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The Mini Astrophysical MeV Background Observatory (MAMBO) CubeSat Mission

Peter F. Bloser
Space Science and Applications Group
Los Alamos National Laboratory

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The MAMBO Team

- The MAMBO CubeSat mission is a collaboration between the **Intelligence and Space Research Division** and **Center for Theoretical Astrophysics** at Los Alamos National Laboratory:

Peter Bloser (PI), W. Thomas Vestrand (Co-PI), Markus Hehlen, Lucas Parker, Darrel Beckman, Justin McGlown, Kim Katko, James Sedillo, Lee Holguin, Greg Lee, Tony Nelson, Christopher Fryer, Aimee Hungerford, Matthew Mumpower

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MAMBO Overview

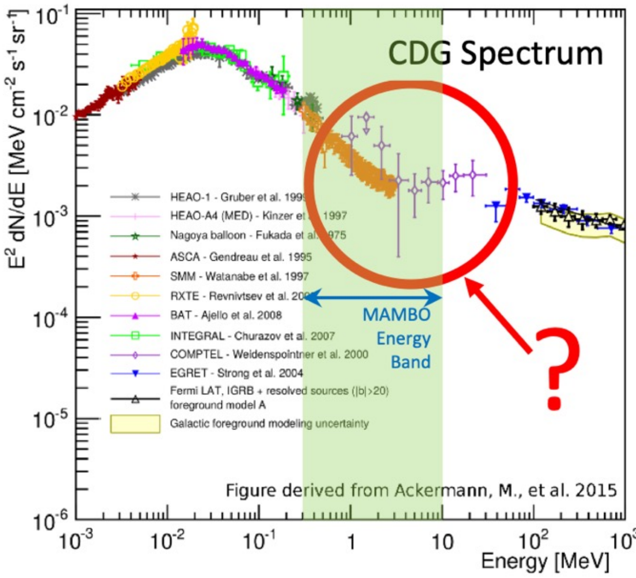
The **Mini Astrophysical MeV Background Observatory (MAMBO)** is an innovative gamma-ray astrophysics investigation that will answer three decades-old questions about the mysterious Cosmic Diffuse Gamma-ray (CDG) background:

- ***What is the detailed spectral shape of the CDG from 0.3 – 10 MeV?***
- ***Is the MeV CDG truly isotropic across the sky?***
- ***What is the contribution of nuclear processes over the history of the Universe to the MeV CDG?***

The MAMBO mission represents a new way of doing MeV astronomy which will solidify Los Alamos' leadership in space-based gamma-ray sensing, and demonstrate a flexible new paradigm for rapid, inexpensive science missions.

Scientific Motivation: The MeV CDG

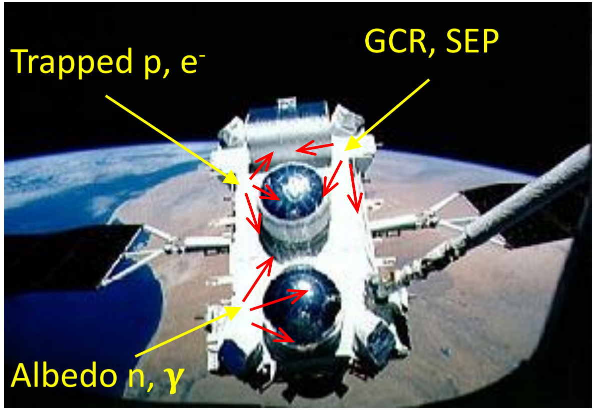
- The origin of the CDG background in the MeV band remains a mystery over 40 years after the first measurements by Apollo 15 & 16 (Trombka et al. 1977)
- It seems certain that blazars (particle acceleration; e.g. Ajello at al. 2009) and Type Ia SNe (nuclear processes; e.g. Ruiz-Lapuente et al. 2016) must contribute
- Other proposed sources include Seyferts, star-forming galaxies, kilonovae, and dark matter interactions
- Existing data indicate multiple sources due to changes in spectral slope; ***however***, these data have issues
- COMPTEL (Weidenspointner et al. 2000) suffered from large systematic errors due to background, and SMM (Watanabe et al. 2000) was constrained to observe the Sun



What is required is a full-sky map of the MeV CDG spectrum and anisotropy collected with a low-background instrument

Low-Background MeV Observations

- **The Problem:** The sensitivity of space-based gamma-ray instruments is severely limited by *locally generated instrumental backgrounds*
- Energetic particles in space interact in spacecraft materials to produce both **prompt** and **delayed** (activation) background signals in the MeV band
- Intensity in a given detector scales as the integral over the mass distribution of $1/d^2 \Rightarrow$ background scales roughly as $\sim(\text{mass})^{1/3}$
- As a result, previous measurements of the MeV CDG suffer from large systematic errors due to subtraction of instrumental backgrounds



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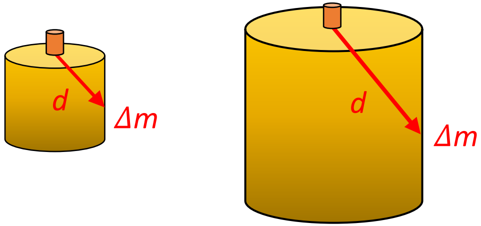


$$\text{Background} \sim \int_V (1/d^2)\,dV \sim (\text{mass})^{1/3}$$

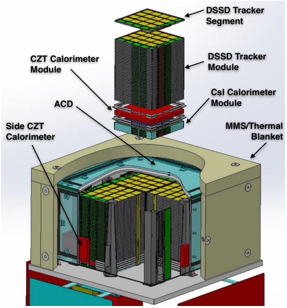
The MAMBO Approach: Low-Mass Spacecraft

- **Traditional approach:** Large, complex instruments to maximize efficiency to faint astrophysical MeV sources
- Leads to 1000+ kg spacecraft and large instrumental background

⇒

- **Our Approach:** To significantly reduce background, *mass must be dramatically reduced*
- The CDG is relatively bright, so *only a small detector needed*
- MAMBO utilizes a 12U CubeSat bus = 24 kg total
- Will experience an *order of magnitude less instrumental background* than COMPTEL on CGRO

CGRO: 17,000 kg



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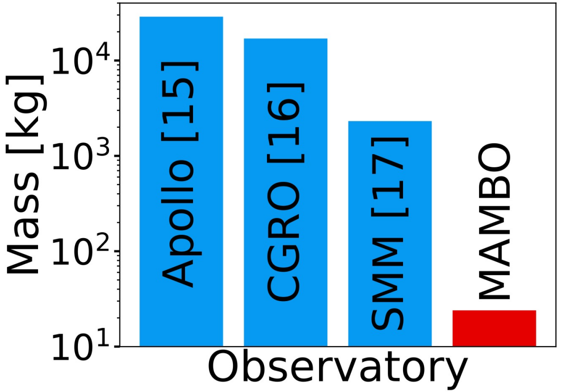
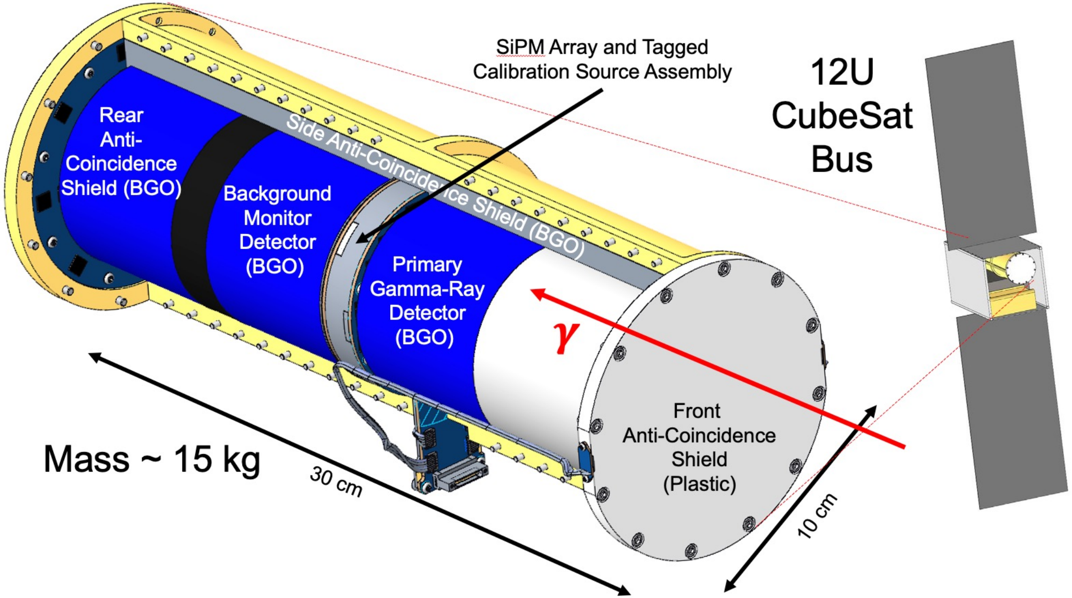
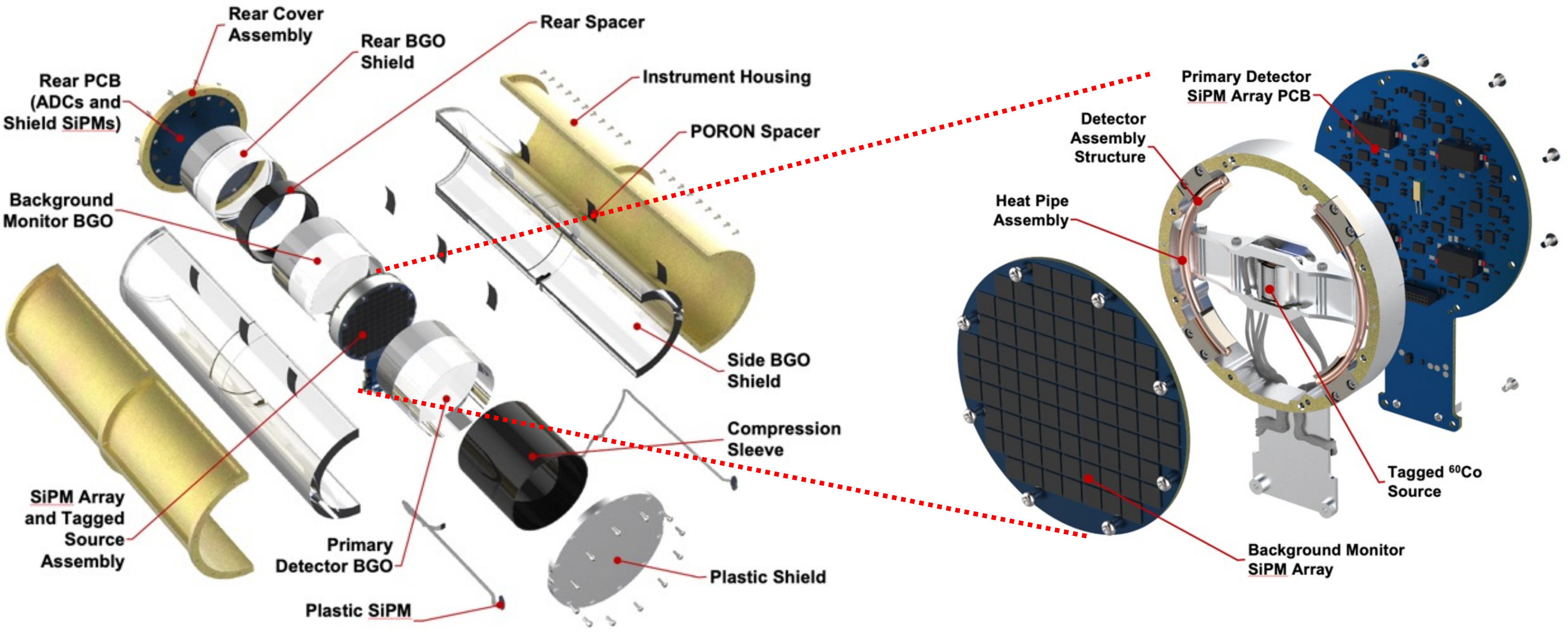


The MAMBO Instrument

- MAMBO achieves high efficiency and exceptional background rejection using an innovative shielding configuration
- The Primary Detector (BGO scintillator) is exposed to the CDG
- The Background Monitor (identical BGO) is shielded from the CDG by the Primary, but exposed to the identical instrumental background
- Gains are kept the same using a **tagged ^{60}Co source**
- *Instrumental background is thus* ***directly measured and subtracted***
- Close spacing is enabled by the use of **silicon photomultipliers (SiPMs)**

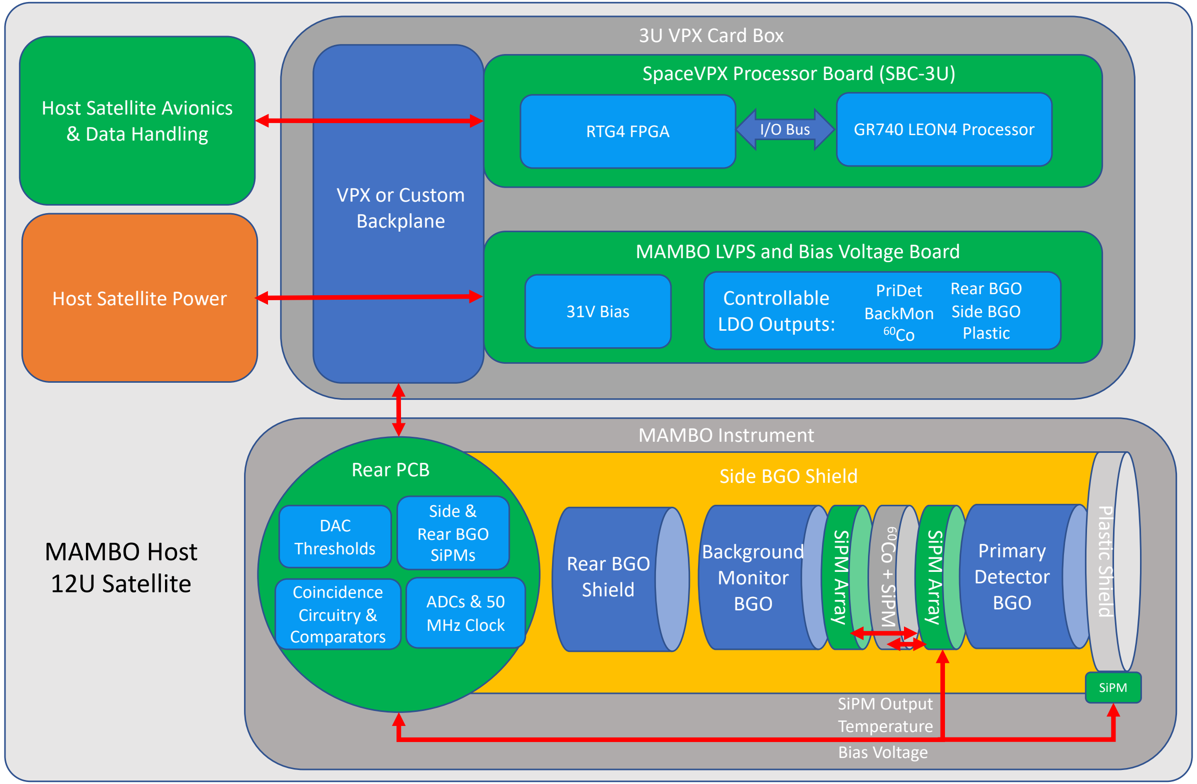


The MAMBO Instrument (Cont.)



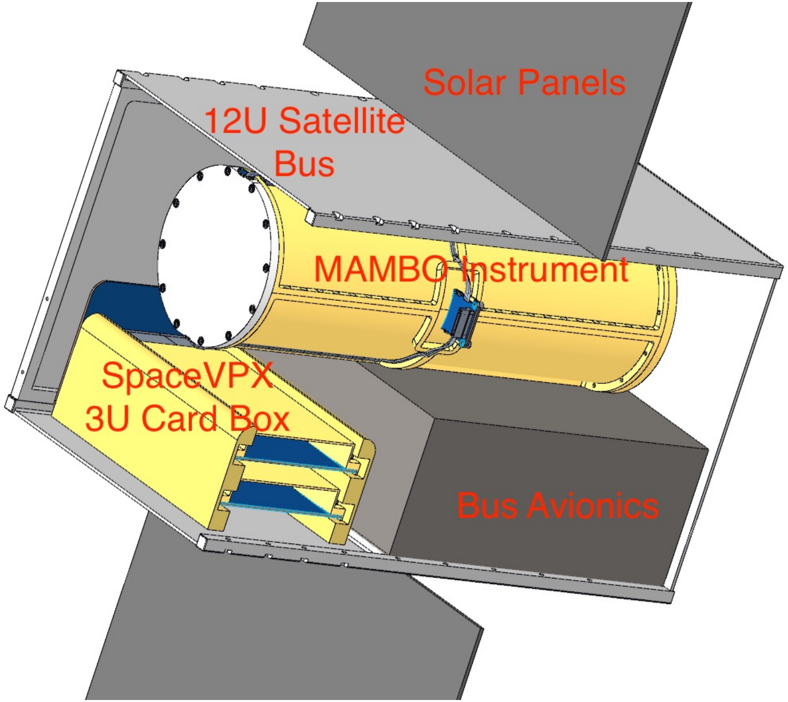
MAMBO Payload Readout

- "Rear PCB" contains analog-to-digital and coincidence electronics, readout SiPMs for Side and Rear BGO shields
- SpaceVPX 3U Card Box houses low-voltage power supply (LVPS) and SiPM Bias Voltage Board
  - Adjusts bias based on temperature and tagged Co-60 events
- Card Box also houses SpaceVPX Payload Processor Board
  - Based on the space grade GR740 quad-core LEON4 processor ASIC with a MicroChip RTG4 FPGA



Mechanical Accommodation

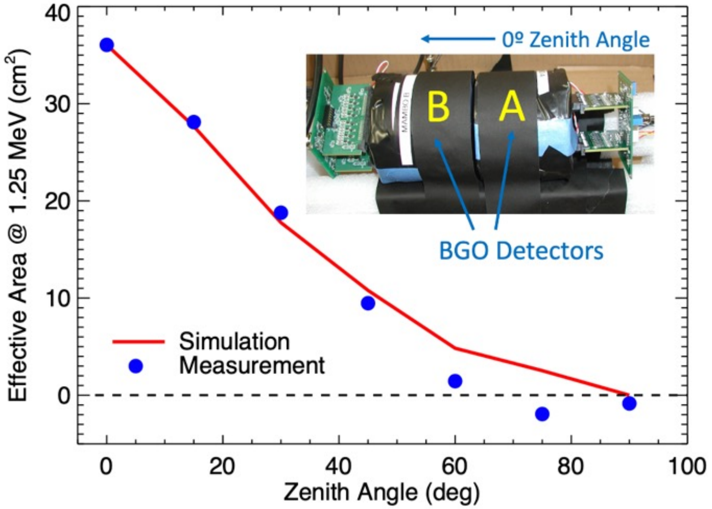
- Ample volume available in generic 12U CubeSat bus
- Mass is just within total 24 kg limit
- Commercial partner to be announced soon

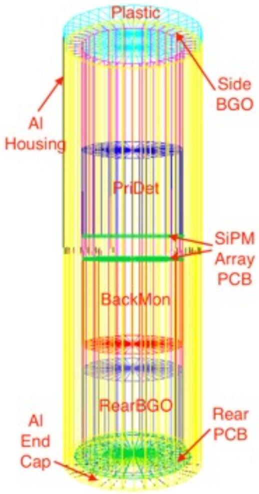


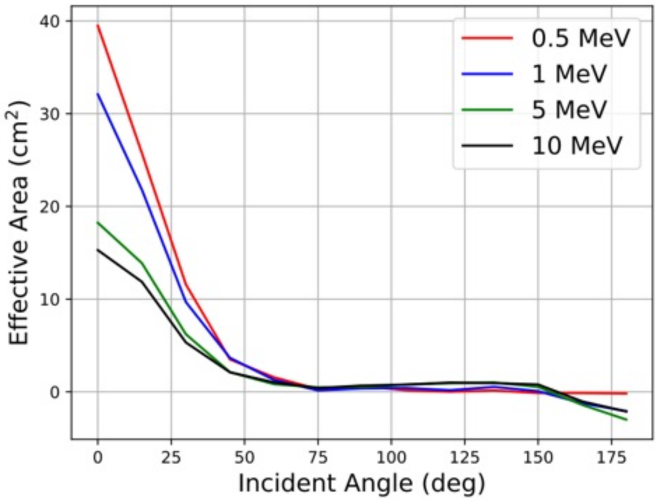
Validation Studies

- **Laboratory demonstration** of background subtraction
- Response is concentrated to the front, in agreement with simulations

- **Simulation studies** of instrument response used to optimize design
- A_{eff} ~ 32 cm^2 at 1 MeV on-axis
- FOV ~ 40º (FWHM)



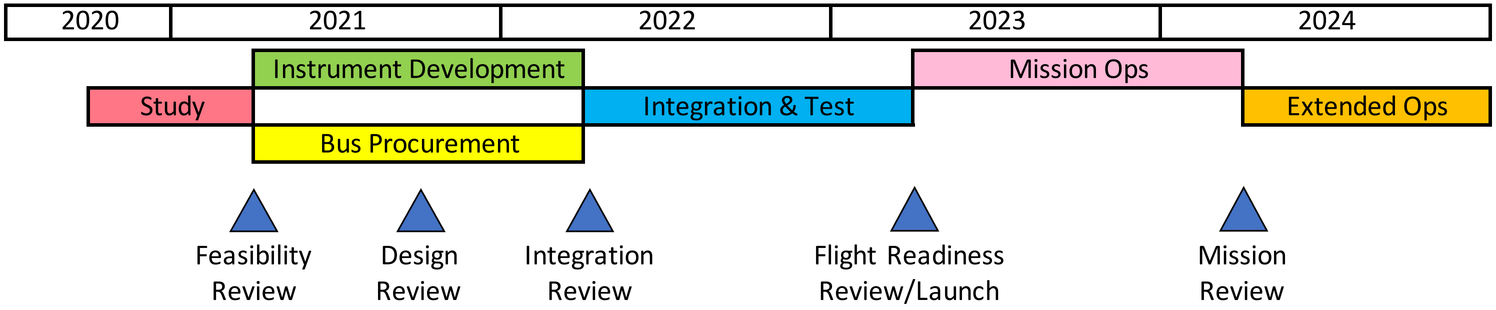




MAMBO Mission Concept

- Ideal science orbit: circular LEO, ~400-500 km, 0º inclination
- For practical reasons (comms, schedule) will accept up to ISS-like orbit (~52º inclination)
- Estimate data rate of $\lesssim$ 600 MB per day
- Pointing accuracy/knowledge of ~1º
- Background noise generated by trapped radiation belts, especially activation in SAA
- Point at high-Galactic-latitude regions for $\gtrsim 10^6$ seconds each; extrapolate time-variable backgrounds to zero
- Minimum of 6 months; desire 2+ years
- Will use commercial or government ground station network for telemetry and commanding

MAMBO Project Timeline



- Six-month Feasibility Study completed in March 2021
- One-year instrument development & bus procurement
- One-year integration & test
- Launch via DoD’s Space Test Program
- One-year baseline mission
- Desire one-year-plus extended mission (propose to NASA for additional funding)

Summary

- The MAMBO CubeSat mission will address an important, decades-old question in gamma-ray astrophysics using an innovative approach
- The low-mass 12U CubeSat platform will provide a uniquely “quiet” environment for MeV observations
- The compact, shielded scintillator spectrometer, enabled by SiPMs, will deliver low-background measurements of the MeV CDG over the entire sky
- MAMBO will also demonstrate the utility of commercial 12U satellite buses and ground station networks for rapid, low-cost space missions