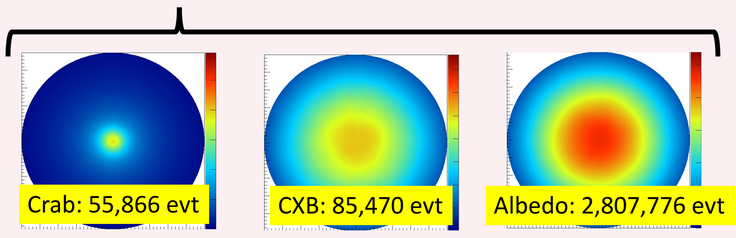
CXB/Albedo: Isotropic radiation



300keV – 1.5MeV Imaging (10^6 s)



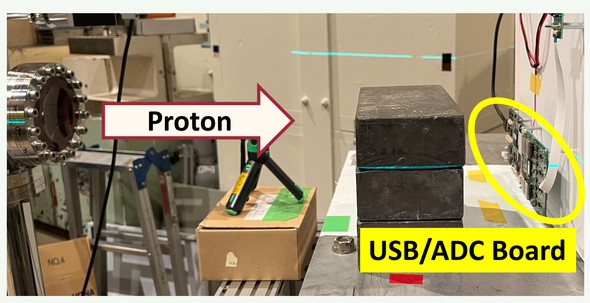




Crab Nebula can be detected at **9.7σ** (300keV-1.5MeV)

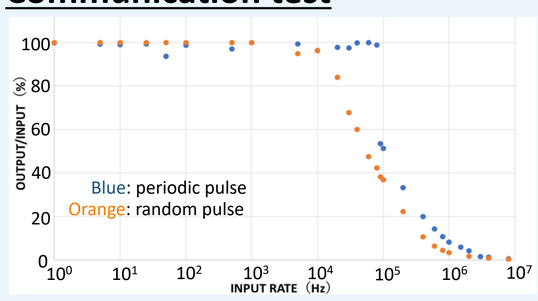
◆ Environmental tests for Launch

☐ Radiation test



- ✓ **~10 years of proton and gamma-ray**
  - ⇨ SEL / SEU: **~1 / yr**
  - ⇨ Operation was confirmed after reboot
- ✓ **Ce:GAGG doesn't radiate in orbit**

☐ Communication test



- ✓ **High-rate data acquisition: ~20kHz**
- ✓ MPPC signal readout using Raspberry Pi

Complete engineering model
⇨ Vibration test, thermal vacuum test ..