Let’s MAMBO (Mini Astrophysical MeV Background Observatory)! A New CubeSat Mission at 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:

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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 et 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.
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

AMEGO

![Mass Comparison Graph](image)
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)
MAMBO Payload Readout

- “Sensor Head PCB” contains analog-to-digital and coincidence electronics, readout SiPMs for Side and Rear BGO shields
- Custom 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 Payload Processor Board
  - Based on LANL-developed rad-hard processor for the SuperCam instrument on the Mars 2020 Rover
Mechanical Accommodation

- Ample volume available in 12U CubeSat bus
- Mass is just within total 25 kg limit
- The 12U bus will be provided by our commercial partner: NanoAvionics
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
- \( A_{\text{eff}} \approx 32 \text{ cm}^2 \) at 1 MeV on-axis
- FOV \( \approx 40^\circ \) (FWHM)
Simulated Scientific Performance

- Simulated background spectra in LEO in Primary Detector ONLY
- Other scintillators acting as anti-coincidence shields
- Simulated background spectra in LEO after subtracting Background Monitor from Primary Detector
- CDG is far more prominent
- Simulated CDG spectrum in $10^6$ s observing time
- Assumes background components fit and subtracted
- MAMBO will make sensitive measurements of the CDG
MAMBO Mission Concept

• Ideal science orbit: circular LEO, ~400-500 km, 0° inclination
• For practical reasons (comms, schedule) will accept up to ISS-like orbit (~52° inclination)
• Estimate data rate of \( \lesssim 650 \) MB per day
• Pointing accuracy/knowledge of \( \sim 1° \)
• Background noise generated by trapped radiation belts, especially activation in SAA
• Point at high-Galactic-latitude regions for \( \geq 10^6 \) seconds each; extrapolate time-variable backgrounds to zero
• Secondary Science: Solar flare, other transients (e.g., X-ray novae)
• Minimum of 6 months; desire 2+ years
• Will use commercial or government ground station network for telemetry and commanding (selection will be made within next month)
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