Experimental Gamma-Ray Astronomy at Los Alamos National Laboratory

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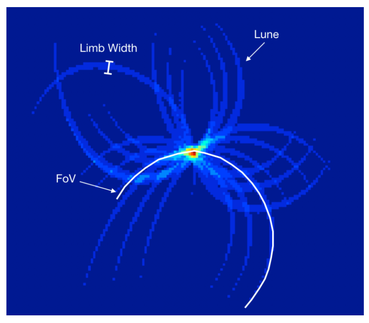
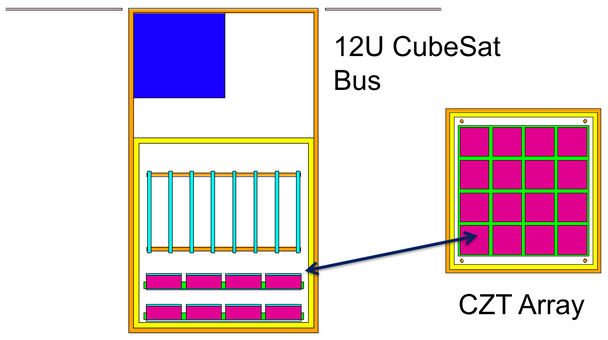
Los Alamos National Laboratory has a long history of discovery in gamma-ray astronomy, from the first detection of gamma-ray bursts by the Vela satellites to extensive involvement in NASA's highly successful Swift and Fermi missions. Looking to the future, several exciting new opportunities are being pursued, leveraging Los Alamos's unique expertise in space-based gamma-ray detector development and data analysis. We describe current experimental efforts at LANL, including: 1) a concept for a Lunar CubeSat mission to measure gamma-ray lines from nuclear processes; 2) development of an advanced Compton telescope based on diamond detectors and fast scintillators; 3) a high-altitude ballooning program to test advanced detector technologies in a near-space environment; and 4) contributions to proposed large-scale NASA missions, including AMEGO, LEAP, and LOX.

Lunar CubeSat Mission Concept

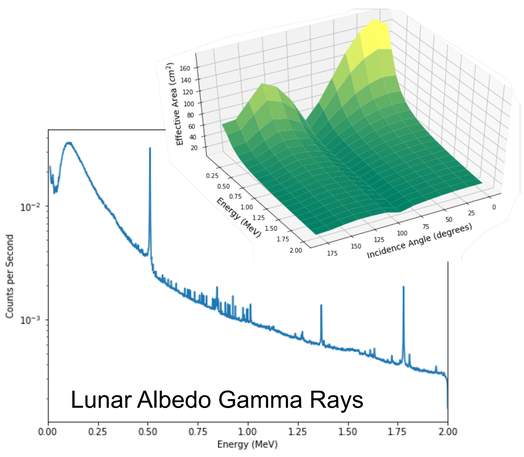
The **Lunar CubeSat** is a concept for a CubeSat mission in Lunar orbit with the objective of studying nuclear gamma-ray line sources using the Lunar Occultation Technique (LOT) developed by Richard Miller of JHUAPL. We have conducted a simulation study to determine whether such a relatively small, inexpensive mission could achieve competitive sensitivity compared to larger missions.



The LOT statistically analyzes changes in count rate during rises and sets of source behind the Lunar limb for flux and location determination.

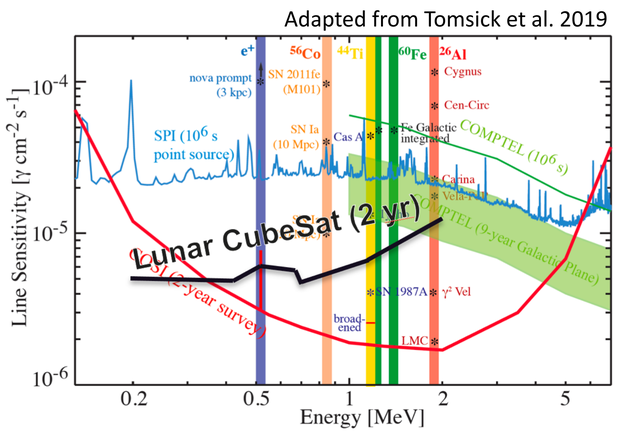


We modeled a payload of 32 cadmium-zinc-telluride (CZT) gamma-ray spectrometers flown in a 12U CubeSat bus (20 × 20 × 30 cm^3) using MCNP.



Detector efficiency vs. energy and incidence angle, as well as background spectra, were simulated and used to calculate sensitivity.

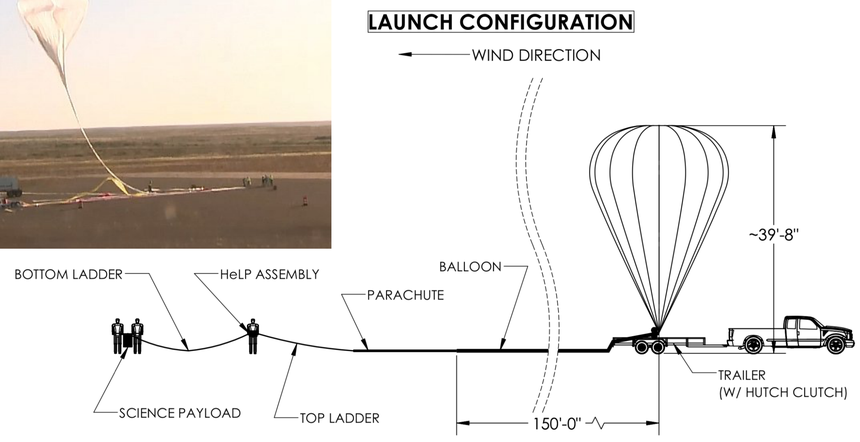
Adapted from Tomsick et al. 2019



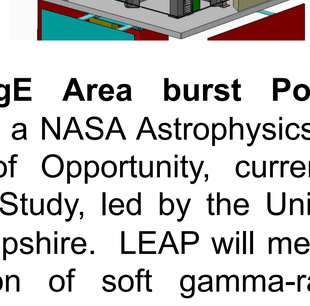
In 2 years the Lunar CubeSat achieves significantly better narrow line sensitivity than previous missions, and is competitive with the proposed COSI Explorer below 1 MeV.

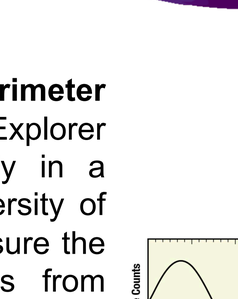
High-Altitude Balloon Program

High-altitude ballooning offers a cost-effective way to test new technologies in an environment similar to outer space. NASA's Columbia Scientific Balloon Facility (CSBF) has flown large (a few tons) scientific payloads from **Fort Sumner, NM**, for many decades. Recently, CSBF introduced a capability to "hand launch" relatively small (< 60 lbs) payloads, which offers a more streamlined process and cleaner environment for testing advanced detector concepts in near-space conditions:



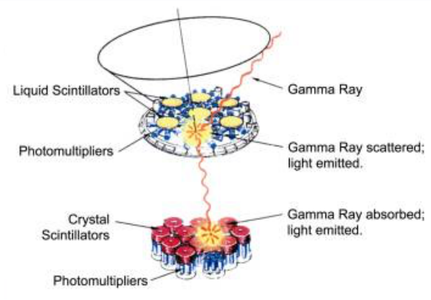
Los Alamos is currently developing a dedicated small balloon platform for use with CSBF's hand-launch capability. The inaugural flight is planned for Fall of 2021 from Fort Sumner, where we will test an advanced imaging gamma-ray detector made of cadmium-zinc-telluride (CZT) in collaboration with the University of Michigan:





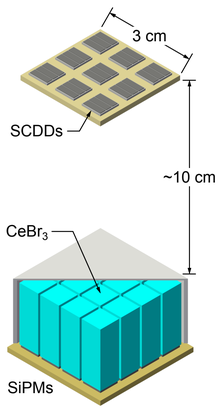
Pixelated CZT gamma-ray detectors offer excellent energy and position resolution. Los Alamos will test them on a balloon flight as a precursor to future space mission proposals.

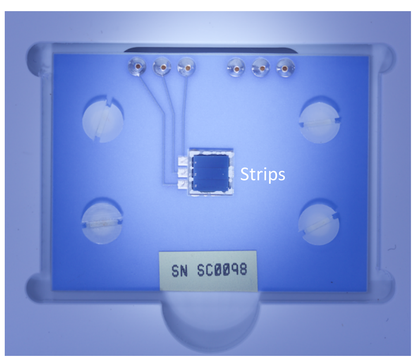
Diamond-Based Compton Telescope

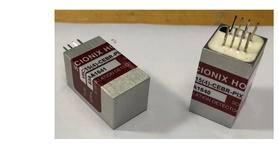


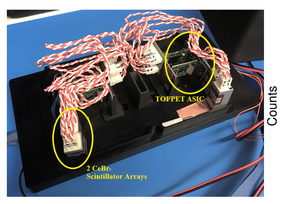
A Compton telescope takes advantage of Compton scattering to form images in the difficult MeV gamma-ray range. The only successful astronomical Compton telescope, COMPTEL, relied on time-of-flight (ToF) measurements between two scintillator detector layers to reject background.

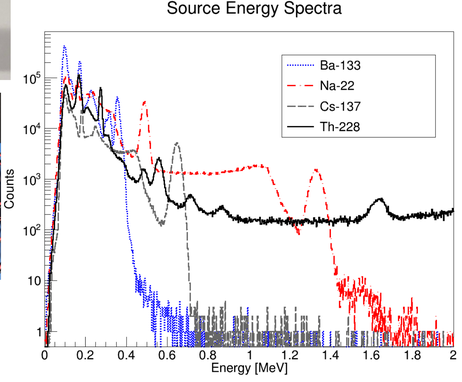
Single-crystal diamond detectors (SCDDs) offer superior efficiency, position resolution, and energy resolution to organic scintillators for Compton scattering, while retaining fast timing for ToF. We are investigating whether SCDDs combined with modern fast scintillators with SiPM readouts could be formed into a superior Compton telescope for MeV gamma-ray astronomy.









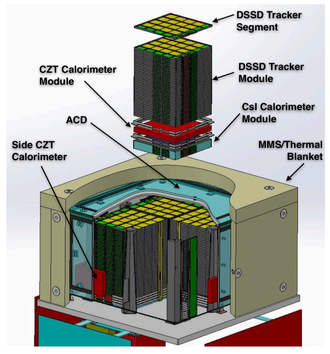


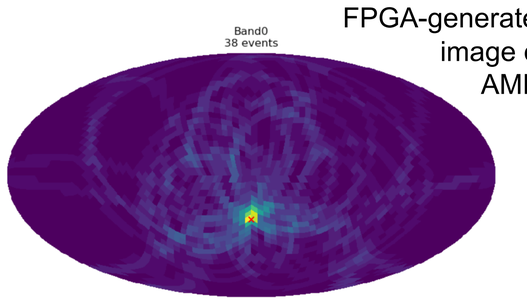
The SCDDs are being developed at Southwest Research Institute. Each is 4.5 × 4.5 × 0.5 mm^3 and patterned with 3 readout strips per side. A custom readout board provides position, energy, and timing signals.

The calorimeters are being tested at Los Alamos. Each contains a 2 × 2 matrix of Cerium Bromide scintillator read by one pixel of a 2 × 2 SiPM array. The signals are recorded using a commercial ASIC.

Contributions to NASA Mission Proposals

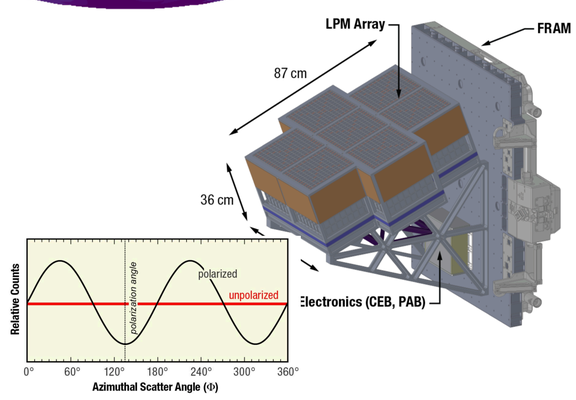
The **All-sky Medium Energy Gamma-ray Observatory (AMEGO)** is a concept for a probe-class NASA mission, led by NASA's Goddard Space Flight Center. It covers the energy range 200 keV – 10 GeV by imaging both Compton scatter and pair production interactions. Los Alamos will contribute expertise in on-board data analysis.

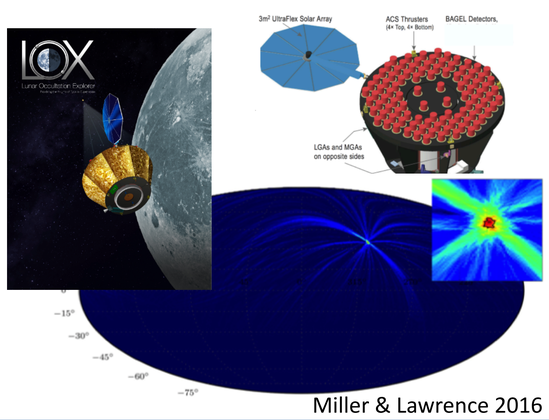




FPGA-generated Compton image of simulated AMEGO events

The **LargE Area burst Polarimeter (LEAP)** is a NASA Astrophysics Explorer Mission of Opportunity, currently in a Phase A Study, led by the University of New Hampshire. LEAP will measure the polarization of soft gamma-rays from gamma-ray bursts. Los Alamos is conducting instrument simulations.





Miller & Lawrence 2016

The **Lunar Occultation Explorer (LOX)** is a NASA Explorer concept led by JHUAPL. LOX will study gamma rays from Type Ia Supernovae and produce high-resolution maps of Galactic MeV sources using the Lunar Occultation Technique. Los Alamos is performing simulations of SNe explosions and developing mapping analysis techniques.