The LargE Area gamma-ray burst Polarimeter (LEAP)
A NASA Mission of Opportunity for ISS

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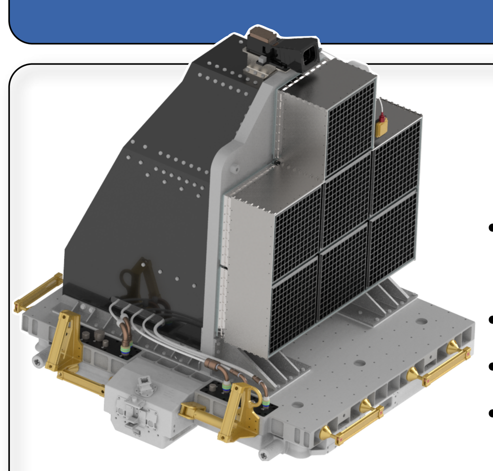
The LargE Area burst Polarimeter (LEAP) will expose the underlying physics that governs astrophysical jets and the extreme environment surrounding newborn compact objects. LEAP will do this by making the highest fidelity polarization measurements to date of the prompt gamma-ray emission from a large sample of Gamma-Ray Bursts (GRBs). The LEAP science objectives are met with a single instrument -- a wide FOV Compton polarimeter that measures GRB polarization over the energy range from 50–1000 keV, performs GRB spectroscopy from 20 keV to 6 MeV, and self-sufficiently determines the source direction. LEAP measures polarization using seven independent polarimeter modules, each with a 12 x 12 array of optically isolated high-Z (CsI(Tl)) and low-Z (plastic) scintillation detectors (including two plastic scintillators infused with 60Co for calibration) read out by individual PMTs. Scatter events recorded by the scintillator array within each module are used to measure polarization. The distribution of azimuthal scatter angles for these events provides a polarization signature, which is further enhanced by measurement of the Compton (polar) scatter angle. The total effective area for polarimetry is ~1000 cm² at energies above 100 keV. To characterize the GRB parameters, spectroscopic measurements (20 keV - 6 MeV) are obtained using all event types (both multiple and singles events), with a total effective area that reaches >3000 cm2 between 50 and 500 keV. If approved, LEAP will be deployed as an external payload on the International Space Station (ISS) in 2027 for a 32-month mission. Over its lifetime, LEAP will, for the first time, measure the level of polarization for a significant number of GRBs with sufficient sensitivity (defined as the Minimum Detectable Polarization, or MDP) to determine the magnetic field structure, the composition (whether dominated by matter or Poynting flux), and the energy dissipation mechanism of GRB jets. Specifically, LEAP will measure 152 GRBs with a 50-300 keV MDP of <30%, 224 GRBs with an MDP of <50%, and 26 GRBs with an MDP of <10%. For brighter events, LEAP will measure the energy and/or time dependence of the polarization. Finally, LEAP will provide burst alerts to the community, following procedures developed by Fermi-GBM.

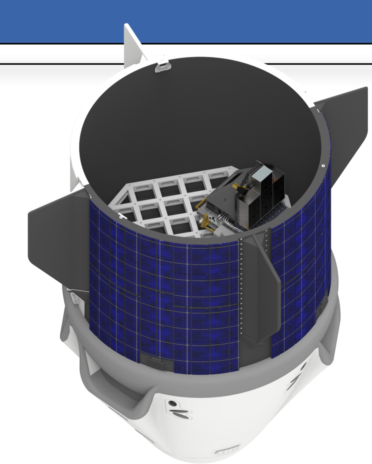
Mission



LEAP Payload

Principal Investigator : Mark McConnell (UNH / SwRI)
Deputy Principal Investigator : Jessica Gaskin (NASA-MSFC)
Project Scientist : Colleen Wilson-Hodge (NASA-MSFC)

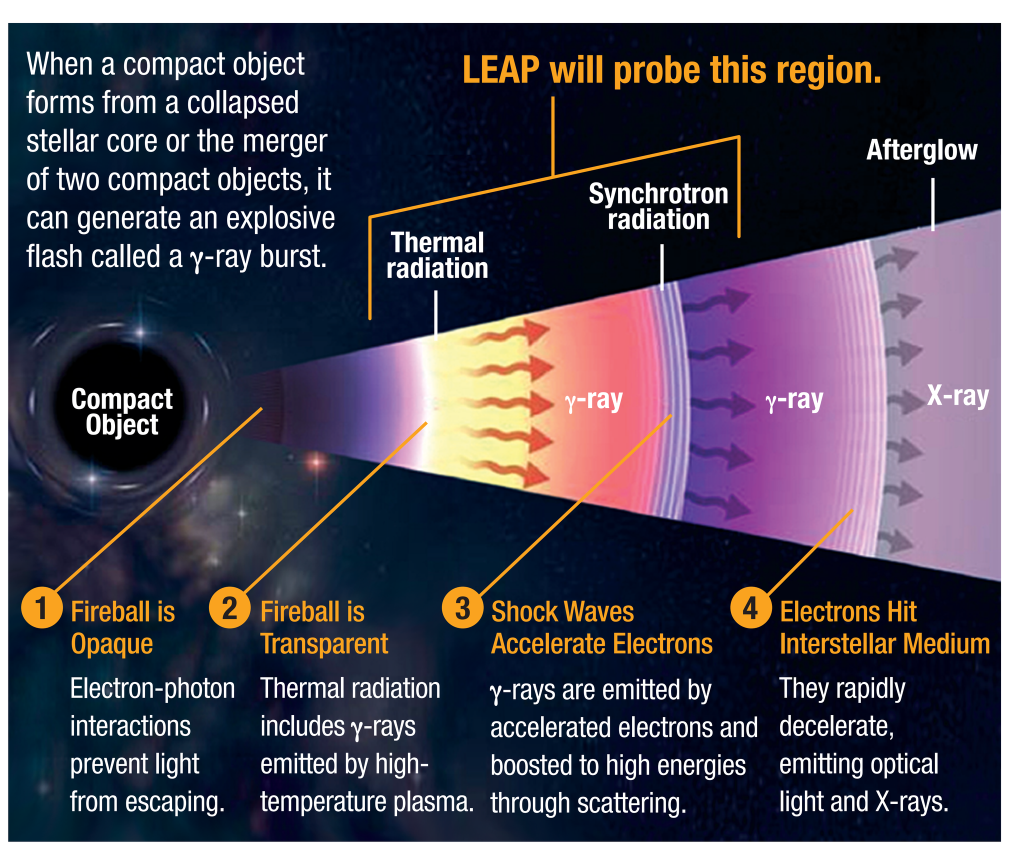
- LEAP is a low-cost, low-risk mission designed to provide GRB polarization measurements from 50 keV to 1 MeV.
- Proposed as a NASA Astrophysics Mission of Opportunity.
- Launch readiness date is December 2027.
- The payload will be launched on a Dragon spacecraft (or equivalent) for delivery to and integration onto the ISS.
- The total mission duration is 32 months.

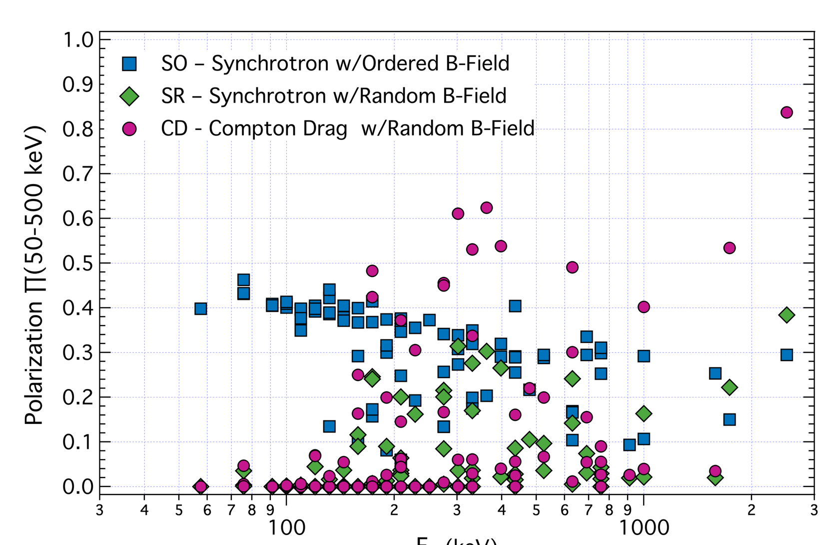


LEAP in Dragon trunk

Science Objectives

The LEAP science goal is to improve our understanding of astrophysical jets and the environment surrounding newborn compact objects. The LEAP science objectives are to determine: 1) the jet magnetic field structure (ordered vs random); 2) the jet composition (dominated by matter or Poynting flux); 3) the jet energy dissipation process (internal shocks our reconnection); and 4) the prompt emission mechanism(s).

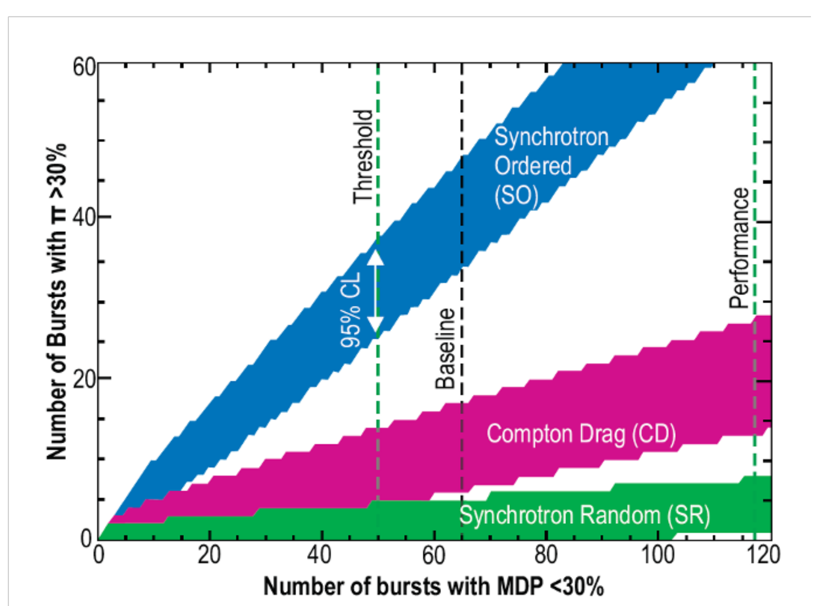




Predicted polarization as a function of E_p (Toma et al. 2009)

LEAP is designed to distinguish amongst three basic models for GRBs (Toma et al. 2009):

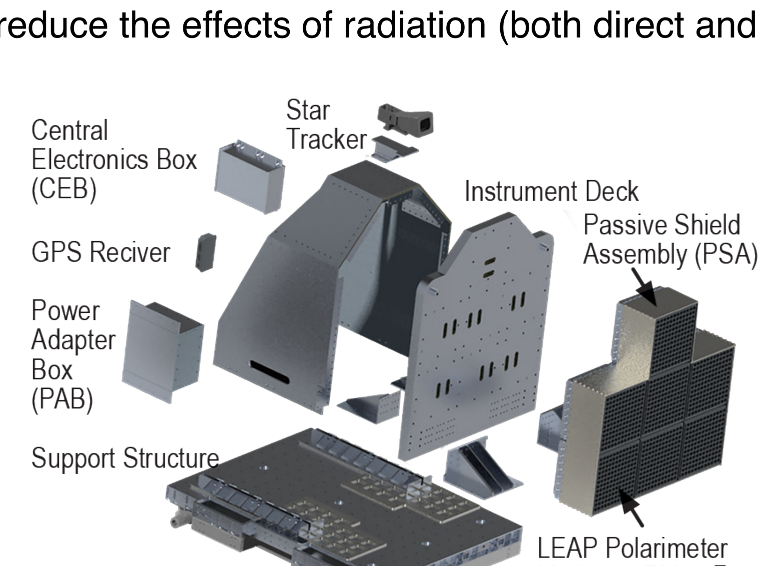
- SO Model - Synchrotron emission model with ordered magnetic fields;
- SR Model - Synchrotron emission model with random magnetic fields, requiring narrow range of observer viewing angles;
- CD Model - Compton Drag (inverse Compton) emission model with random magnetic fields, requiring narrow range of observer viewing angles.

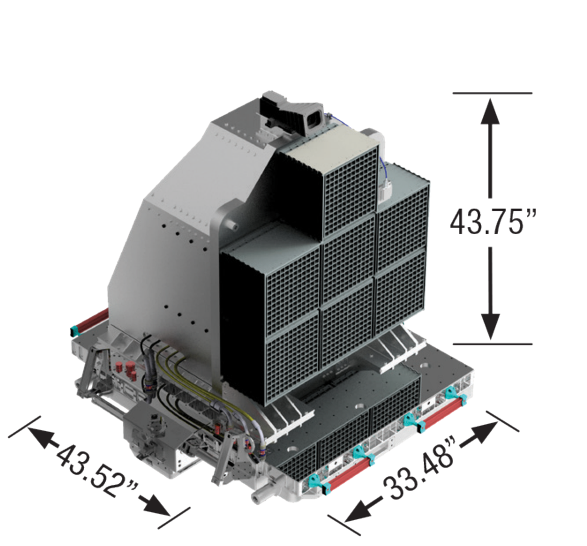


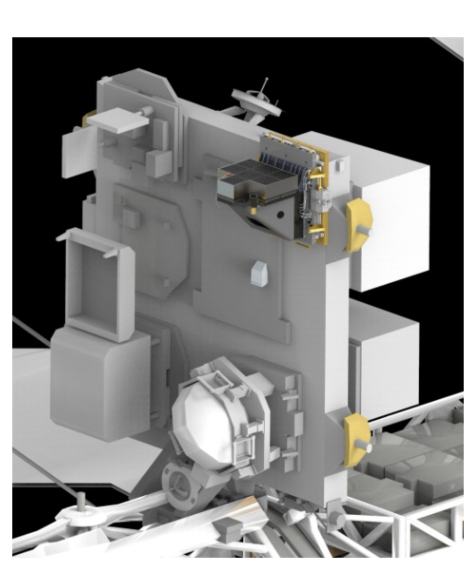
The number of GRBs with measurable polarization vs. the number of GRBs observed with MDP < 30%.

ISS Accommodation

In principle, LEAP can be accommodated by any of the external attachment sites on ISS. Mission requirements, in particular the need for a relatively unobstructed view towards the zenith, and availability, define three preferred site options (ELC3/3, ELC2/7, and Columbus-SOZ). The baseline is a site on the ExPRESS Logistics Carrier (ELC) 3. Final site selection will be determined during Phase B. Passive shielding is used to further reduce the effects of radiation (both direct and scattered) from ISS components.





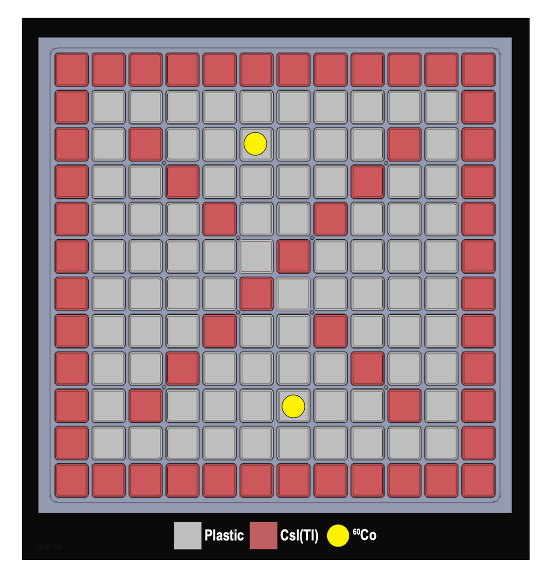


LEAP at ELC3

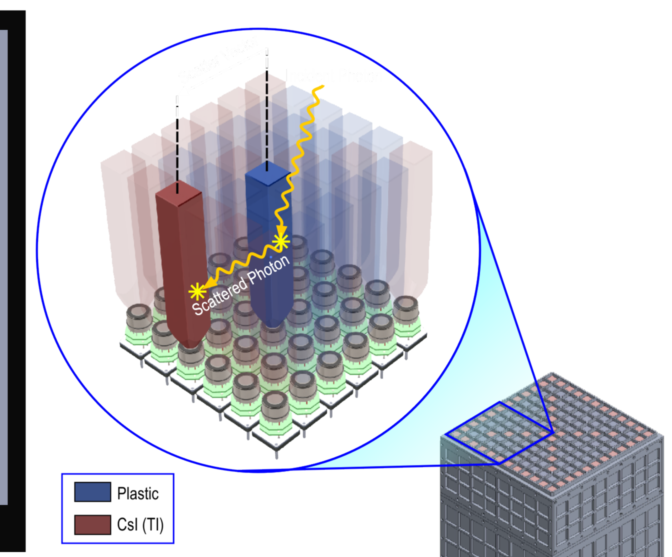
The Central Electronics Box (CEB) includes the Central Data Processing Unit (CDPU) and provides the electrical interfaces for each LPM and the data/command interfaces for the ISS. The Power Adapter Box (PAB) coverts the 120 V ISS power to the 28 V power used by the CEB. The ISS telemetry accommodates the large data volume of LEAP's event-based data stream, and permits rapid dissemination of GRB data (location and time histories) to ground-based observers.

Instrumentation

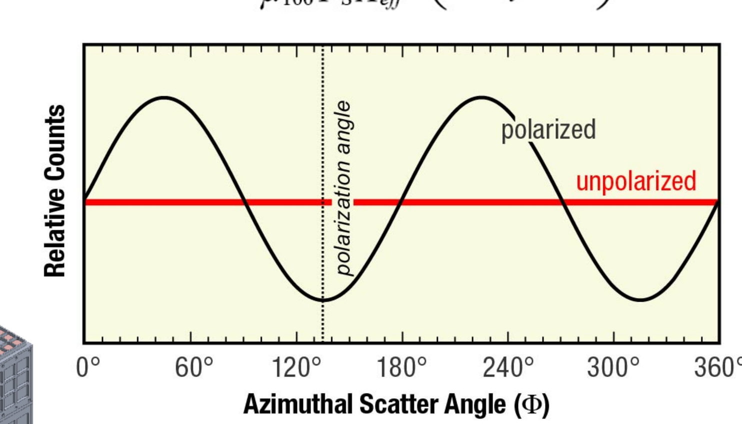
LEAP science objectives are met with a single instrument – a wide FOV non-imaging Compton polarimeter that measures GRB polarization over the energy range from 50 keV to 1 MeV and performs GRB spectroscopy from 20 keV up to 6 MeV. The instrument is based on well-established, flight-proven scintillator-photomultiplier tube (PMT) technologies. LEAP self-sufficiently provides the source localization required for analysis of the polarization data using the relative response of more than 400 detector elements. The LEAP measurement principle relies on detecting photons scattering between two detector elements. Since Compton scattered photons tend to scatter at right angle with respect to the incident polarization vector, the distribution of azimuthal scattering angles carries the signature of the source polarization.



Detector Element Geometry

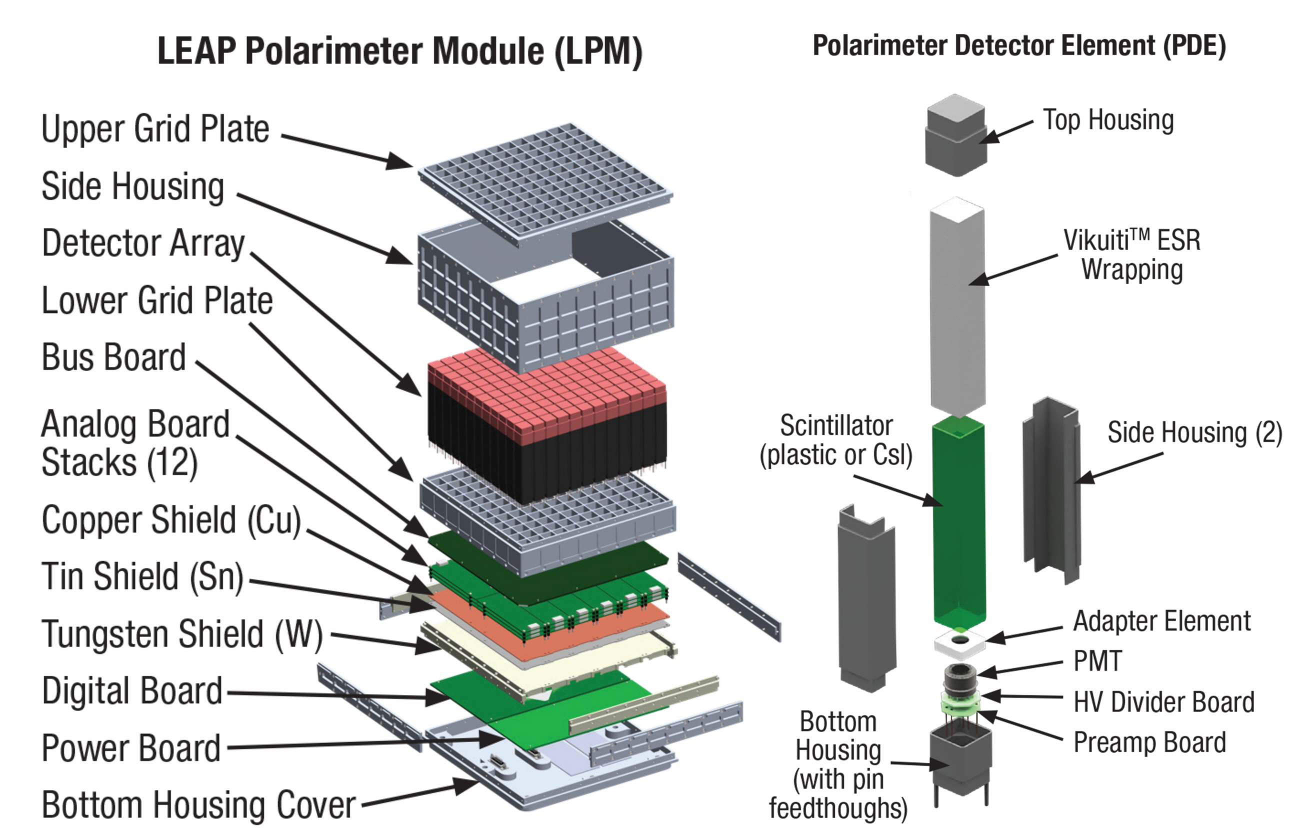


$$MDP = \frac{4.29}{\mu_{100} F_S A_{eff}} \left(\frac{F_S A_{eff} + R_B}{t} \right)^{1/2}$$

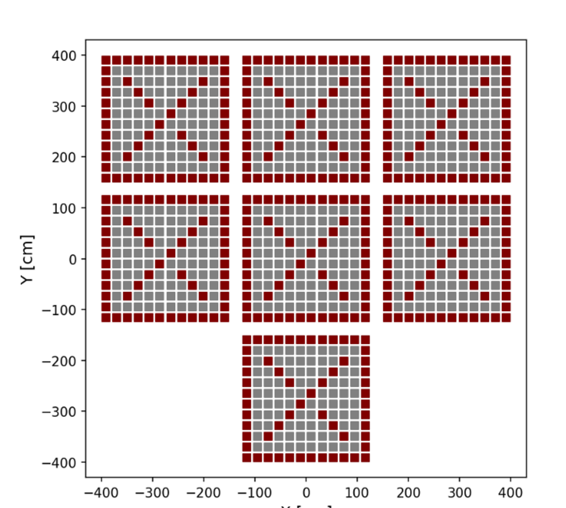


Measurement Principle

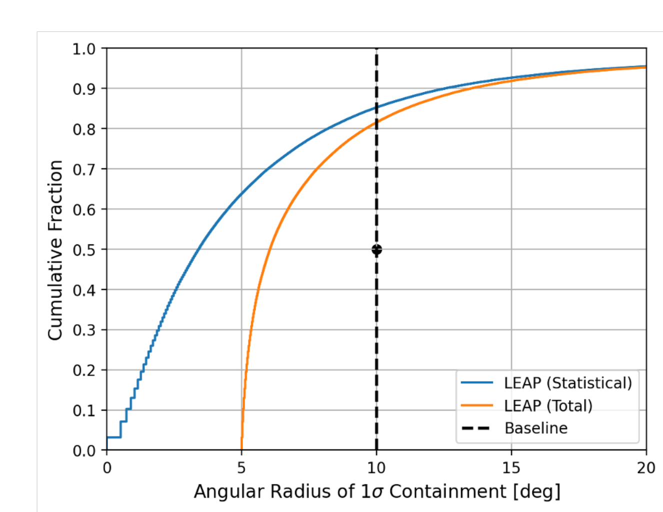
The full instrument assembly consists of 7 independent LEAP Polarimeter Modules (LPMs) and associated electronics. Each module is a 12 x 12 array of 144 independent, optically-isolated plastic and CsI(Tl) scintillator elements, arranged in a pattern that optimizes the polarization sensitivity. Each module also houses a tagged ^{60}Co source for in-flight calibration.



GRB localization utilizes singles events from all 406 CsI(Tl) detectors, whose relative response provides a unique source location. These detectors are shown below as colored elements. With a conservative systematic uncertainty estimate of 5°, roughly 80% of all GRBs will be contained to with a 1σ error radius of 10°. This is somewhat better than is currently achieved by Fermi-GBM. Utilizing the existing ISS communications infrastructure, these locations will be rapidly disseminated to the community through the GCN.



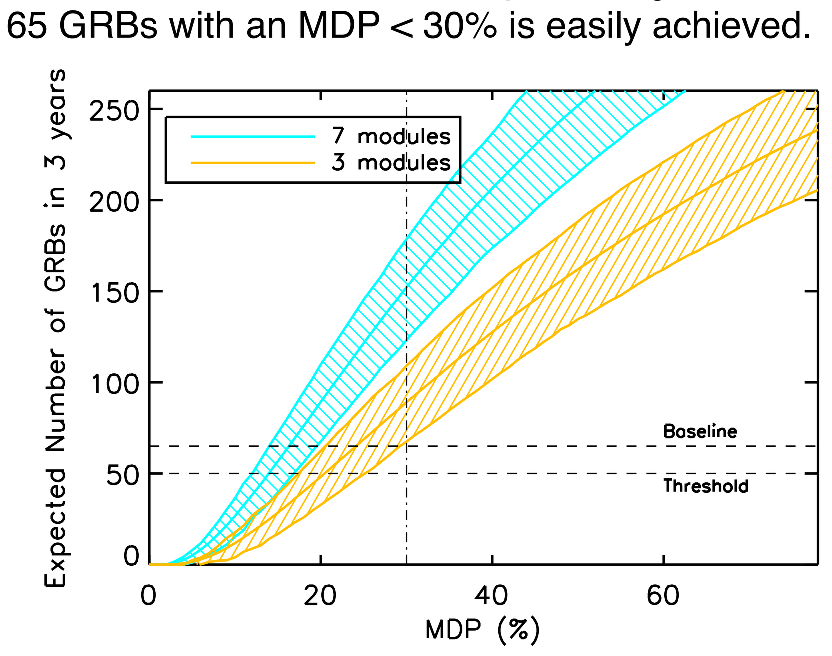
Detector Layout of 7 Modules

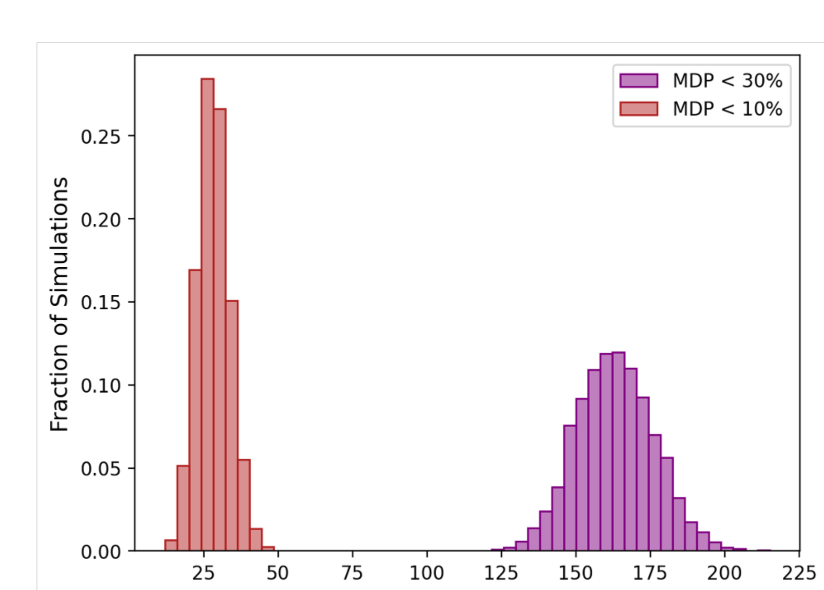


GRB Localization

Instrument Performance

Detailed simulations have been used to define the instrument characteristics. The left-hand plot shows the expected number of GRB events as a function of MDP. The right-hand plot shows the expected number of events measured less than or equal to a given MDP value during the 32 month mission. The baseline goal of 65 GRBs with an MDP < 30% is easily achieved.





LEAP was not selected to continue with its development. "Neither of the Mission of Opportunity investigations were continued for programmatic reasons."