Gas selection for Xe-based LCP-GEM detectors onboard the CubeSat X-ray observatory NinjaSat

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Programs for Junior Scientists

1. Introduction

NinjaSat Project (Enoto+20)

- 6U-size (10×20×30 cm³) CubeSat X-ray observatory for monitoring bright X-ray compact objects (**Fig.1**)
- Will be launch with Falcon 9 rocket in **Oct. 2023**
- Flexible observation strategies
  1. Long-term monitoring of persistently bright sources simultaneous with optical and/or radio observation
  2. Prompt follow-up observations of bright X-ray transient

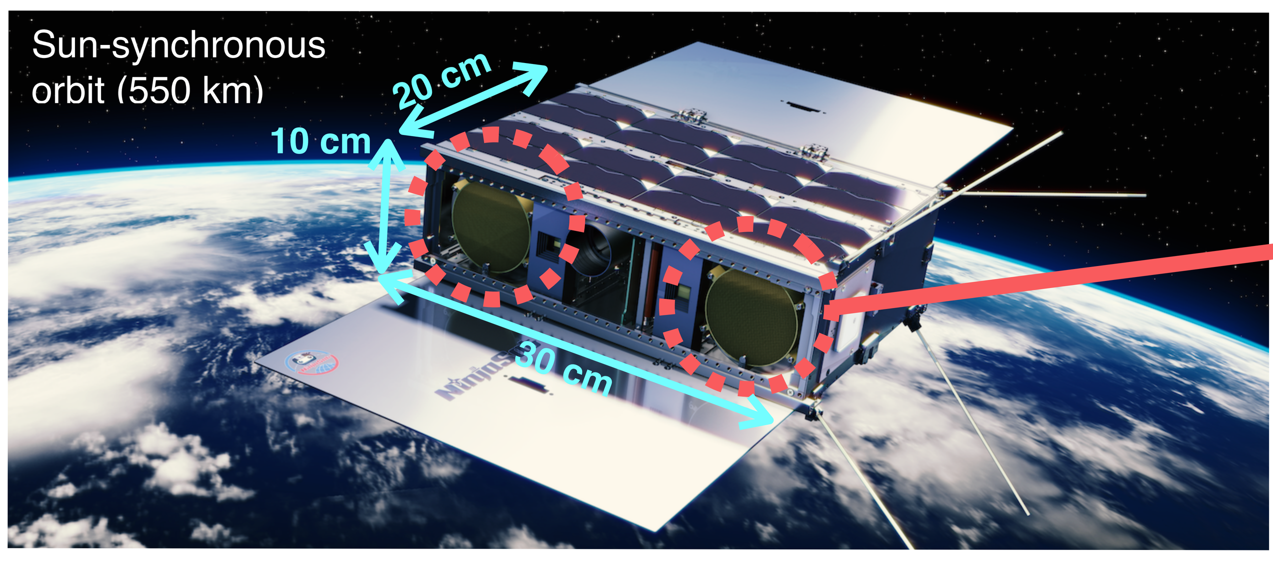


Fig.1. Schematic 3D illustration of NinjaSat in orbit

Gas Multiplier Counter (GMC)

- 1U-size non-imaging gas X-ray detector × 2 (**Fig.2, 3**)
  - Energy bandpass: 2–50 keV
  - Effective area: **32 cm² @6 keV** <– gas detector is the best choice to achieve a large effective area at a low cost
- Gas Electron Multiplier with liquid crystal polymer (**Fig. 4**)
- **Sealed gas: XeArDME (75%/24%/1%) @0°C, 1.2 atm**
  <– **The purpose of this study is to select the sealed gas and characterize it.**

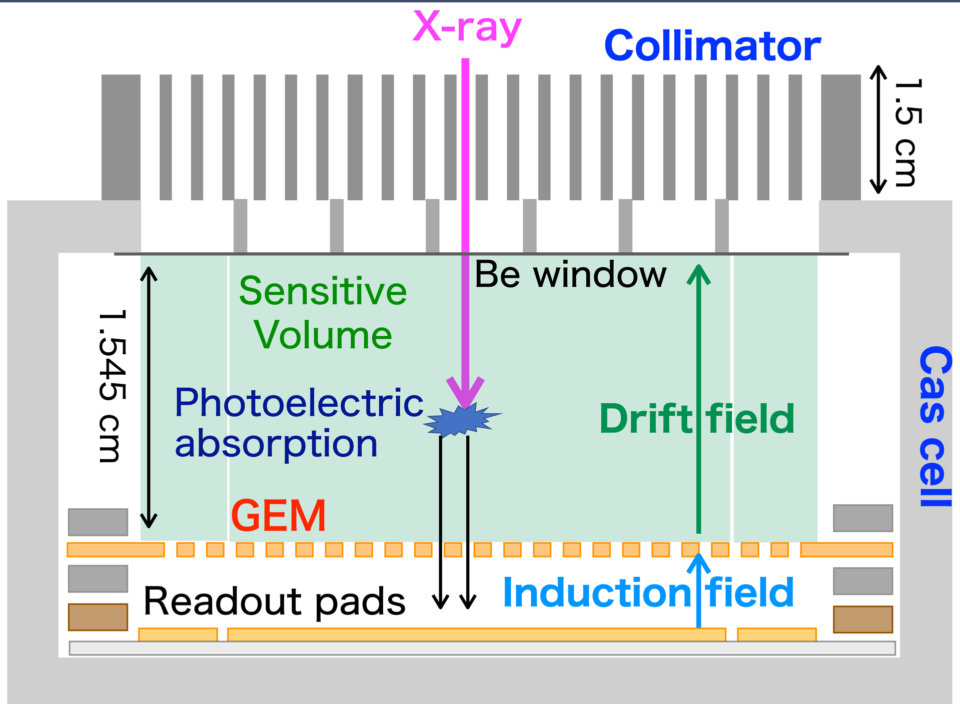


Fig. 3. Cross-sectional view of the gas cell

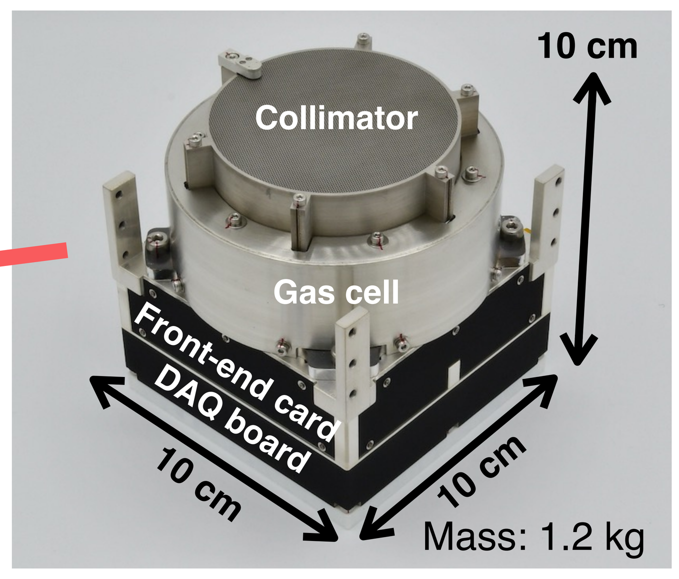
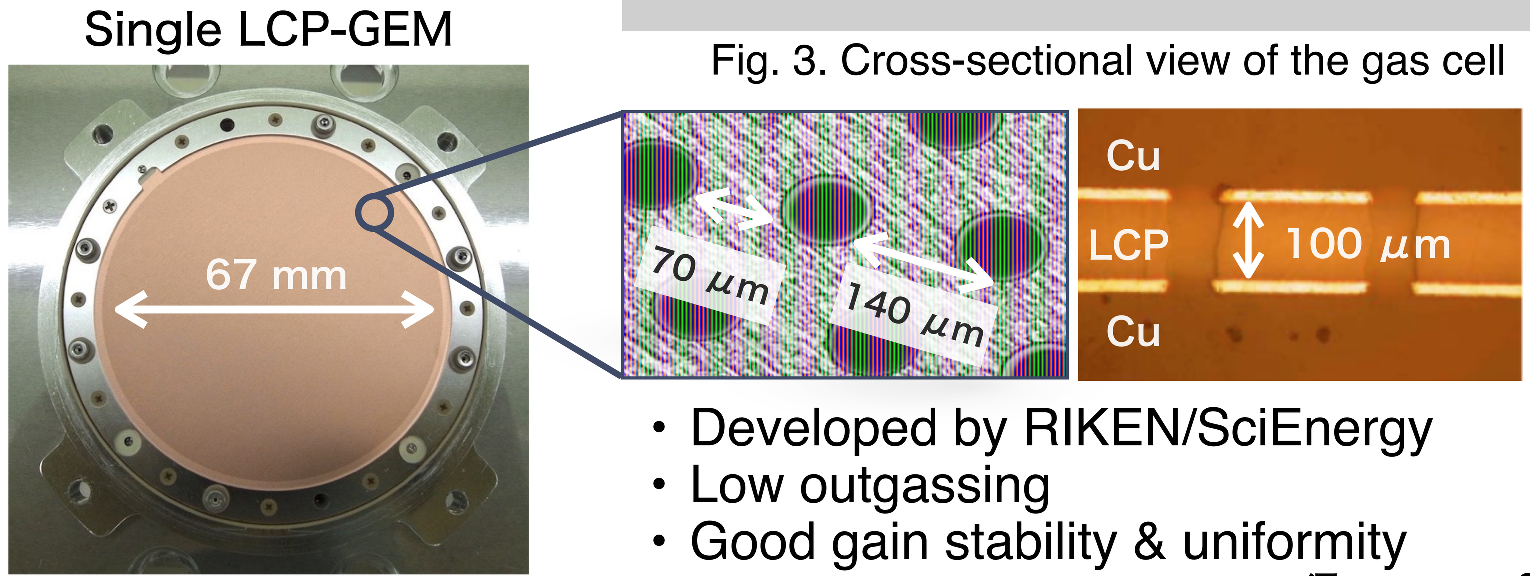


Fig. 2. Appearance of the GMC

Single LCP-GEM



- Developed by RIKEN/SciEnergy
- Low outgassing
- Good gain stability & uniformity

(Tamagawa+09)

Fig. 4. Top and cross-sectional view of the LCP-GEM

2. Gas Selection

Requirements

- **Sensitivity to the high energy X-rays above 10 keV**
  –> candidate: Xe-based mixtures @0°C, 1.2 atm (fixed)
- **GEM gain > 300** to improve S/N ratio

No gases met these requirements in previous studies.

Gain measurements

- Nine Xe-based gas mixtures (combinations of Xe, Ar, CO_2, CH_4, and dimethyl ether; DME) at 1.0 atm.
- **High gains above 1000** without a discharge were obtained in only **XeArDME mixtures**
- Gains of $XeArCO_2$, $XeArCH_4$, and mixtures of Xe and a quencher are below them.
- The highest gain of XeArDME mixture is likely due to the penning effect between Ar and DME/Xe.

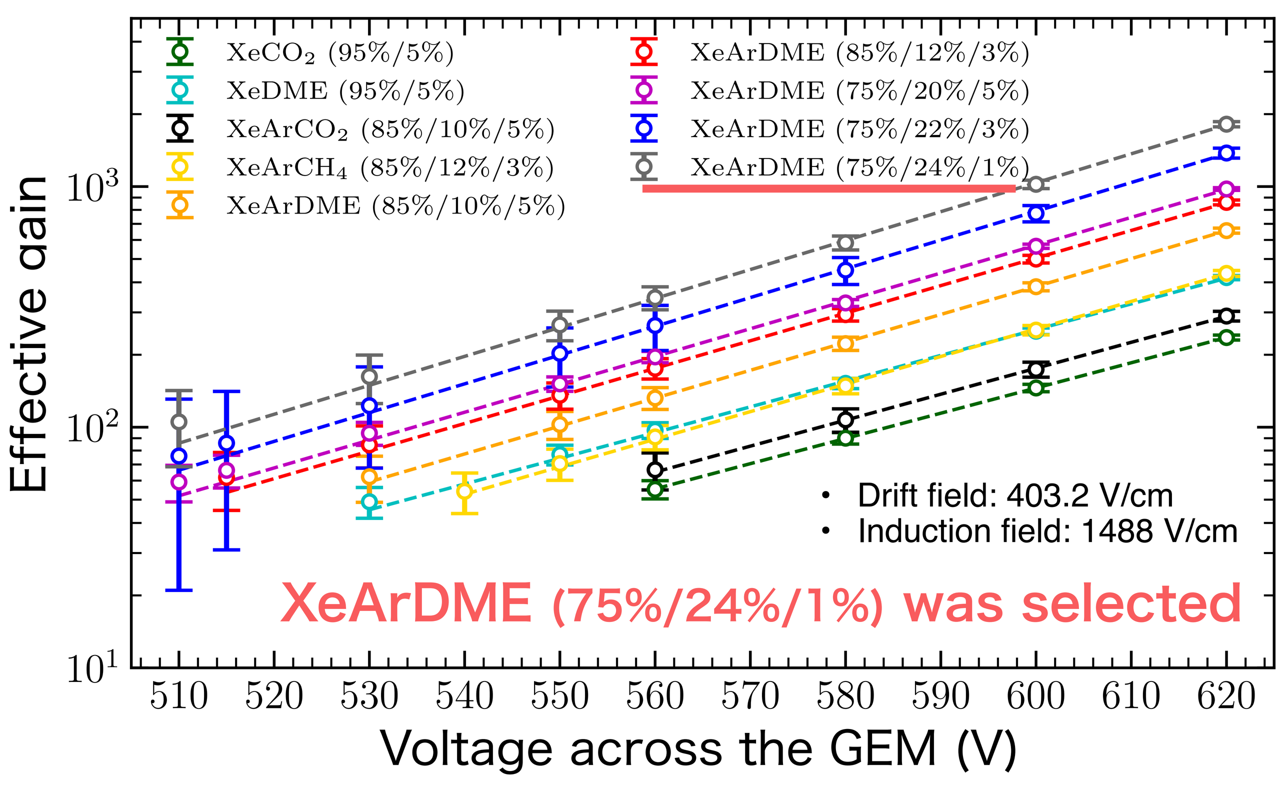


Fig. 5 Effective gain of single LCP-GEM as a function of the applied voltage to the GEM in Xe-based gas mixtures with a pressure of 1.0 atm.

Effective area with XeArDME (75%/24%/1%)

- **32 cm² @6 keV**
  - A pressure of 1.2 atm and an effective depth of 1.55 cm is assumed.
- More than two orders of magnitude larger than previous X-ray detectors onboard CubeSats. (e.g., Feng+19, Kaaret+19)

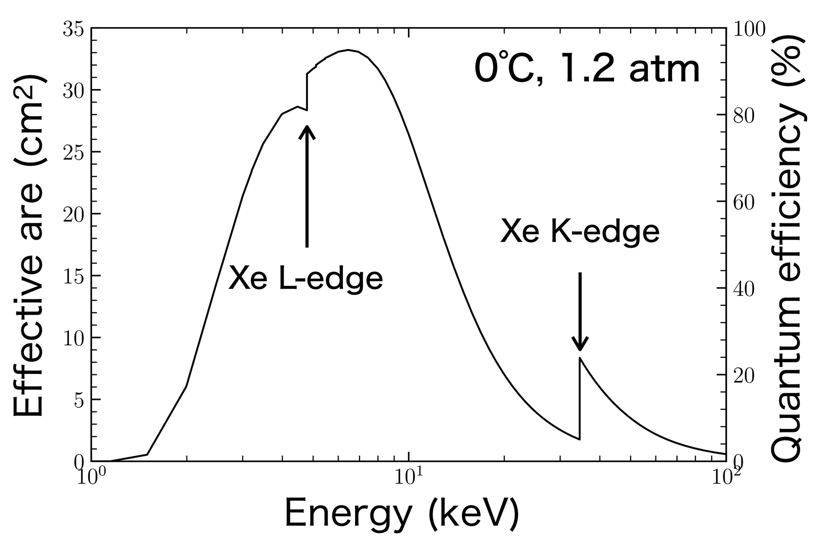


Fig. 6 Effective area and quantum efficiency as a function of energy

3. Properties of GEM in XeArDME (75%/24%/1%)

Measuring properties of LCP-GEM in XeArDME (75%/24%/1%) at 1.2 atm

1) Gain performance
2) Gain dependencies on the drift and induction fields
3) Linearity of energy scale & energy resolution

1) Gain performance

- **Gain ~ 250** at GEM applied voltage of 610 V (**Fig.7**)

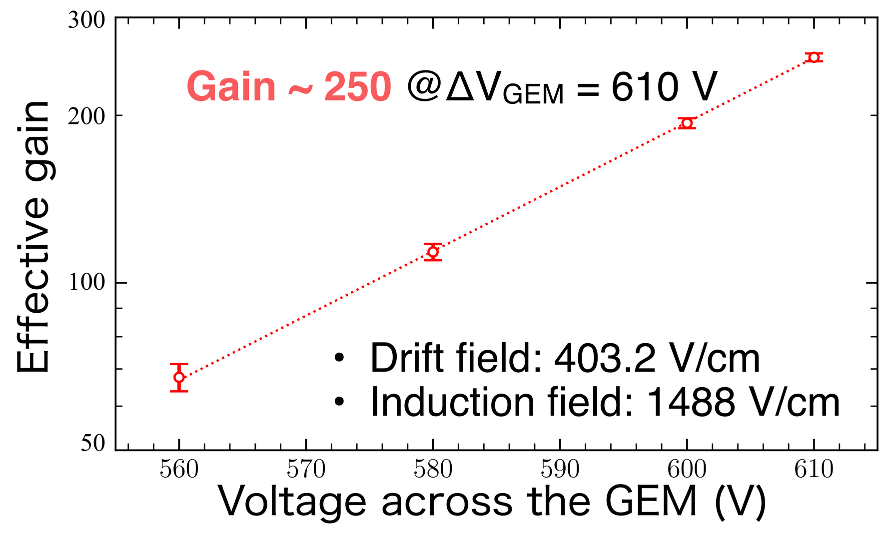


Fig. 7 Effective gain as a function of the applied voltage to the GEM in 1.2 atm

2) Dependencies on the drift&induction fields

- The effective gain (∝ collected charge) depends weakly on the **drift field**, whereas it is approximately linearly proportional to the **induction field** (**Fig.8**).
- After optimization of the two electric fields, **the gain of 460** is achieved with the applied GEM voltage of 590 V.

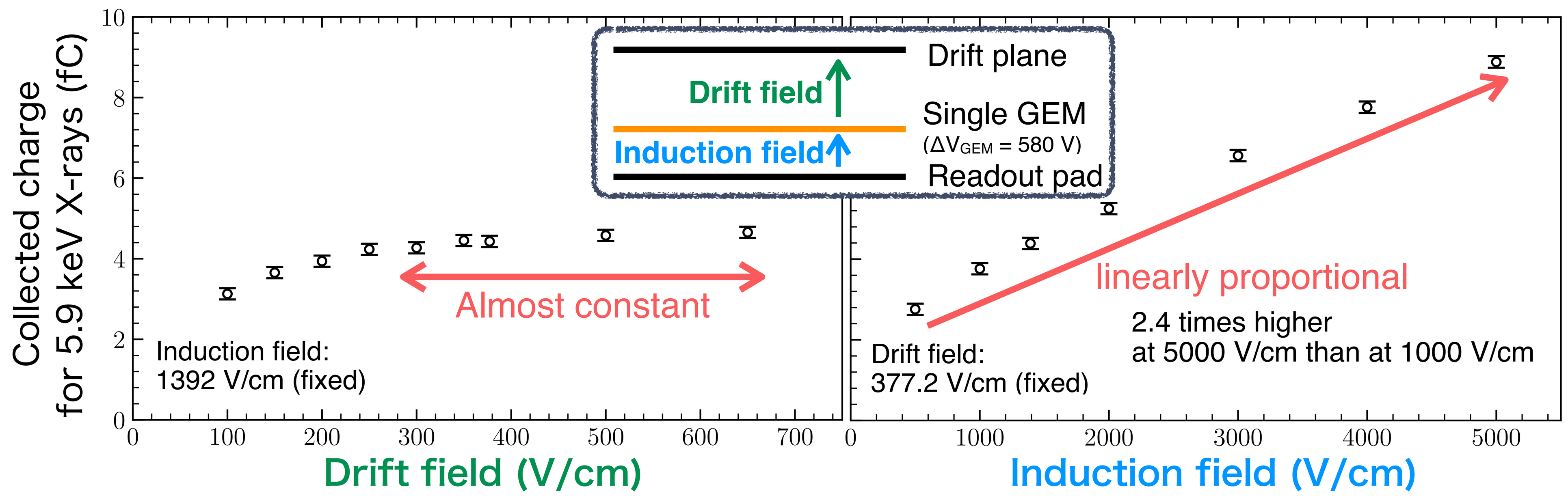


Fig. 8 Collected charge for 5.9 keV X-rays as a function of (left) drift and (right) induction fields

3) Energy scale & Energy resolution

- Monochromatic collimated X-rays at 12 different energies: 6.4–50 keV (**Fig.9**)
- Nonlinearity of energy scale < 1.1% (**Fig.10**)
- Energy resolution is 14% at 6.4 keV (**Fig.11**)

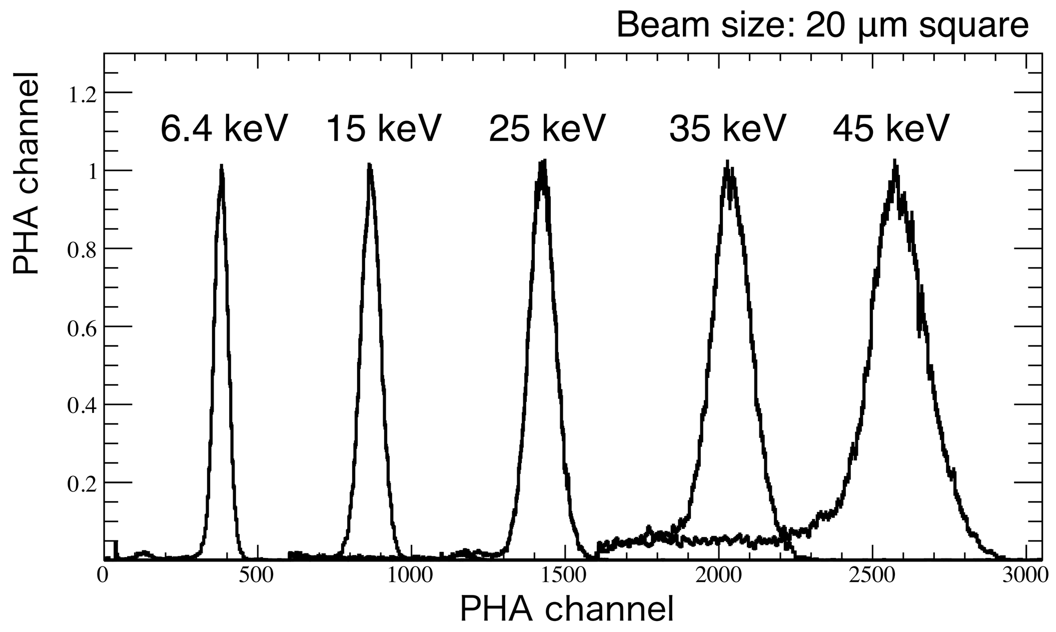


Fig. 9 ADC spectra for 6.4, 15, 25, 35, and 45 keV X-rays. Xe escape peaks for 35 and 45 keV X-rays are hidden for visibility.

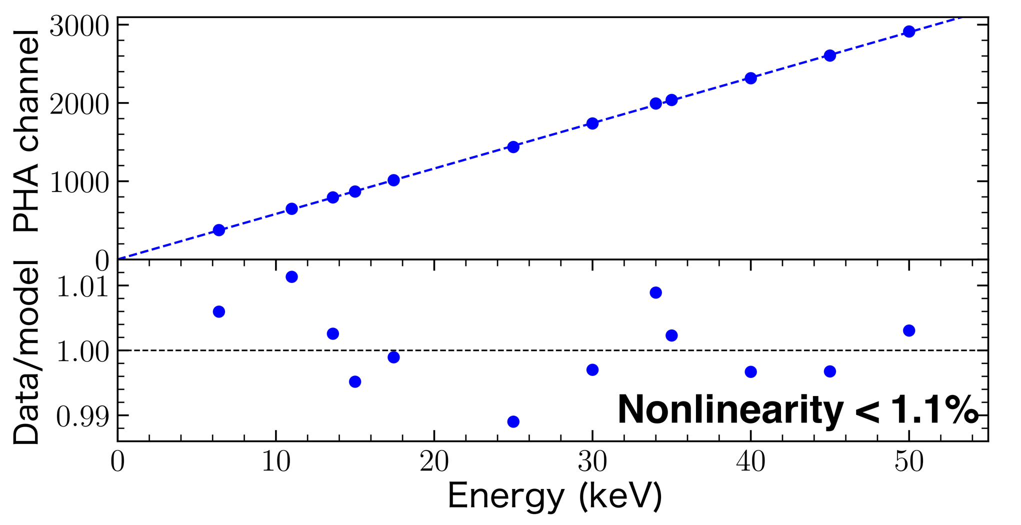


Fig. 10 Linearity of energy-PHA (pulse height amplitude) relation

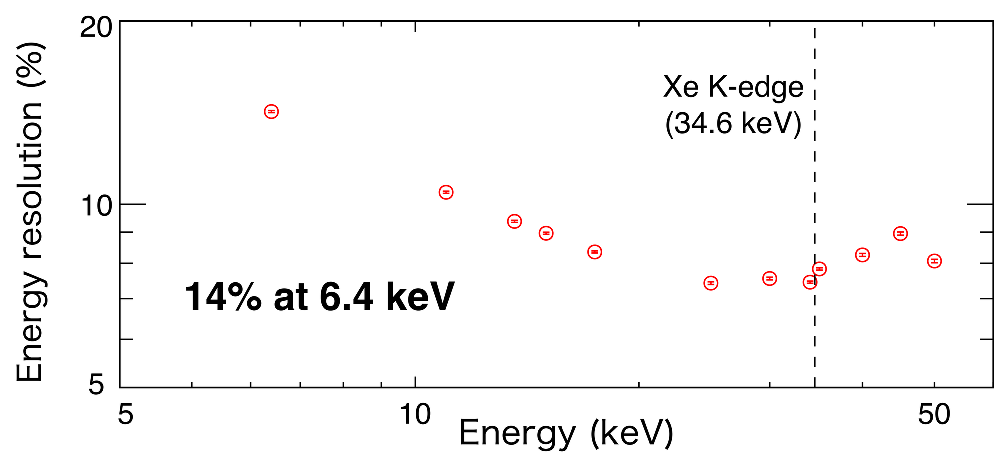


Fig. 11 Energy resolution (FWHM) against the X-ray energy

4. Summary

- We selected a XeArDME (75%/24%/1%) @0°C, 1.2 atm as a sealed gas of GEM-based X-ray detectors onboard the CubeSat X-ray observatory NinjaSat.
- Properties of single LCP-GEM in XeArDME (75%/24%/1%)
  - Simultaneously achieves high gain (460 at ΔVGEM = 590 V) and large effective area (32 cm² at 6 keV).
  - The nonlinearity of energy scale is less than 1.1%.
  - The energy resolution in FWHM is 14% at 6.4 keV.

Reference

∗ Enoto et al., 2020, Proc. SPIE 11444, 114441V
∗ Tamagawa et al., 2009, NIMA, 608, 390
∗ Feng et al., 2019, EXPA, 47, 225–243
∗ Kaaret et al., 2019, ApJ, 884, 162