# GRAMS project: A MeV gamma-ray large area telescope using liquid argon and its concept study

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## Introduction

- While imaging spectroscopy of X-ray (~80 keV) and high energy gamma-ray (1 GeV~) have provided rich scientific results, that of middle range (MeV gamma-ray) have suffered from its low sensitivity.

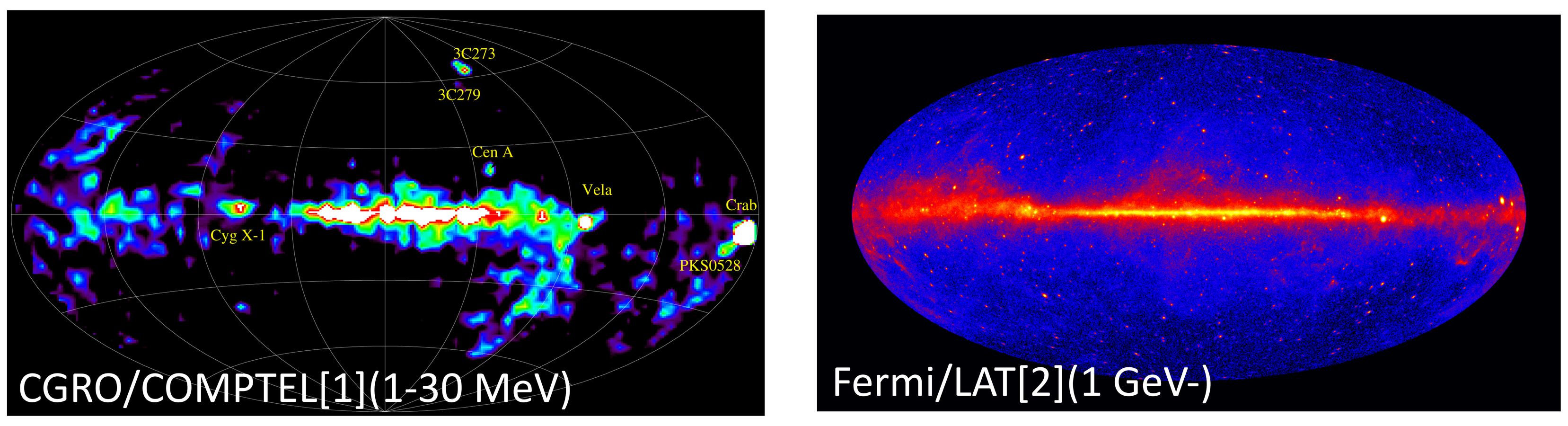


**Fig. 1.** Gamma-ray sky maps of two bands (Credit: NASA). While Fermi/LAT have identified more than 3000 objects. CGRO/COMPTEL found only 32 steady sources.

- Nuclear lines are essential for exploring the chemical evolution of the Universe. Since the typical band of the lines is MeV gamma-ray, the number of examples is very limited. (e.g. $^{44}$Ti[3], $^{26}$Al[4])

## Science Goal

- Gamma-Ray and AntiMatter Survey (GRAMS) Mission is a balloon experiment[5]. It aims to observe MeV gamma-ray sky and to perform indirect dark matter search simultaneously.

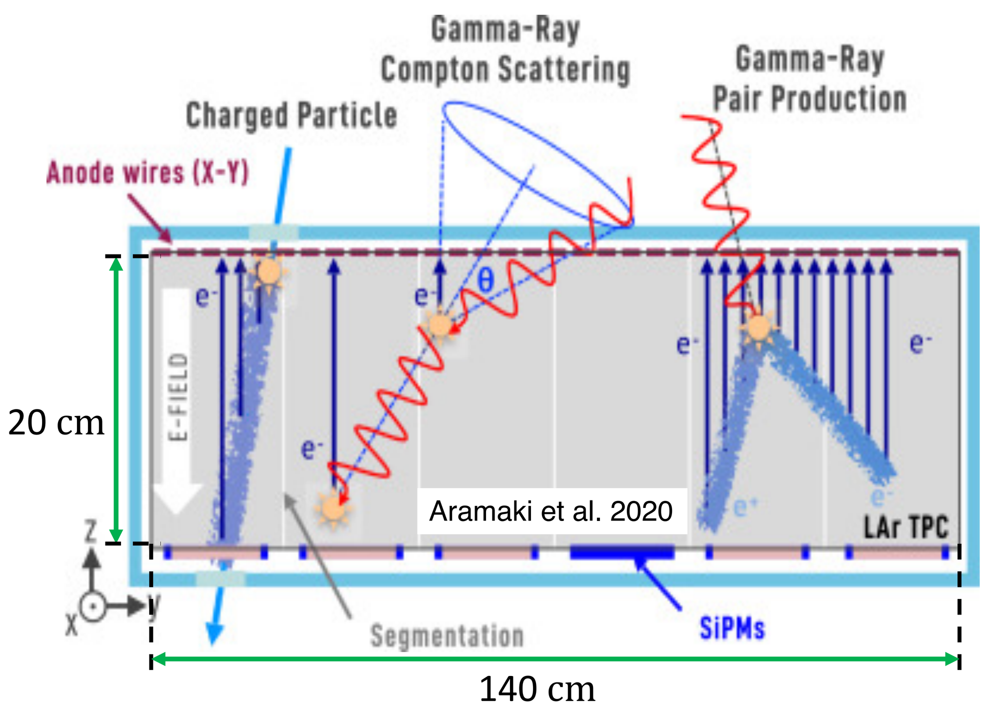


**Fig. 2.** The geometry of the GRAMS telescope. The size of LArTPC is 140 cm×140 cm×20 cm. When an incident photon interacts with an argon atom, it is ionized and emits electrons. Because E-field is applied between anode wires and a cathode plate, the electrons drift toward wires. Thanks to the sensitive wires and scintillation light in liquid argon, we can reconstruct 3-D tracks of electrons and their energy deposits (the number of ionized electrons).

- Using a liquid argon time projection chamber (LArTPC) as a sensitive volume, we can realize cost-effective development and earn an unprecedentedly large effective area.

### 1. MeV gamma-ray observation → Main topic

Owing to the large sensitive volume of LArTPC, we will achieve the sensitivity one order of magnitude better than CGRO/COMPTEL in the MeV range.

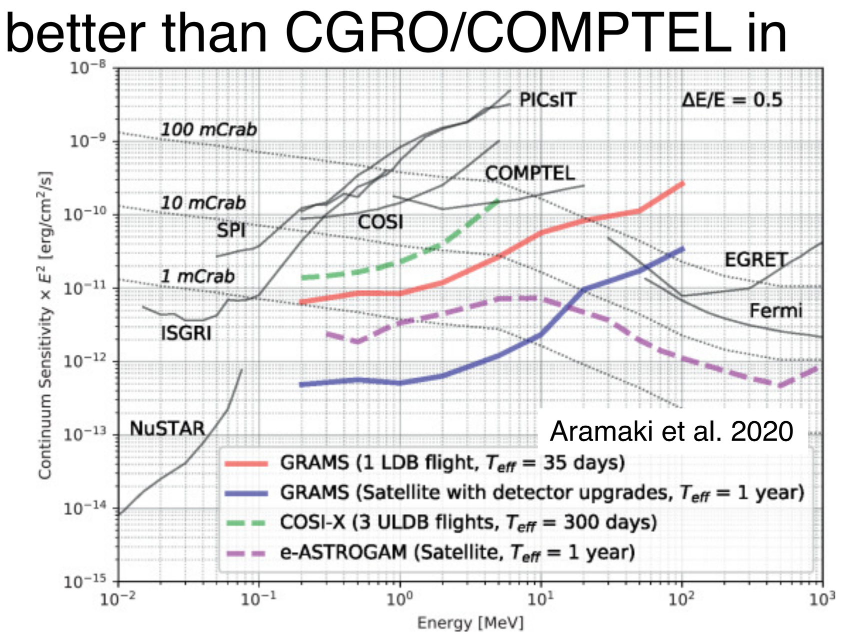


**Fig. 3.** Telescope sensitivities in X and gamma-ray band. For GRAMS, the curve of Long-Duration Balloon(LDB) and the future satellite mission are drawn. Combined with the observation of NuSTAR and Fermi, we can explore many energetic phenomena.

### Examples of GRAMS targets

- Nucleosynthesis

  Thanks to better sensitivity, GRAMS can explore weaker emission lines and extend the observable domain to the deep space.

- Extremely energetic jets

  In the Universe, some high energetic phenomena emit jets (e.g. Active Galactic Nuclei, Gamma-Ray Bursts, Black Hole Binaries). Such jets usually accompany MeV gamma-ray.

### 2. Indirect dark matter search

Some DM particles are predicted to decay or annihilate to antiparticle such as antiproton, antideuteron. When antiproton or antideuterons interacts with an argon atom, they could form an excited exotic atom. By measuring their characteristic X-ray, we can identify what particle came. The GRAMS sensitivity can be a few times better than current generation experiments, GAPS, and AMS-02.

## Design

GRAMS experiment utilizes a LArTPC for imaging spectroscopy and detecting antiparticles.

### Liquid Argon Time Projection Chamber

A LArTPC is a 3-D tracking detector filled with liquid argon (LAr) and can also evaluate each energy deposit. It has been mainly used for particle physics such as neutrino experiments (e.g. DUNE[6]).

### Compton Camera

For Compton scatters in liquid argon, the detector measures the energy deposit and position coordinate of each hit. Considering the physics of Compton scattering, we can reconstruct a gamma-ray image.

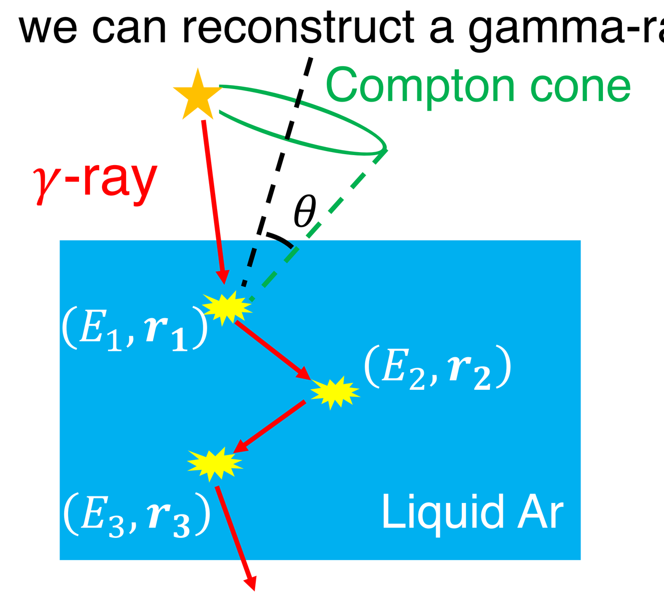


**Fig. 4.** A schematic of interaction in the LArTPC. Compared with precedented Compton cameras (e.g. CGRO/COMPTEL, Hitomi/SGD[7]), the large effective area can be achieved.
Using energy-momentum conservation law, we can constrain the incoming direction to a Compton cone.

$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E_1} - \frac{1}{E}\right) \quad E\text{: initial energy}$$

The order of multiple hits must be determined for the event reconstruction. We have developed some methods to predict the order from the detector output using likelihood or neural network.

## Concept study

### Aim

No LArTPC has ever been used as a Compton Camera. Therefore at least, we have to prove that

1. LArTPC can detect multiple Compton scattering events
2. energy and position resolution is enough for imaging.

This time, we especially focused on 1. and 2. ability to measure z-position

### Method

We analyze multiple Compton events in LAr with real detector data. Waseda U ANKOK group has developed a double phase liquid argon TPC for direct DM search[8]. We extract multiple Compton events in an ANKOK5 detector whose fiducial part is about 5 kg LAr.

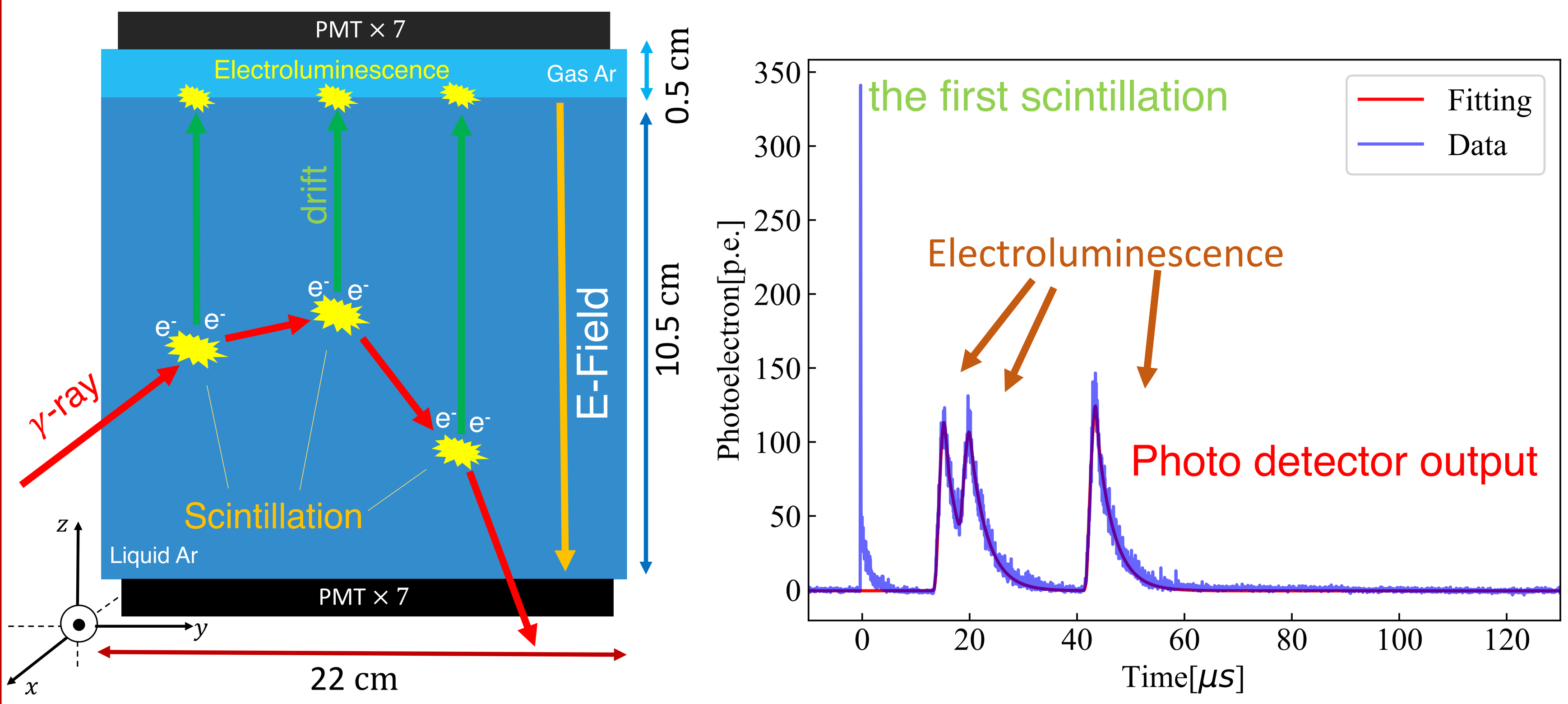


**Fig. 5.** The left figure shows the structure of the ANKOK5 detector. The right figure is an example of the detector output. Incident gamma-ray causes scintillation light which plays a role in a trigger when it interacts with an argon atom. Then ionized electrons from the argon atoms drift toward the surface along the drift electric field and they also cause electroluminescence. Extracting the information from the output with function fitting, we can evaluate the coordinate along the field and energy deposition.

### Result

We performed fitting the photodetector output with a function based on electroluminescence process model. That allows us to evaluate drift time (→ z-position) and the energy deposit of each hit.

### Future prospect

Unlike ANKOK, GRAMS detects ionized electrons with stacked wires. We will develop a compact LArTPC for advanced study including experiments with beam.

## Summary

- GRAMS project is a future balloon mission for MeV gamma-ray observation with the highest sensitivity.
- GRAMS telescope can be used for indirect dark matter search as well.
- The better sensitivity by more than an order of magnitude compared with CGRO/COMPTEL can shed light on high energy phenomena such as nucleosynthesis and jets.
- We have analyzed double phase argon detector data for the concept study of gamma-ray imaging.

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