

The GRAMS Project:

MeV Gamma-Ray Observations and Antinuclei-Based Background-Free Dark Matter Searches with a LArTPC



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on behalf of the GRAMS Collaboration



What is GRAMS



GRAMS = Gamma-Ray and AntiMatter Survey

Science

- Gamma-ray observations at “**MeV-gap**”
- **Background-free** indirect DM searches with low-energy antinuclei

Technology

- Breakthrough with a low-cost, large-scale **LArTPC** (liquid argon time projection chamber) detector for a balloon flight/satellite mission

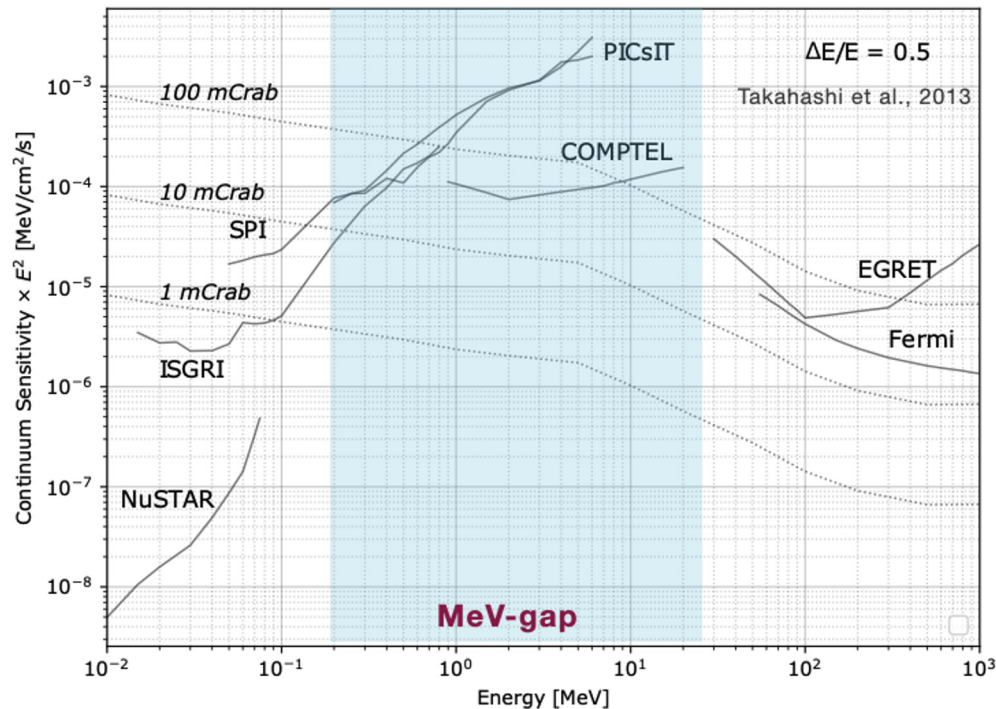
Project Status

- One of the NASA **Physics of the Cosmos** suborbital missions
- Funded for the prototype flight

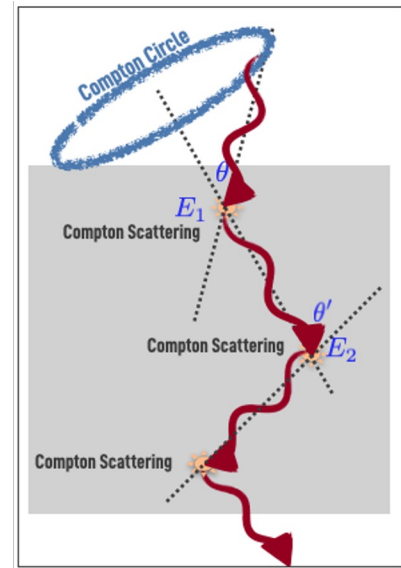
MeV Gamma-Ray Observations



Previously **poorly-explored** MeV energy region = “**MeV-gap**”



Compton scattering process dominates in MeV
Good **energy** & **spatial** resolution required



Need a **large-scale** (large effective area), high-resolution **Compton Camera**

MeV Gamma-Ray Science



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Essential to investigate the MeV-gap

Physics processes/nucleosynthesis

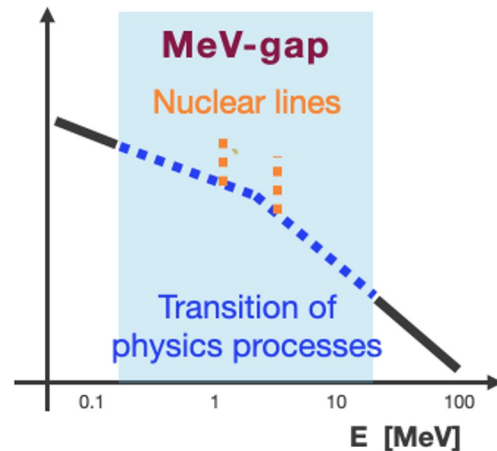
- Transition of physics processes in MeV
- Particle acceleration in Pulsar Wind Nebula
- Relativistic flows in stellar/supermassive BHs, pulsars, magnetars
- **Nuclear lines** from radioactive isotopes in astrophysical environments
 - Galactic center, classic novae, SNe, etc
 - r-process for the origin of heavy elements

See talks by Eric (#8), Tiffany (#16), Zorawar (#28), and Paolo (#53)

Multi-messenger astrophysics

- MeV gamma rays + GWs
- MeV gamma rays + high-energy neutrinos
 - NS/BH mergers, GRBs, SNe, AGNs

Indirect Dark Matter and PBH searches



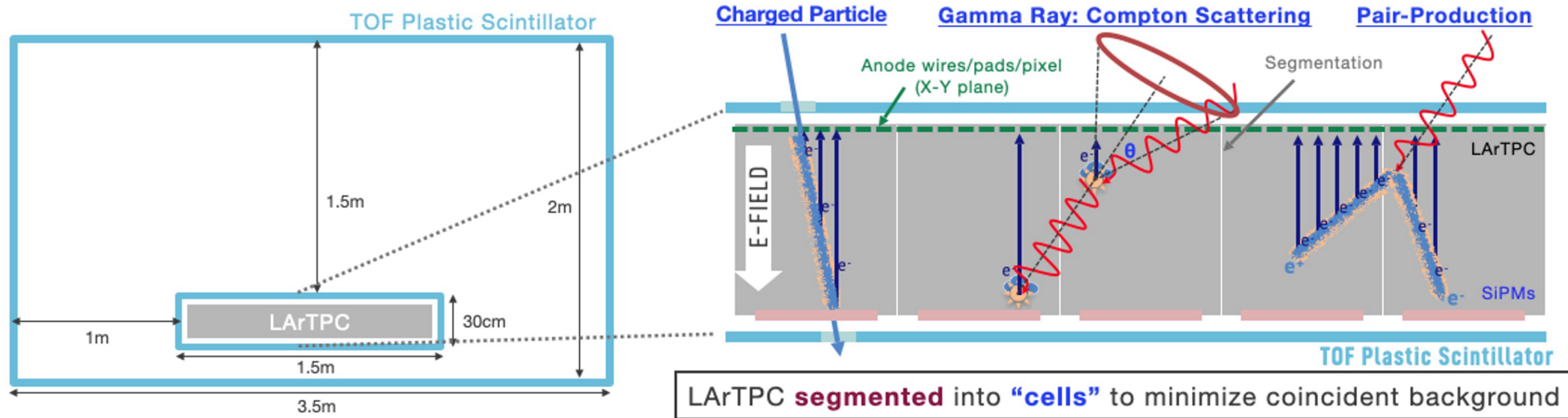
GRAMS Detector Design



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LArTPC surrounded by plastic scintillators

	Antimatter	Gamma ray
Plastic Scintillator	Time of Flight to measure velocity	VETO Counter to reject charged particles
LArTPC	Particle Tracker, Calorimeter	Compton Camera, Calorimeter

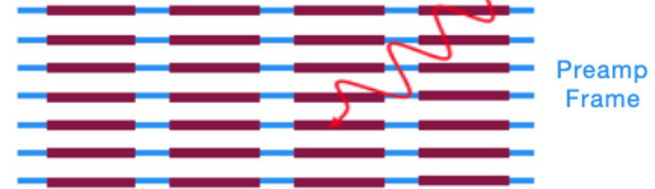
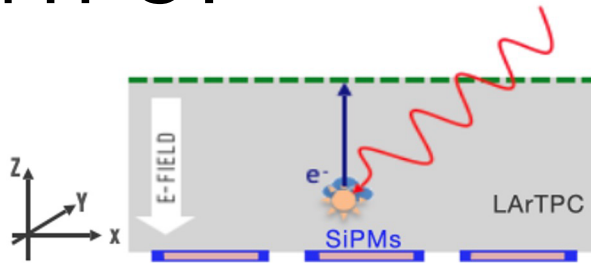


Large-scale, low-energy threshold LArTPC has been **well-studied** and **widely-used** in underground **dark matter** and **neutrino** experiments

Why LArTPC?



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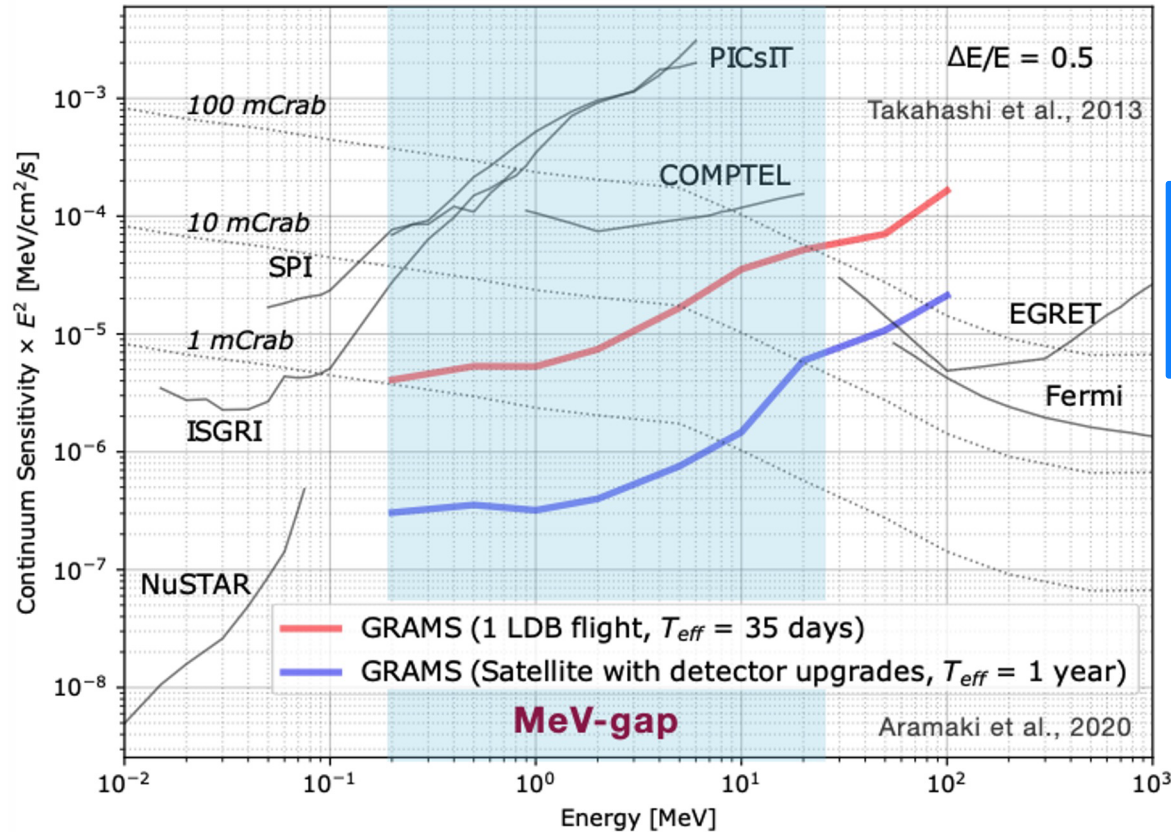


	LArTPC	Semiconductor/Scintillator
ρ (g/cm ³)	1.4	2.3/5.3 (Ge/Si)
$T_{\text{operation}}$	~80K	~240K/~80K
Cost	\$	\$\$\$
Signals	Scintillation light + ionization electrons	Electrons, holes
X, Y positions	Wires/pads on anode plane (X-Y)	Double-sided strips
Z position	From drift time	From layer #
# of layers	Single layer	Multi-layers
# of electronics	#	###
Dead volume	Almost no dead volume	Detector frame, preamps
Neutron bkg	Identified with pulse shape	No rejection capability

LArTPC is **cost-effective** and easily expandable to a **larger scale**

Almost **no dead volume** and **high detection efficiency**

GRAMS MeV Gamma-Ray Sensitivity



See talks for future MeV missions:
Regina (#66), Richard (#73), Liz (#88),
Tom (#106), Andreas (#152)

Long-duration balloon
(LDB) flight: ~35 days

Balloon flight: Order of magnitude improved, **Satellite**: Comparable to future missions

Puzzling Excesses in DM Searches

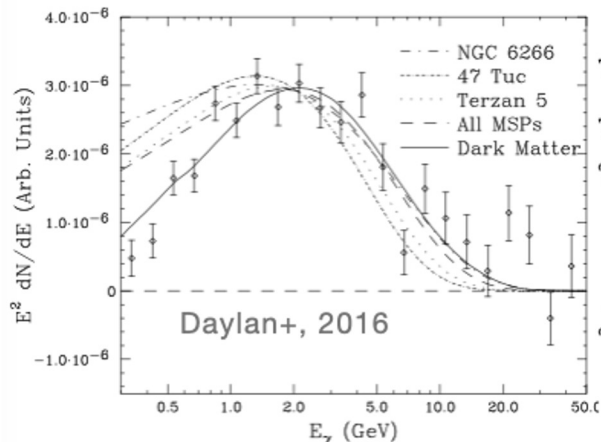
Snowmass2021 CF White Paper



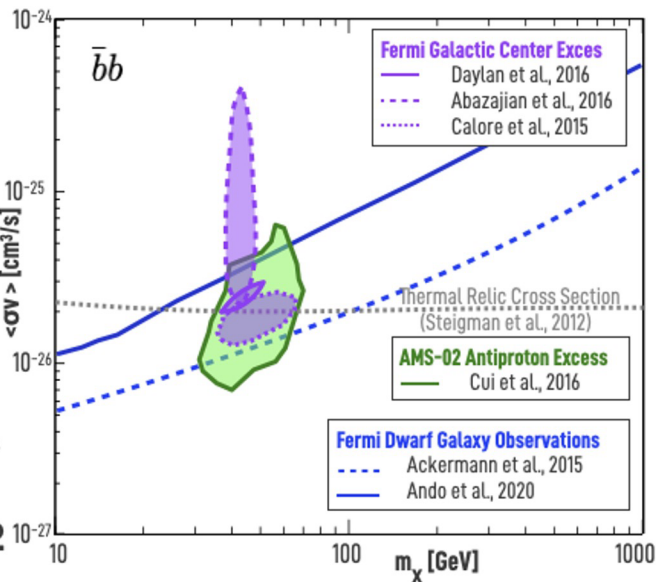
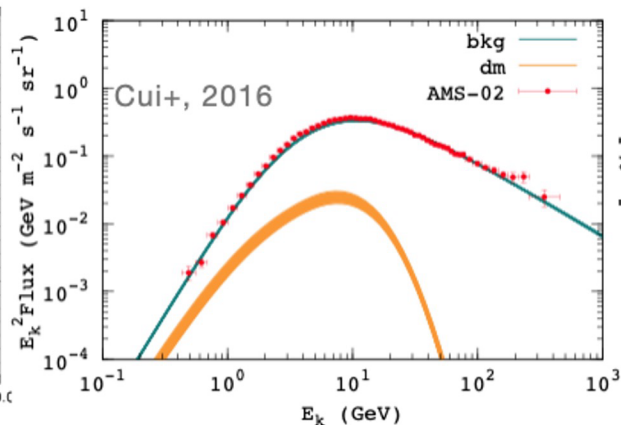
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- arXiv:2209.07426: Report of the Topical Group on Particle Dark Matter for Snowmass 2021
- arXiv:2203.06859: Puzzling Excesses in Dark Matter Searches and How to Resolve Them
- arXiv:2203.06894: The landscape of cosmic-ray and high-energy photon probes of particle dark matter

Fermi gamma-ray excess



AMS-02 antiproton excess



Detection of antideuteron/antihelium-like events in AMS02

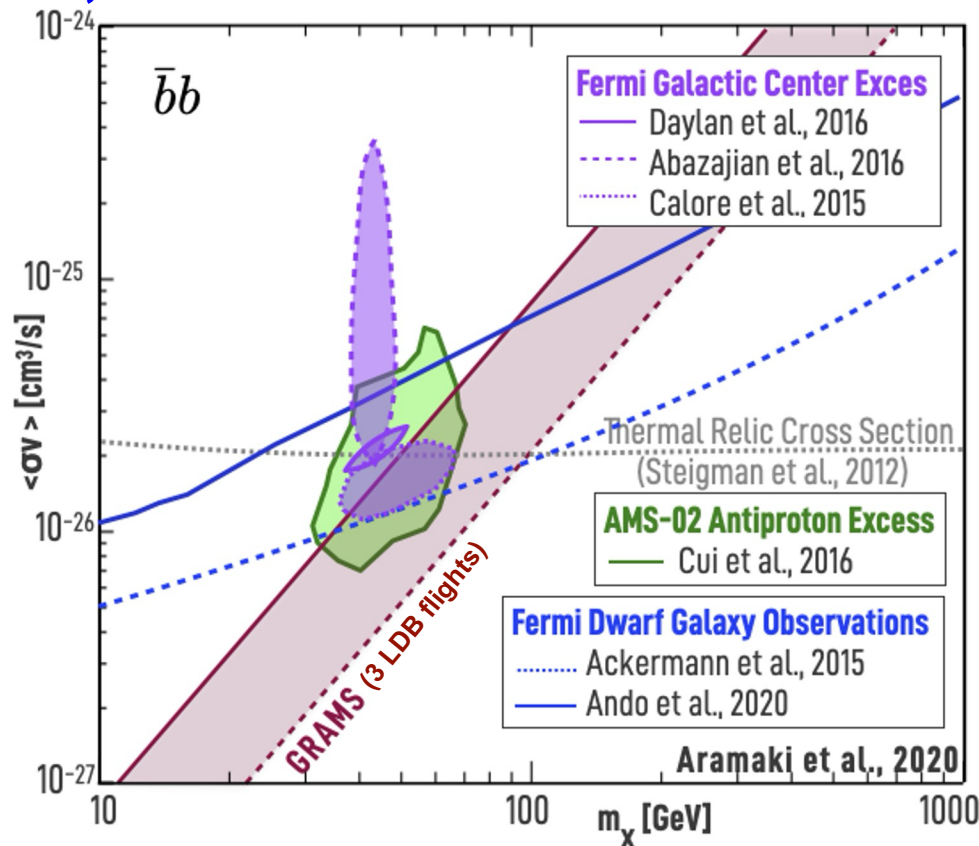
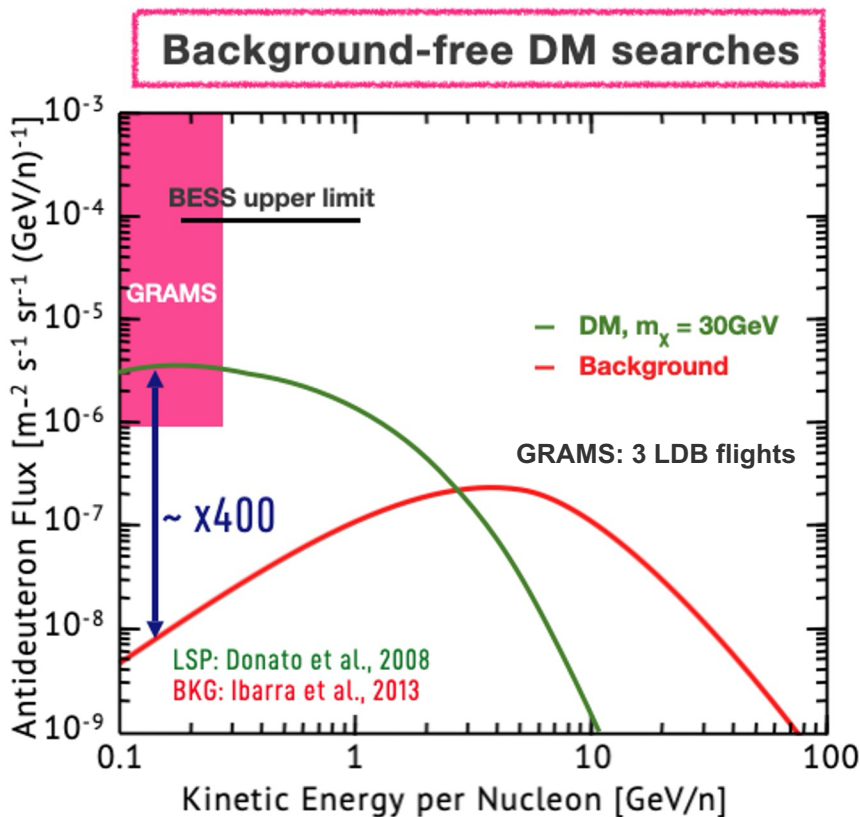
How do we validate these results?

GRAMS Antideuteron Sensitivity



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Deeply explore DM parameter space, validate Fermi/AMS-02 results

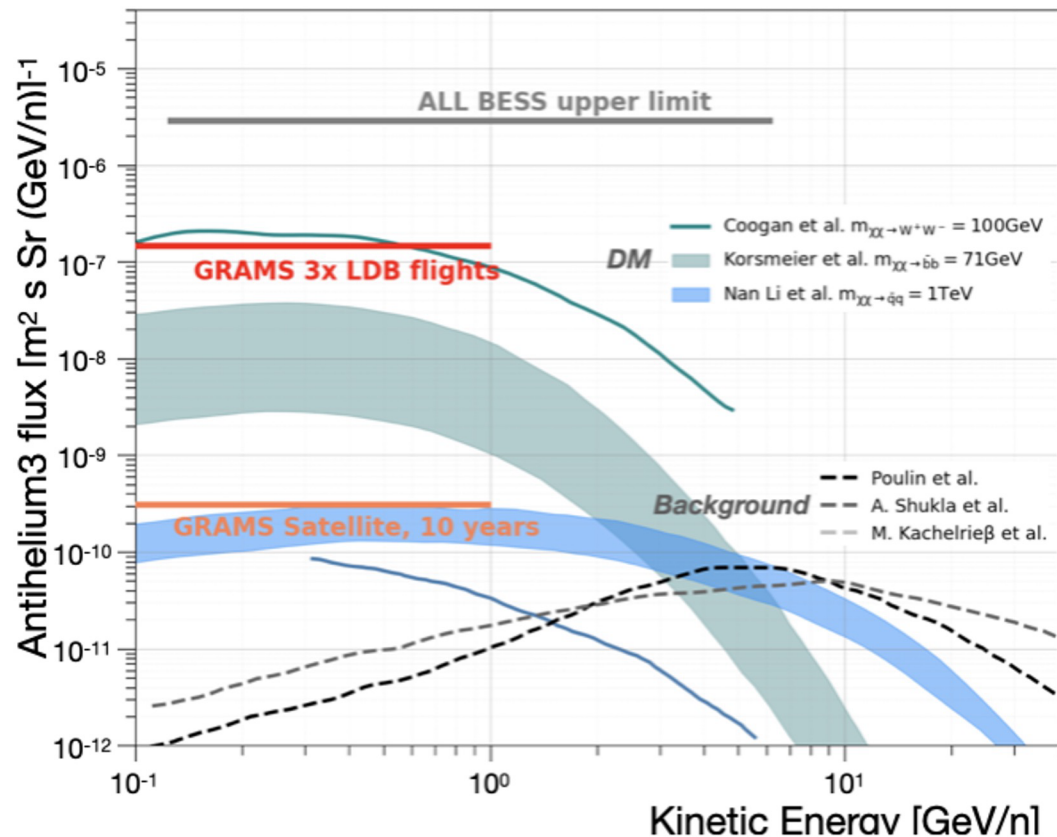


GRAMS Antihelium-3 Sensitivity



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Extensively investigate some DM models



Balloon

- 3 LDB Antarctic flights (~ 35 days x 3)

Satellite at L2

- Sun-Earth Lagrange Point 2 (L2)
(minimize geomagnetic cutoff effect)

ASTRA White Paper

Available in arXiv: [arXiv:2608.27787](https://arxiv.org/abs/2608.27787)

Low-energy antinuclei measurements for background-free indirect dark matter searches and PBH signatures

Tsuguo Aramaki (Northeastern University), Ilias Cholis (Oakland University),

Philip von Doetinchem (University of Hawaii at Manoa), Fiorenza Donato (University of Torino/INFN),

Priyarthini Ghosh (University of Maryland, Baltimore County),

Dan Hooper (University of Wisconsin-Madison), Timothy Linden (Stockholm University),

Keith McBride (University of Chicago), Stefano Profumo (University of California, Santa Cruz),

Stephanie Wissel (Pennsylvania State University)

For PhysPAG

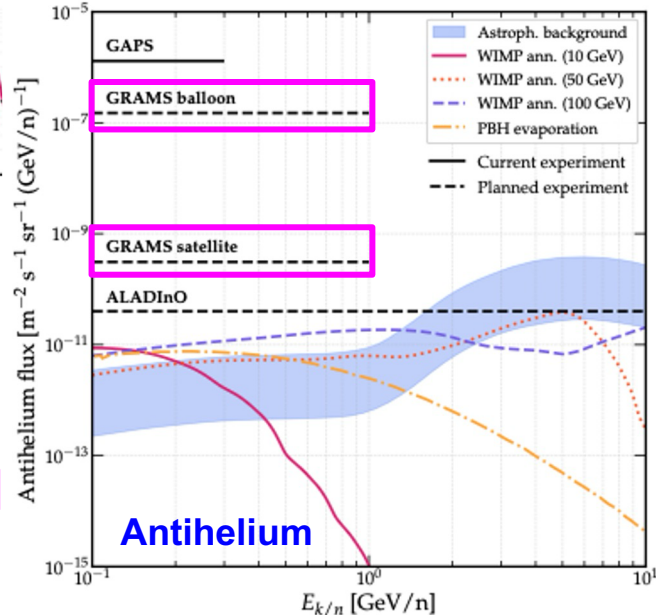
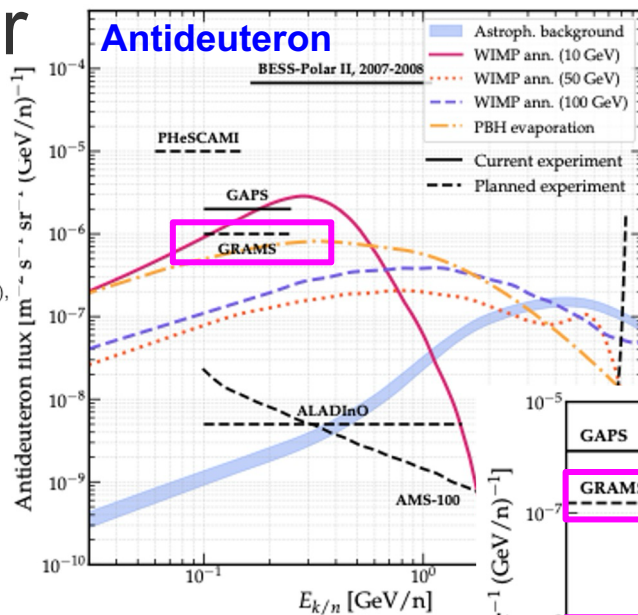
Planning to organize a CRN-SAG (Science Analysis Group)

Current-generation

Mission	Detection concept	Detector technology	Mission destination	Ref
BESS	Particle trajectory	Superconducting magnet	Balloon (Antarctic)	[90, 91]
AMS-02	Particle trajectory	Permanent magnet	Satellite (ISS)	[81, 97]
GAPS	Exotic atom decay	Silicon tracker	Balloon (Antarctic)	[85]

Next-generation

Mission	Detection concept	Detector technology	Mission destination	Ref
GRAMS	Exotic atom decay	LArTPC	Balloon, Satellite (L2)	[86]
PHeSCAMI	Exotic atom decay	high-pressure helium gas	Satellite	[100]
AMS-100	Particle trajectory	HTS magnet	Satellite (L2)	[99]
ALADInO	Particle trajectory	HTS magnet	Satellite (L2)	[98]



See Philip's talk (#27)

Engineering Flight (eGRAMS)

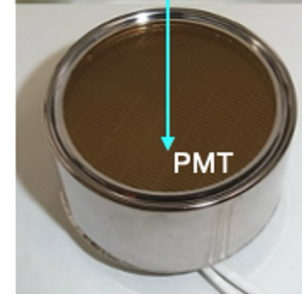
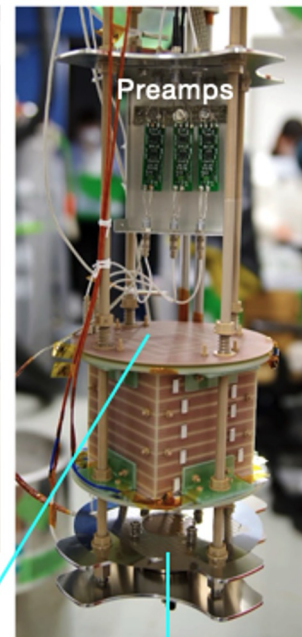
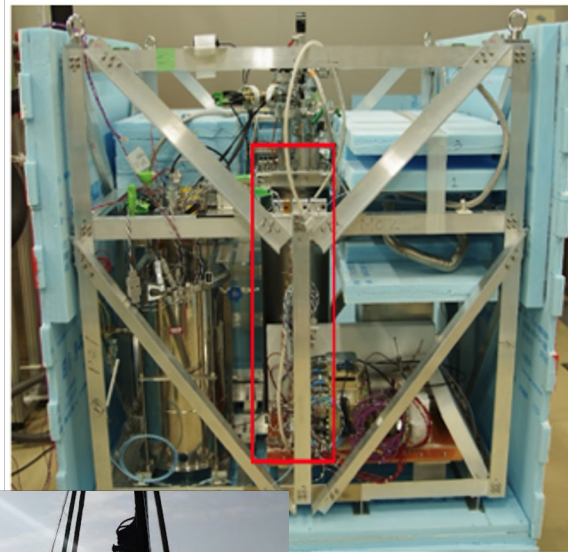


Successful Engineering flight in 2023

- **First** stable LArTPC operation at stratosphere
- TPC: $10 \times 10 \times 10 \text{ cm}^3$



@JAXA TARF



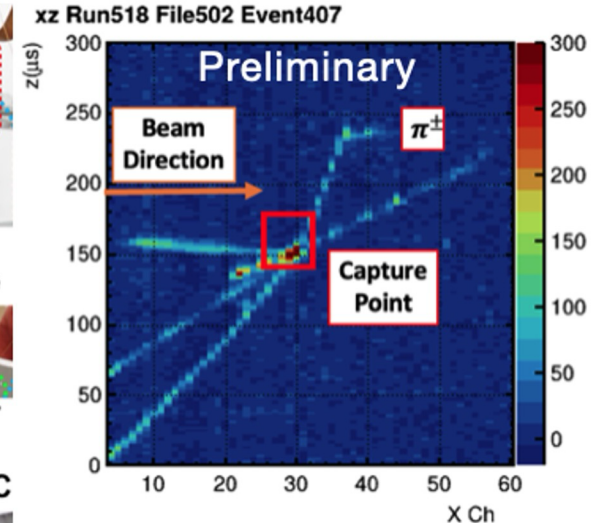
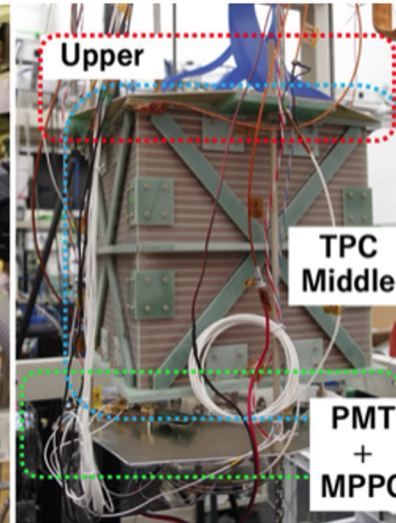
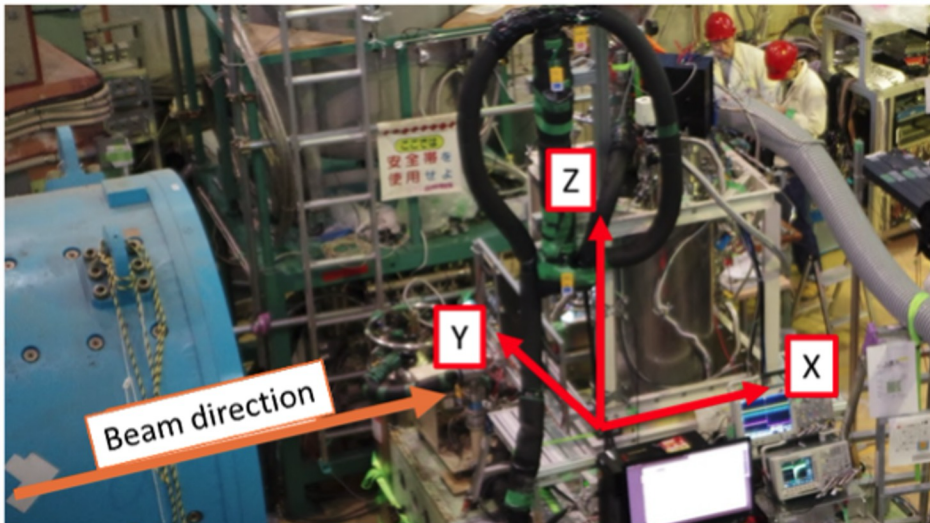
Antiproton Beam Test



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@J-PARC in Feb 2025

- Antiprotons with 0.7 GeV/c
- Validated LArTPC performance as an antimatter detector
 - TOF + Aerogel Cherenkov detector to reject pion events
 - WasedaTPC: 30 cm x 30 cm x 30 cm
 - Successfully measure annihilation products: pions/ protons



Prototype Flight (pGRAMS)



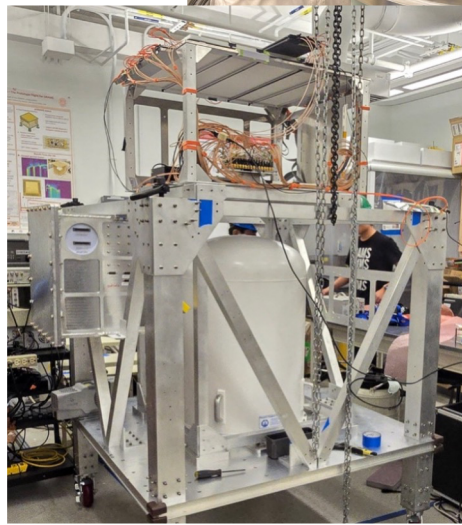
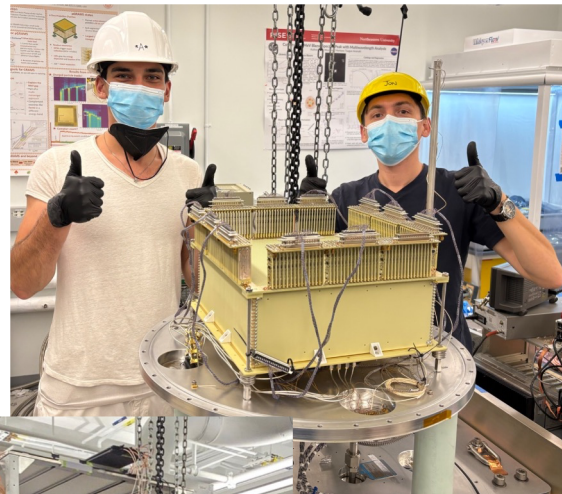
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Scheduled @**World View** (Arizona) in **Fall 2026**

- Currently under payload integration at Northeastern
- NASA PhysCos Suborbital mission funded by NASA APRA
- Demonstrate LArTPC performance in flight
 - **Particle tracking** for charged particles
 - **Gamma-ray detection**
- ~10+ hours of flight without cooling/circulation system
- **MiniGRAMS** TPC: (30 x 30 x 10 cm³)
 - Segmented into **9 cells**
 - Tile/pads (~3mm pitch) for x/y directions
 - 180 charge channels, 36 light channels

Science flights with **MiniGRAMS** (30 x 30 x 20 cm³)

- One of the **largest** flight-capable Compton cameras
- Cooling/circulation system onboard
- New proposal for a **2029 ULDB flight from NZ**



GRAMS Collaboration



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International collaboration with different backgrounds/expertise

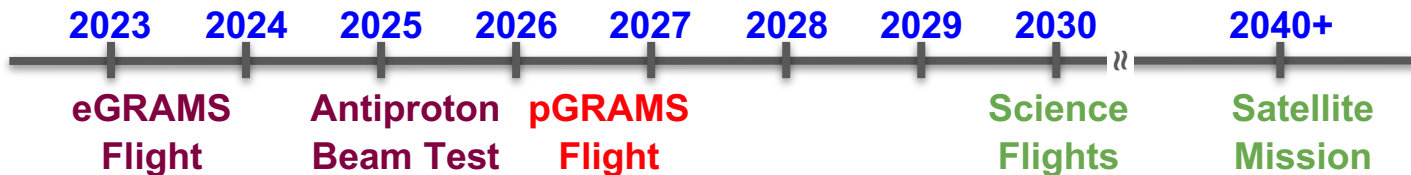
Gamma-rays, X-rays, Cosmic-rays, Neutrinos, Direct/Indirect DM searches

International (Japan)

- Hiroshima University
- IPMU
- JAXA
- Kanagawa University
- Kyoto University
- Nagoya University
- National Defense Medical College
- Osaka University
- RIKEN
- Rikkyo University
- Tokyo University of Science
- University of Tokyo
- Waseda University
- Yokohama National University

USA

- Barnard College
- Columbia University
- Howard University
- NASA GSFC/UMB
- Northeastern University
- Oak Ridge National Lab
- University of California, Berkeley
- University of Chicago
- UT Arlington
- Washington University at St. Louis
- Yale University



Summary



- GRAMS can breakthrough two major scientific goals:
 - **Gamma-ray** observations in the **poorly explored MeV** range
 - **Background-free** indirect DM searches with **low-energy antinuclei**
- A cost-effective, large-scale LArTPC detector can provide:
 - **About an order (two orders)** of magnitude improved sensitivities to MeV gamma rays with a **single balloon flight (Satellite)** compared with the previous missions.
 - Extensively explore DM parameter space including the DM models suggested by **Fermi GCE** (Galactic Center Excess) and **AMS-02 antiproton excess**.
- Successful **engineering flight** in 2023 and **antiproton beam test** in 2025, and currently preparing for a **prototype flight** this Fall, followed by multiple science balloon flights.
- The project will be expanded to a **satellite** mission, potentially at the Sun-Earth **L2 point**.