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OVERVIEW OF THE GRAMS PROJECT (Gamma-Ray and AntiMatter Survey)

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On behalf of the GRAMS Collaboration

GRAMS = Gamma-Ray and AntiMatter Survey

A newly proposed project with an international collaboration

Aims to be the first balloon/satellite mission with a low-cost, large-scale LArTPC detector

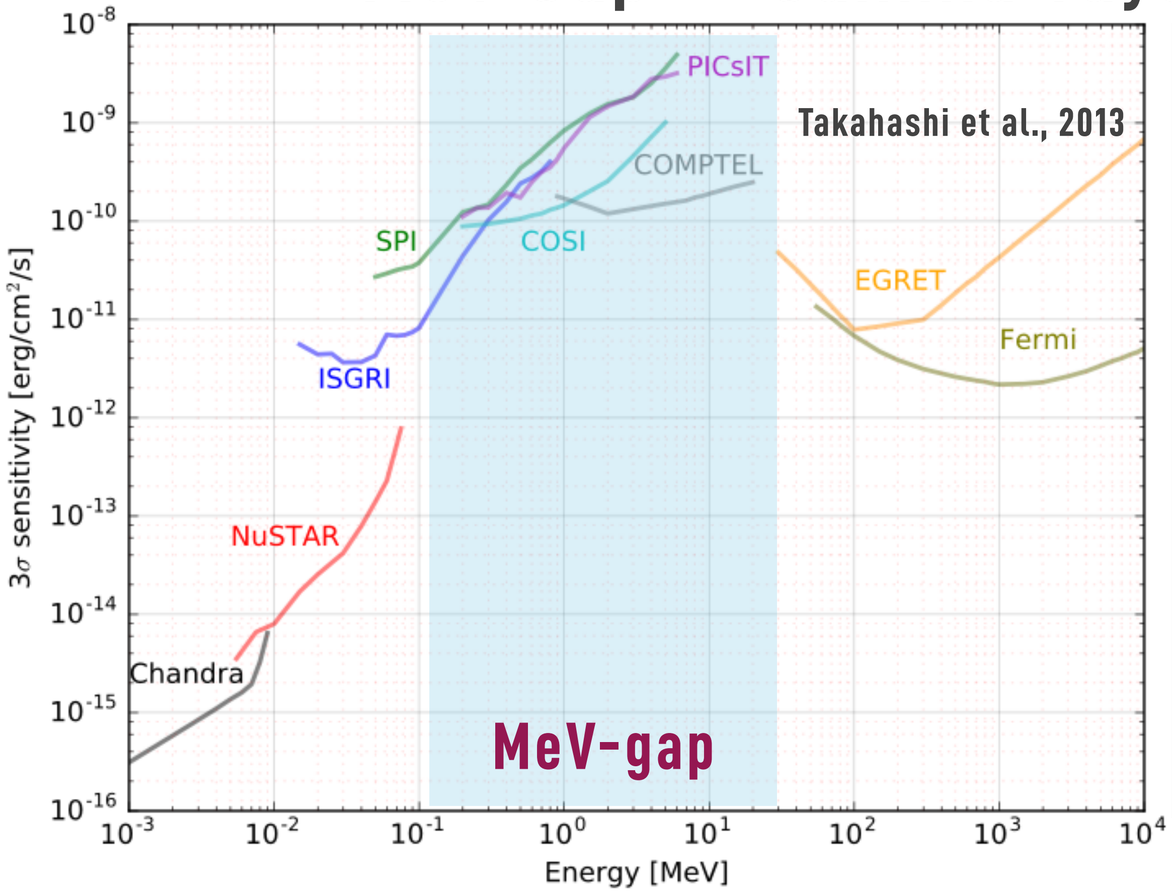
First experiment to target both astrophysical observations with MeV gamma rays and dark matter searches with antimatter

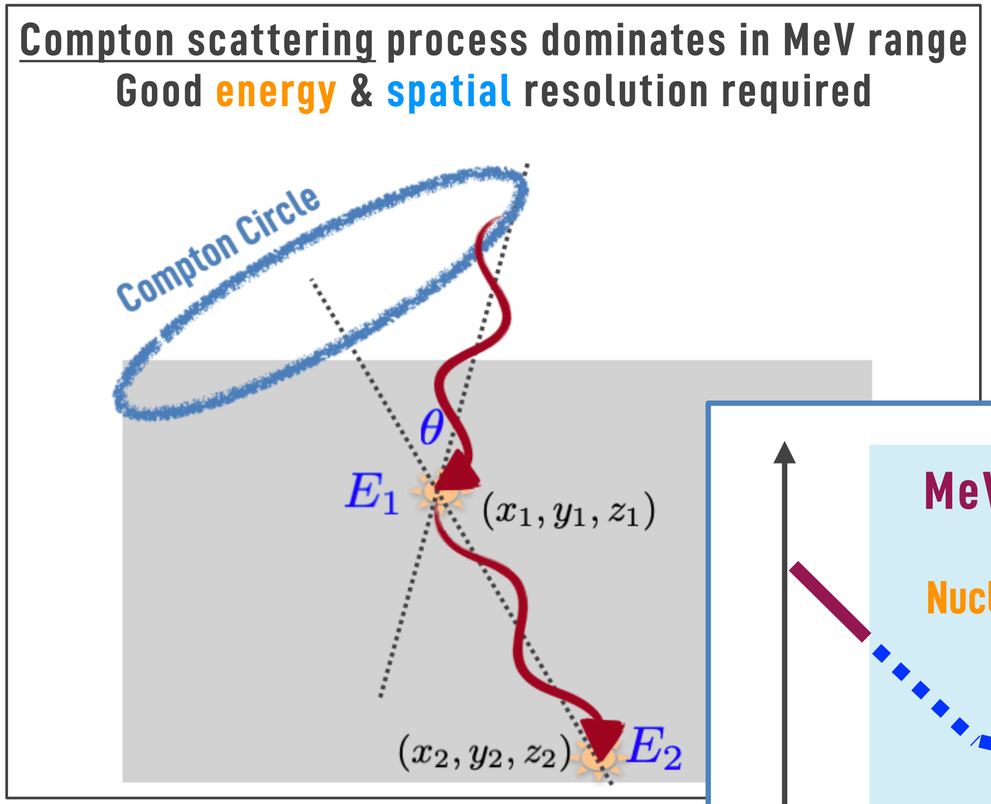
GRAMS First Paper: (1901.03430, Astropart. Phys)

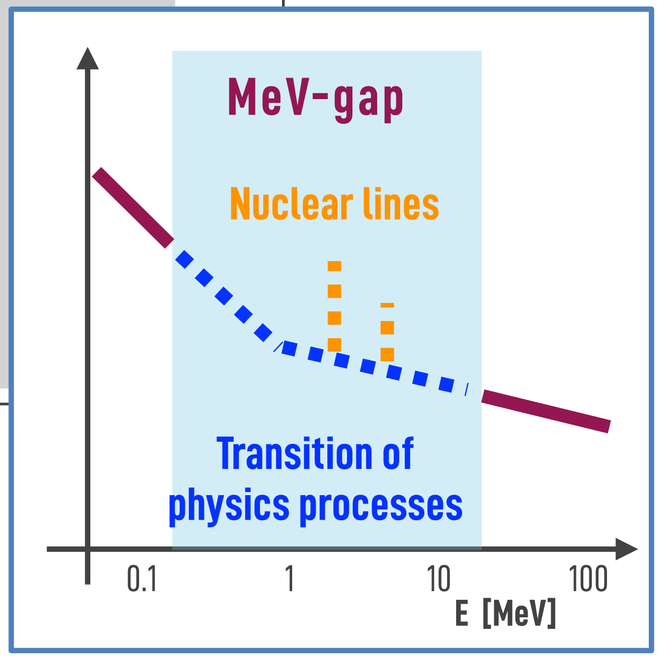
Snowmass-2021 LOI: arXiv:2009.03754

GRAMS MeV Gamma-Ray Observations

"MeV Gap" = Gamma-rays in MeV region poorly explored







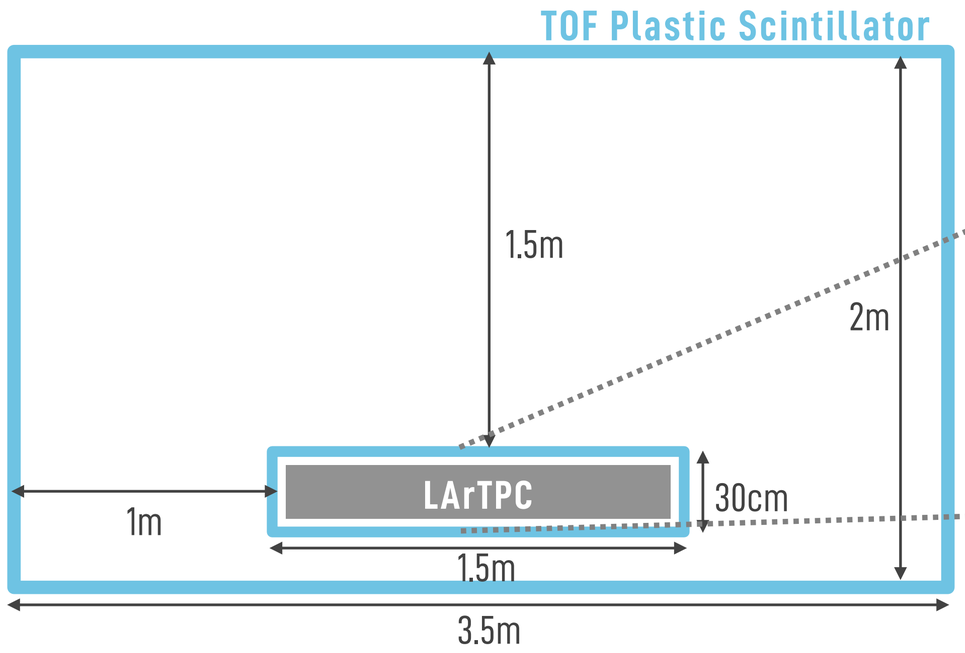
MeV gamma-ray spectrum/lines

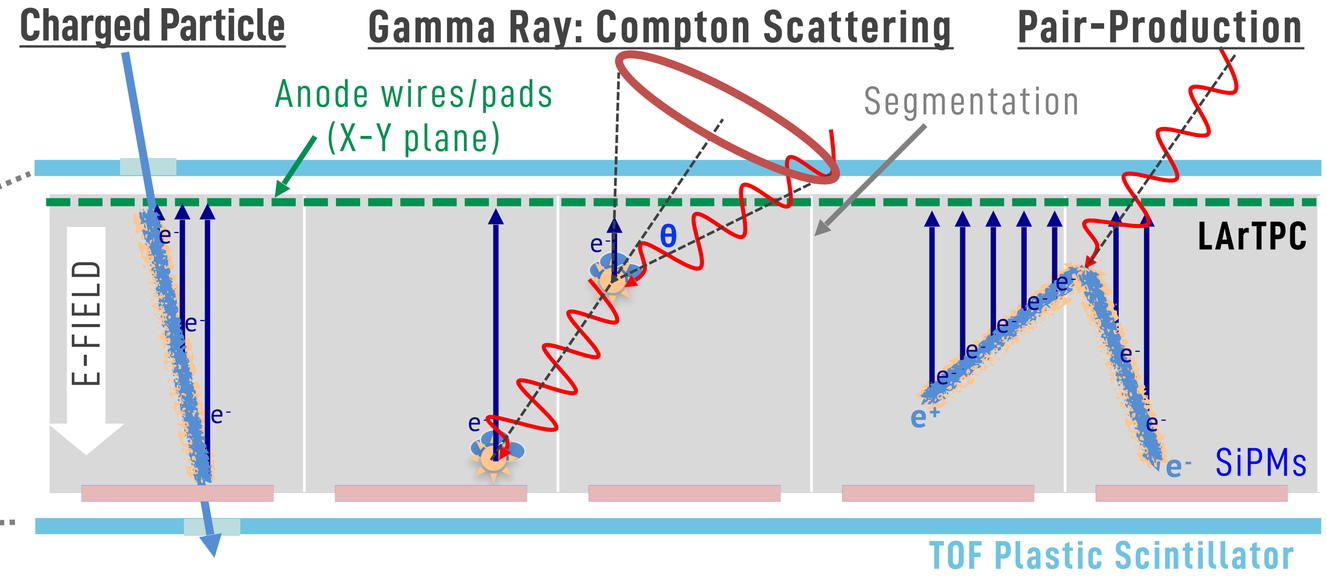
- Physics processes/nucleosynthesis
- Multi-messenger astronomy
- Indirect dark matter searches/PBH searches -> See Jon Leyva's Talk

GRAMS Detector Design

LArTPC detector surrounded by plastic scintillators
LArTPC measures scintillation light and ionization electron

	Antimatter	Gamma Rays
Plastic Scintillators	Time of Flight to measure velocity	VETO Counters to reject charged particles
LArTPC	Particle Tracker, Calorimeter	Compton Camera, Calorimeter

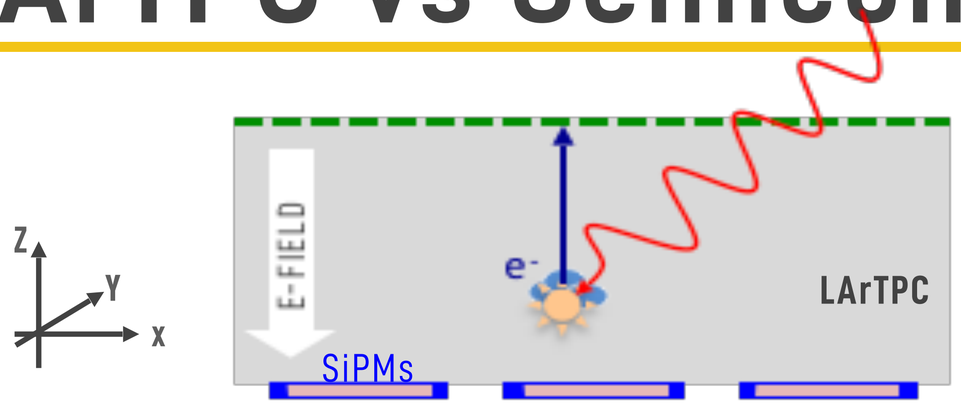


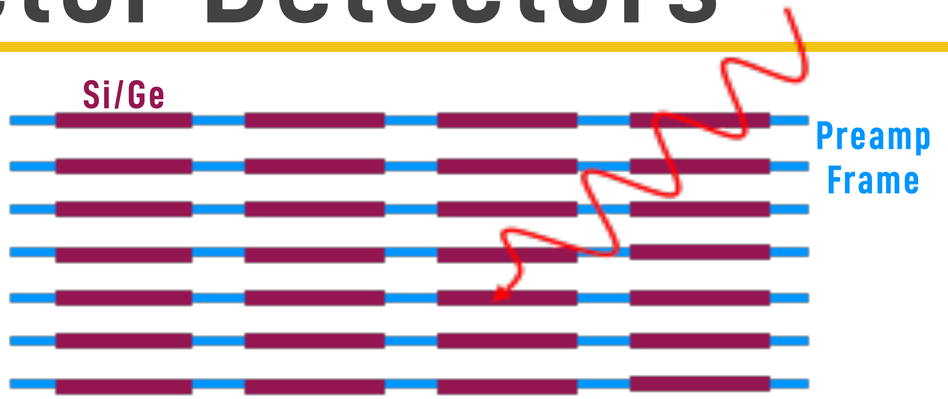


LArTPC segmented into "cells" to minimize coincident background

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

LArTPC vs Semiconductor Detectors

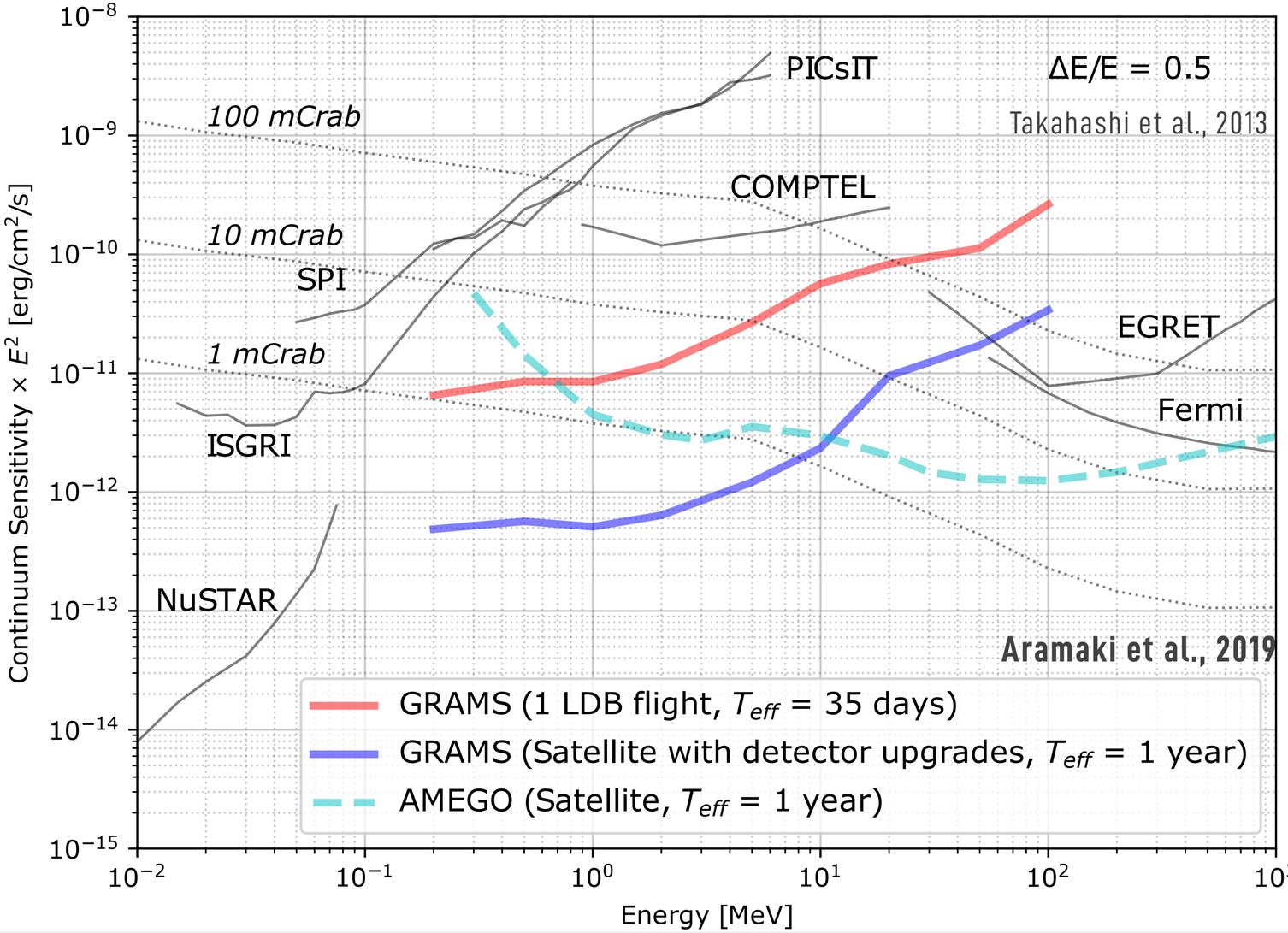




	LArTPC	Semiconductor Detector (Ge/Si)
ρ (g/cm^3)	1.4	2.3/5.3
$T_{operation}$	~80K	~240K/~80K
Cost	**$**	$$$
Signals	scintillation light + ionization electrons	electrons, holes
X, Y Positions	wires on anode plane (X-Y)	double-sided strips
Z Position	from drift time	from layer #
# of Layers	**1 layer**	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 almost no dead volume, easily expandable to a larger scale with high detection efficiency

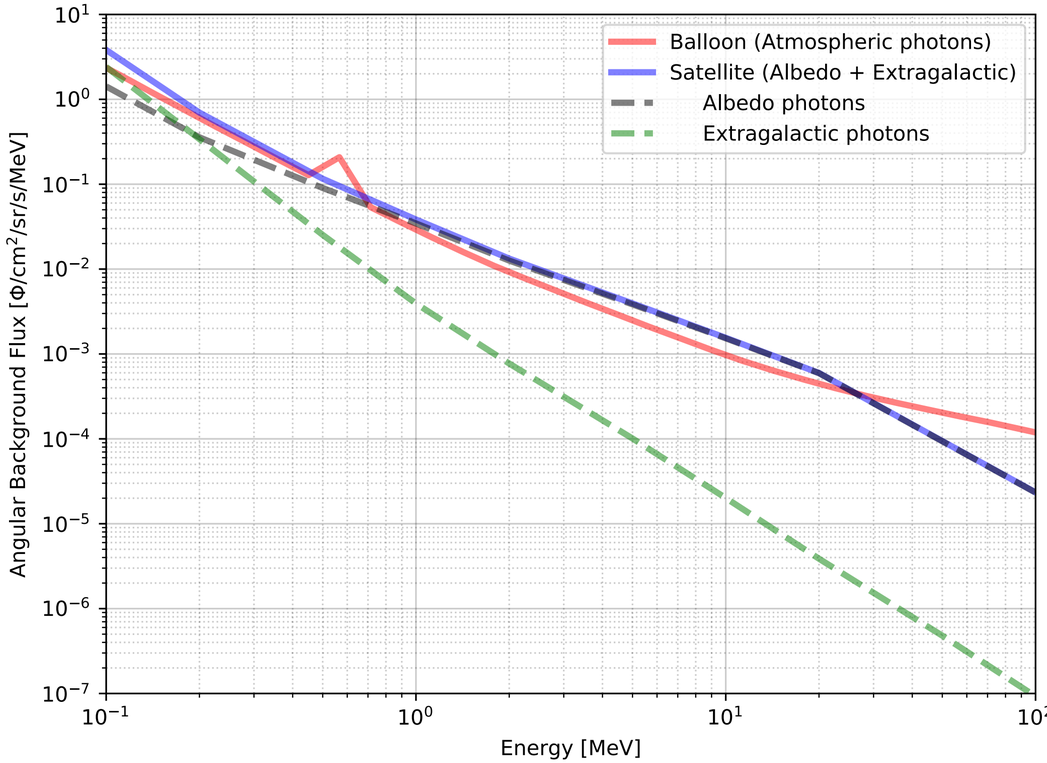
GRAMS MeV Gamma-ray Continuum Sensitivity



Background model (EXPACS)

Atmospheric photons dominate for **balloon**

Albedo photons dominate for **satellite**

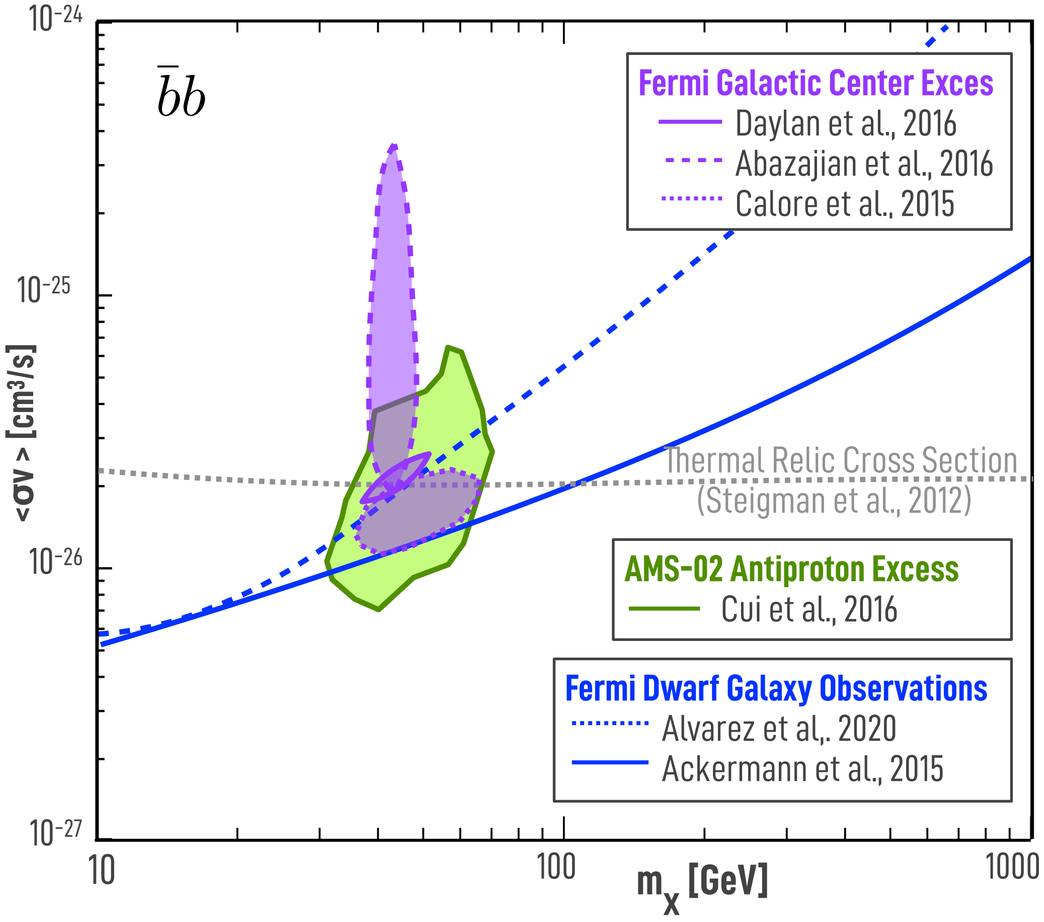


Balloon flight: an order of magnitude improved

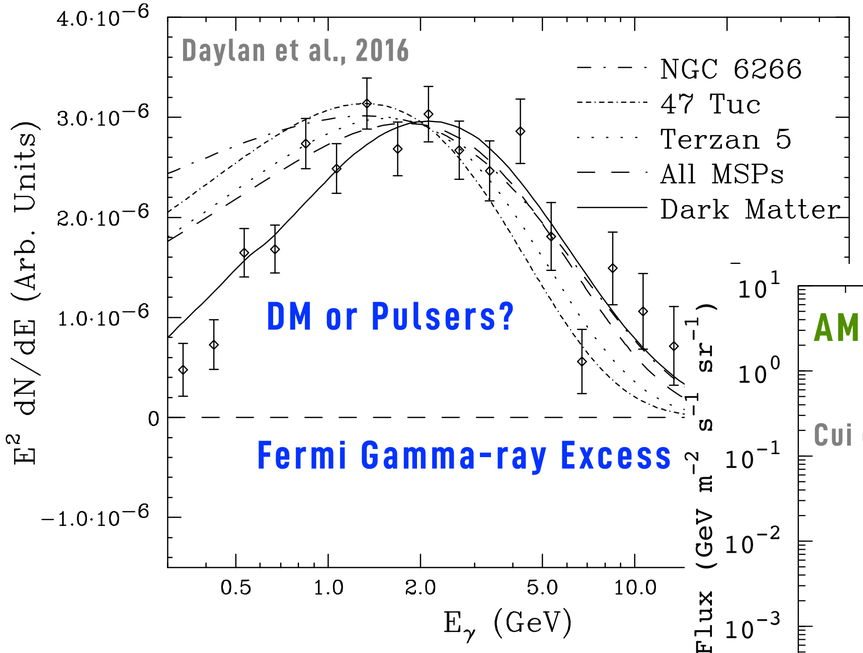
Satellite mission: comparable to future missions

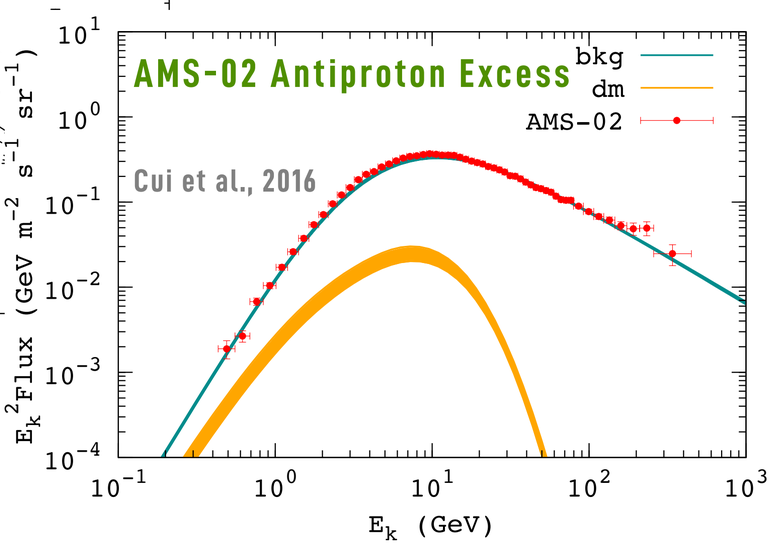
Fermi and AMS-02 Results

Possible DM signature in FERMI GCE and AMS-02 antiproton excess?
AMS-02 detected antiheliums?



How do we validate these results?



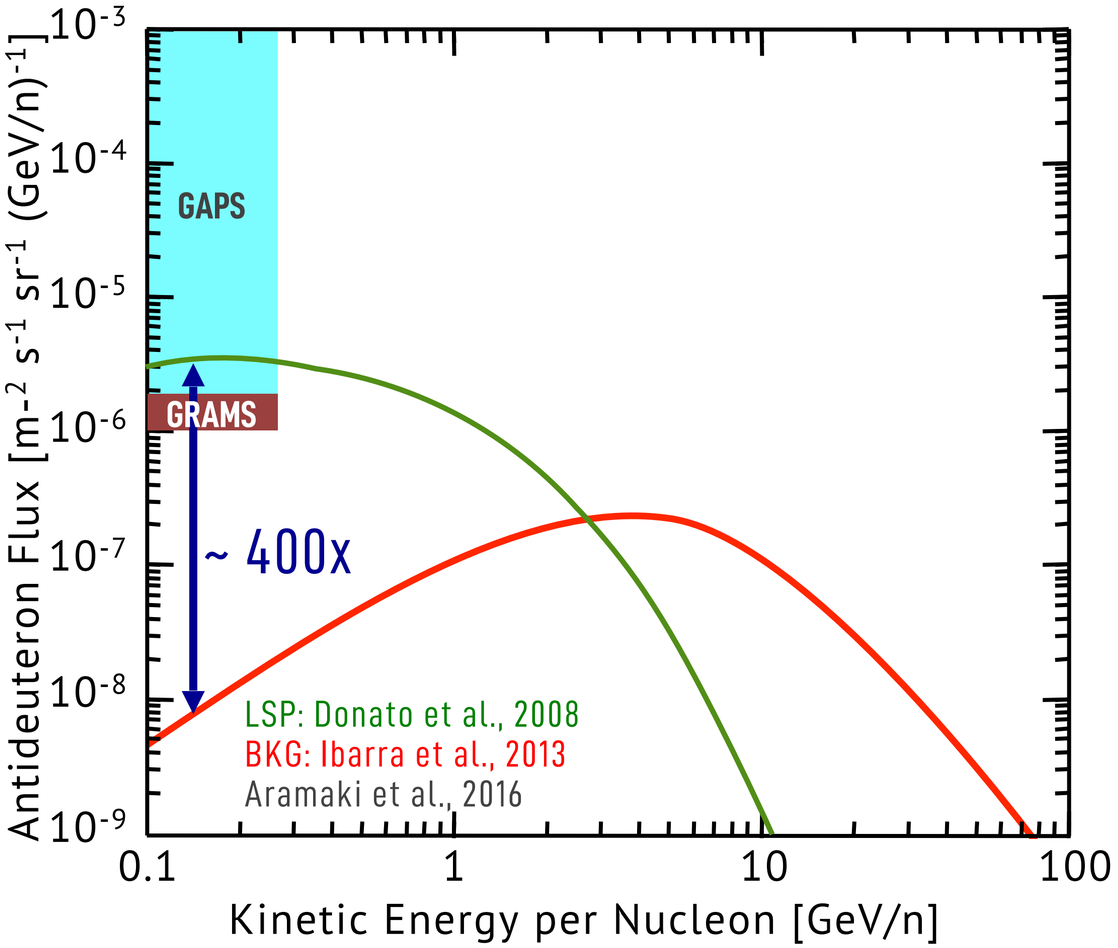


Difficult to verify DM signatures due to background/uncertainty

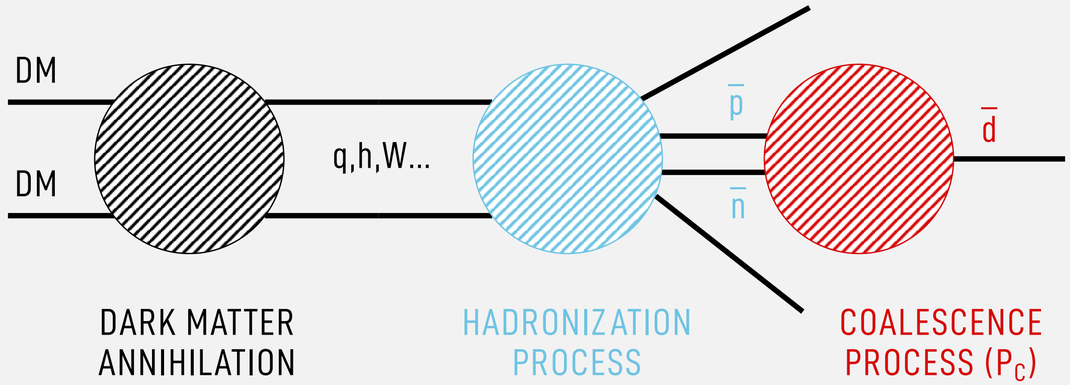
A new approach/experiment is crucial to investigate these results

Why Antideutetrons?

Background-free DM Search at low-energy region



PRIMARY FLUX = DM ANNIHILATION/DECAY



SECONDARY FLUX = COSMIC RAY INTERACTION

$$p\,(CR) + H\,(ISM) \rightarrow p + H + p + n + \bar{p} + \bar{n}$$

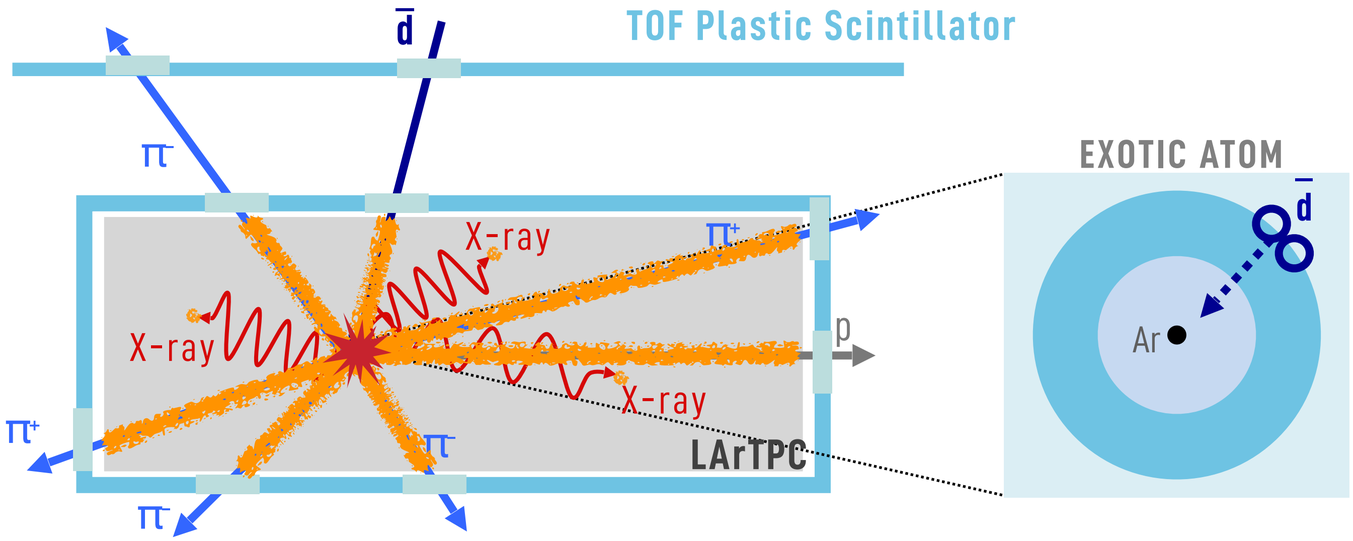
$\bar{p} + \bar{n} \rightarrow \bar{d}$

GAPS first science flight from Antarctic in 2022/2023

GRAMS: next generation mission

GRAMS Antimatter Detection Concept

Plastic Scintillators: TOF, LArTPC: 3D particle tracker/calorimeter
Measure atomic X-rays and annihilation products

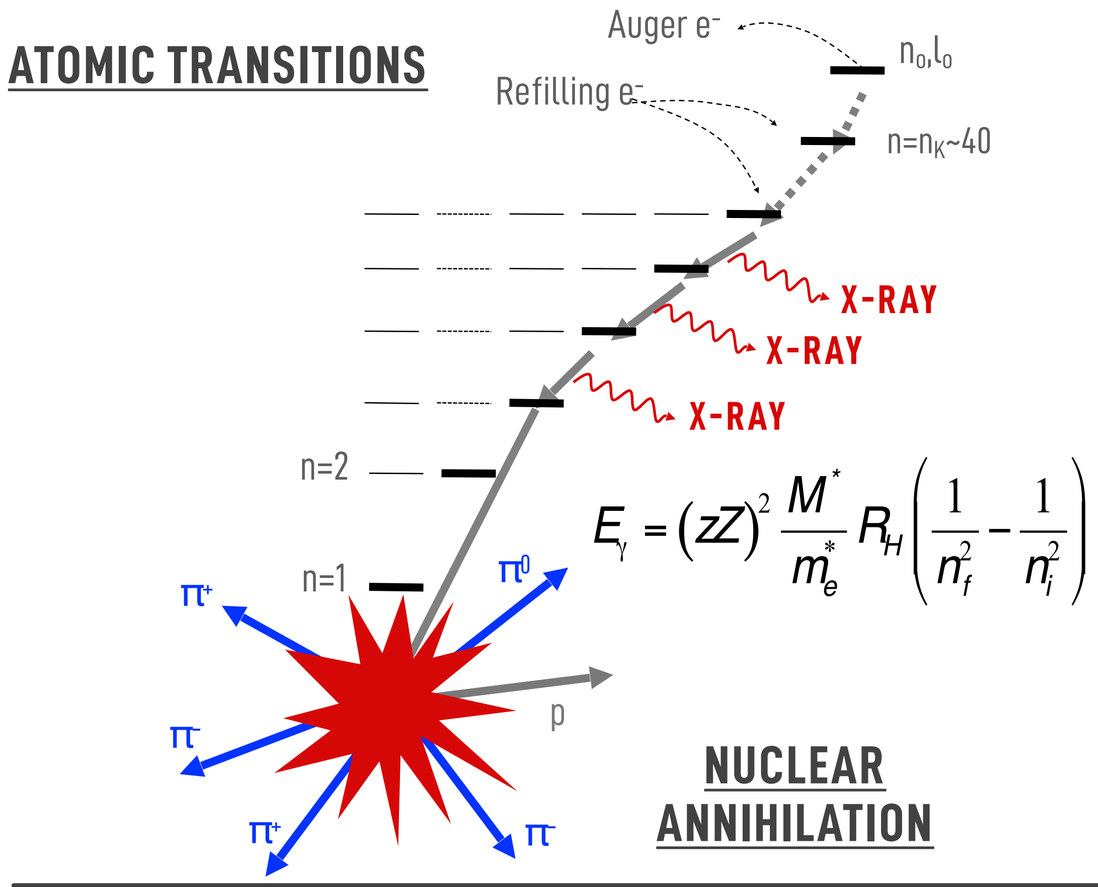


A time of flight (TOF) system tags candidate events and records velocity

The antiparticle slows down & stops, forming an excited exotic atom

De-excitation X-rays provide signature

Annihilation products provide additional background suppression

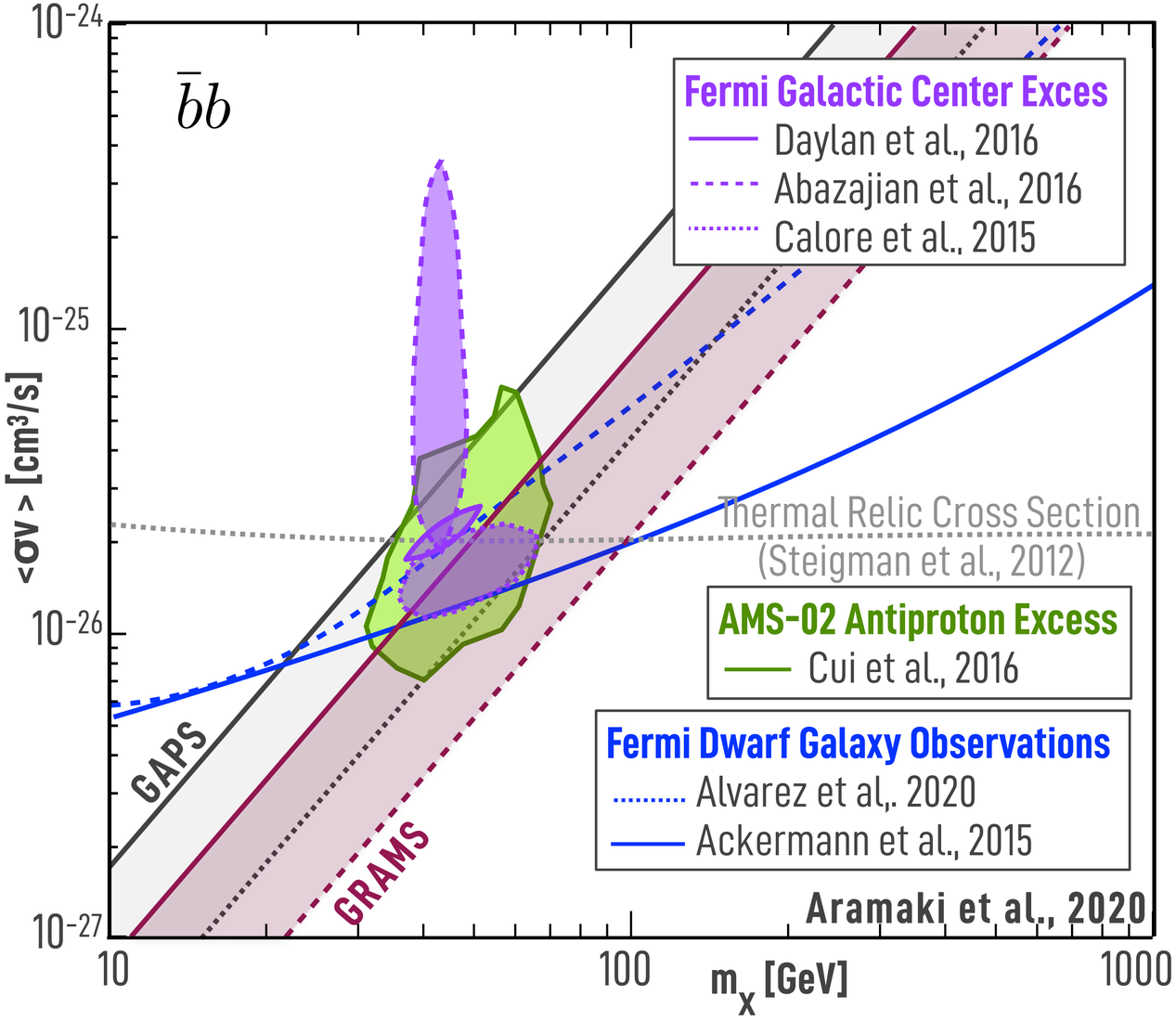


$$E_\gamma = (zZ)^2 \frac{M^*}{m_e^*} R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

LArTPC (almost no dead volume) provides
- Excellent 3D particle tracking capability
- High particle detection efficiency

GRAMS Sensitivity in DM Parameter Space

Strong tensions with Fermi GCE/dSphs and AMS-02 results



GRAMS can extensively explore DM parameter space and Fermi/AMS-02 results

Timeline

R&D FOR PROOF OF CONCEPT - Present

- Validate **detection concept** with a small-scale prototype detector
- Establish **event reconstruction techniques**

Developed event reconstruction algorithm for multiple Compton scattering events: NIM-A
Building a prototype detector (MiniGRAMS) at Northeastern University

FIRST BALLOON FLIGHT - IN ~5 YEARS

- MeV gamma-ray observations focusing on **bright objects,** nuclear lines
- Indirect DM search with antimatter

SATELLITE MISSION - IN > 10+ YEARS

- **All sky survey** in the MeV energy domain
- Antimatter-based (including **antihelium**) DM search

Summary

- GRAMS is a proposed next-generation mission to target both **gamma-ray observations** in the **poorly explored MeV energy band** and **indirect dark matter searches with antimatter**.
- The Project will begin with a **balloon experiment** as **a step forward to** a **satellite mission**.
- With a **cost-effective, large-scale LArTPC** detector, the sensitivity to **MeV gamma rays** can be more than **an order of magnitude improved** compared to previous experiments with a single balloon flight.
- GRAMS antideuteron measurements can be essentially **background-free dark matter searches** while investigating and validating the possible dark matter detection indicated in **Fermi GCE** and **AMS-02 antiproton excess**.
- The project is currently in the **R&D phase,** and we have developed the **event reconstruction techniques** for multiple Compton scattering events.
- **A small-scale prototype detector**, **MiniGRAMS,** is currently being built at Northeastern University.

GRAMS Collaboration

WE ARE EXPANDING OUR COLLABORATION! PLEASE JOIN US!

Barnard College
Reshmi Mukherjee

Columbia University
Georgia Karagiorgi, William Seligman

MIT
Kerstin Perez

Northeastern University
Tsuguo Aramaki, Jon Leyva, Jiancheng Zeng

Osaka University/RIKEN
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Oak Ridge National Lab
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University of Tokyo
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Waseda University
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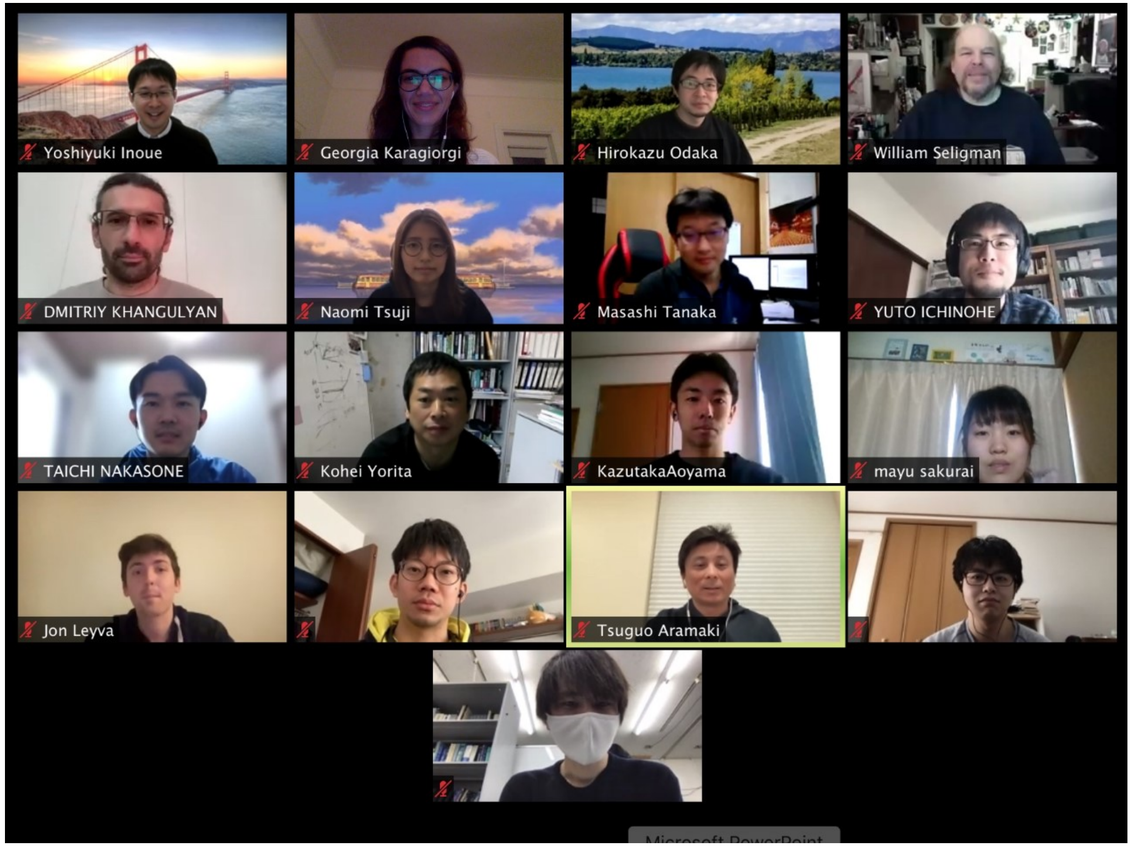
Kazutaka Aoyama, Taichi Nakasone, Mayu Sakurai

3rd GRAMS Collaboration Meeting, Feb 2021



Theoretical support/advice
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