LEAP - A LargE Area gamma-ray burst Polarimeter for the International Space Station

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Polarization studies of prompt GRB emission offer a unique opportunity to learn more about both the energy dissipation process in the inner jet and the mechanisms responsible for the emission. Although some evidence of polarized gamma-ray emission has been accumulated in recent years, the limited significance and conflicting nature of these results does not yet paint a consistent picture of GRB polarization. A more sensitive and systematic study of GRBs, providing definitive measurements for a large sample of events, will address several important questions. The LargE Area burst Polarimeter (LEAP) is a mission that has been proposed for deployment on the International Space Station (ISS) in 2025. It is a Compton scattering polarimeter, employing a large array of discrete scintillation detector elements to measure the polarization of the incident flux. The detection principle of the LEAP instrument utilizes both plastic and CsI scintillation detectors to identify Compton scatter events. The azimuthal distribution of Compton scattered photons provides a measure of the source polarization. As a wide-FoV, non-imaging instrument, it is well-suited for measuring the polarization of transient events, such as GRBs and solar flares. With a total geometric scintillator area of 3000 cm² and an effective area for polarization (double scatter) of ~1000 cm², LEAP will provide high quality polarization measurements in the energy range of 50-500 keV. Data from individual detector elements will also provide spectral data from 20 keV up to 5 MeV. Designed for a lifetime of 2.5 years, the LEAP mission will provide polarization results on more than 100 GRBs.

Mission

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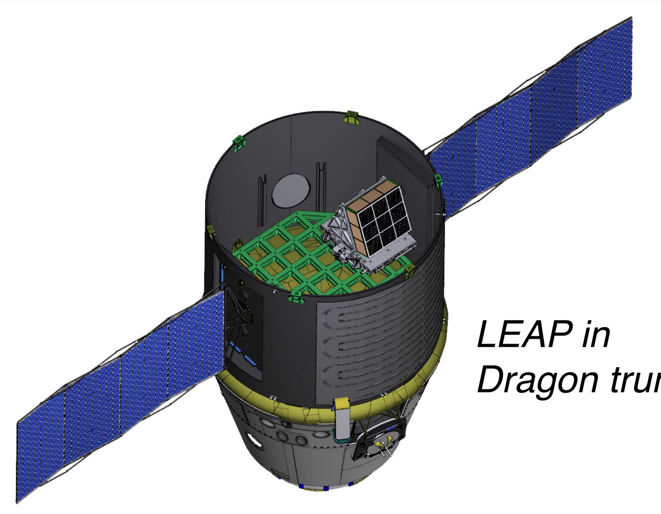
Project Scientist : Colleen Wilson-Hodge (NASA-MSFC)

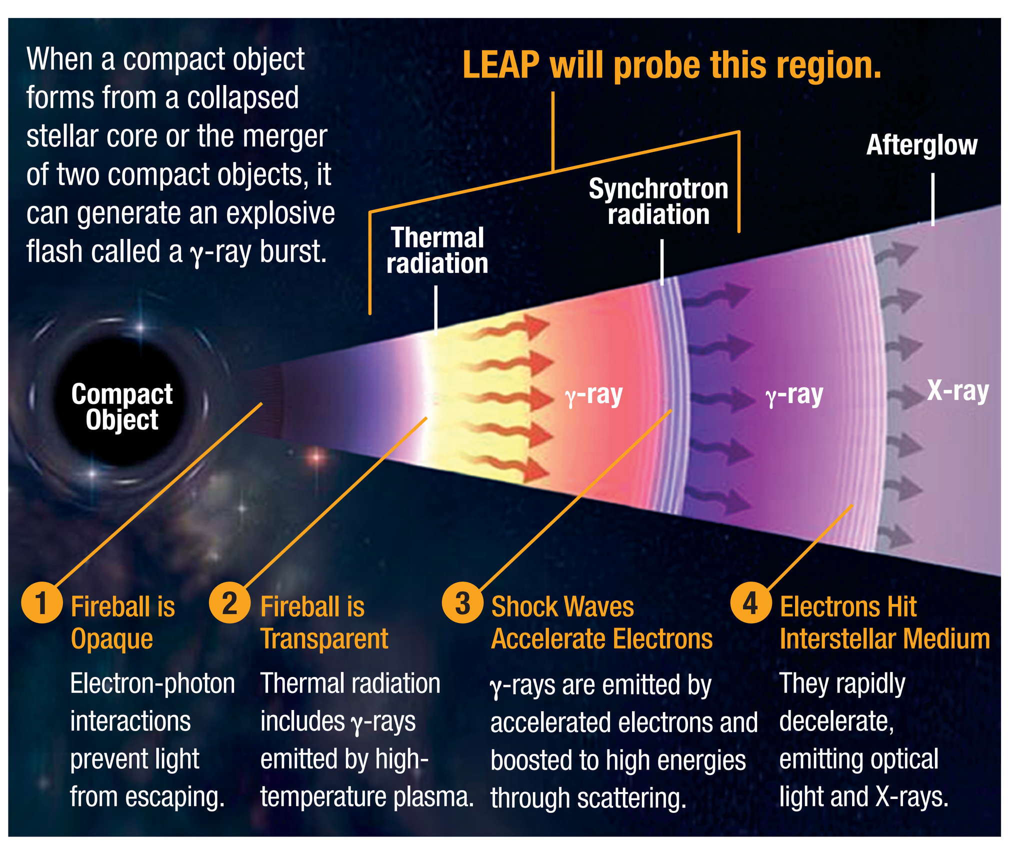
- LEAP is a low-cost, low-risk mission designed to provide polarization measurements of the prompt emission from GRBs.
- Proposed as a NASA Astrophysics Mission of Opportunity.
- Launch readiness date is March 2025.
- The integrated payload will be launched on a Dragon spacecraft (or equivalent) for delivery to and integration onto the ISS.
- The total mission duration necessary to achieve the proposed science objectives is 2.5 years.

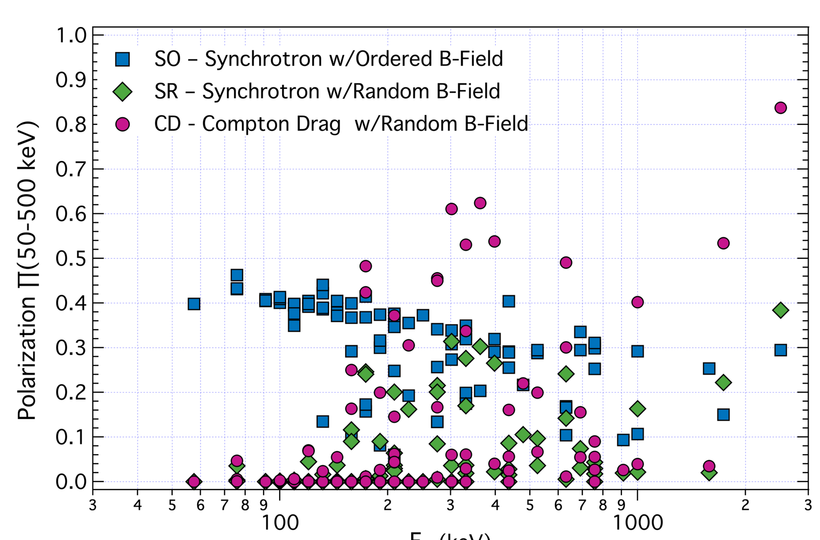


LEAP in Dragon trunk

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).

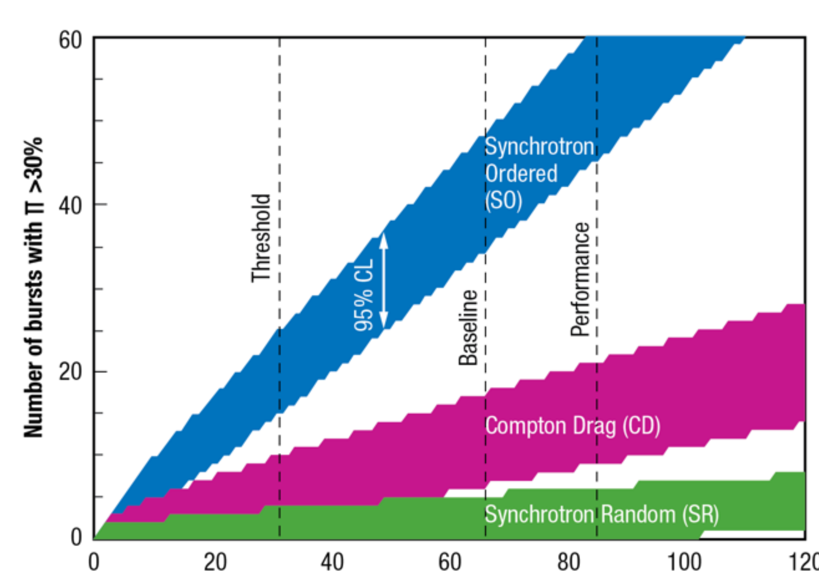




Predicted polarization as a function of E_p (Toma et al. 2009)

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

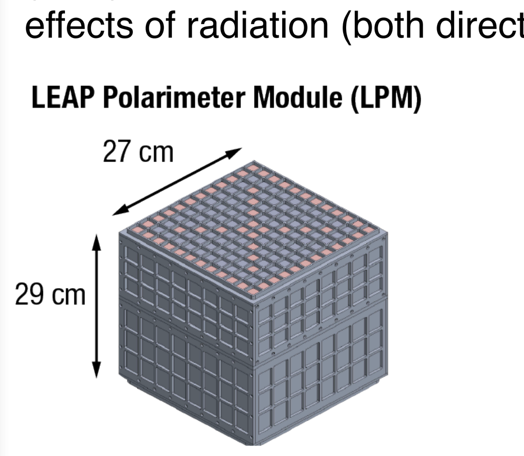
- SO Model - Synchrotron emission model with ordered magnetic fields;
- SR Model - Synchrotron emission model with random magnetic fields, requiring narrow range of observer viewing angles;
- CD Model - Compton Drag (inverse Compton) emission model with random magnetic fields, requiring narrow range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



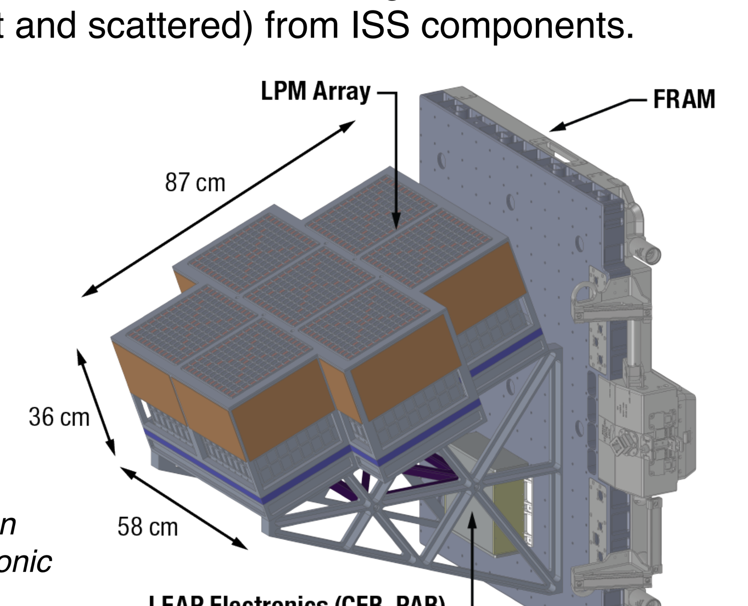
The number of GRBs with measurable polarization vs. the number of GRBs observed with MDP < 30%.

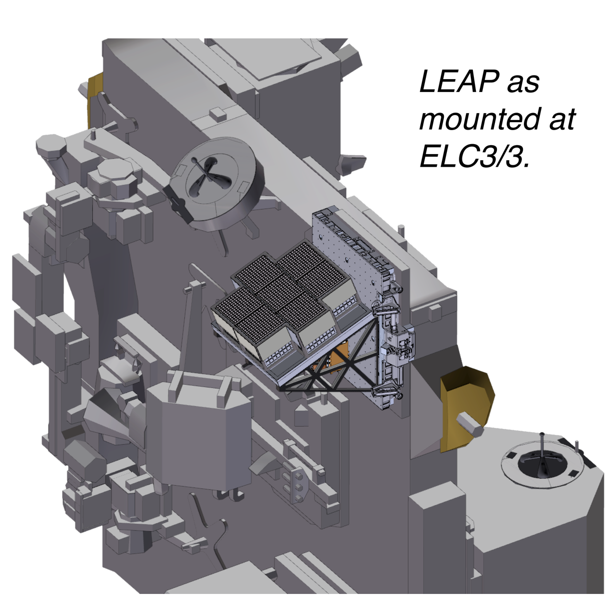
ISS Accommodation

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 A. Passive shielding is used to further reduce the effects of radiation (both direct and scattered) from ISS components.



The LEAP payload consists of seven polarimeter modules and two electronic boxes (the CEB and the PAB).



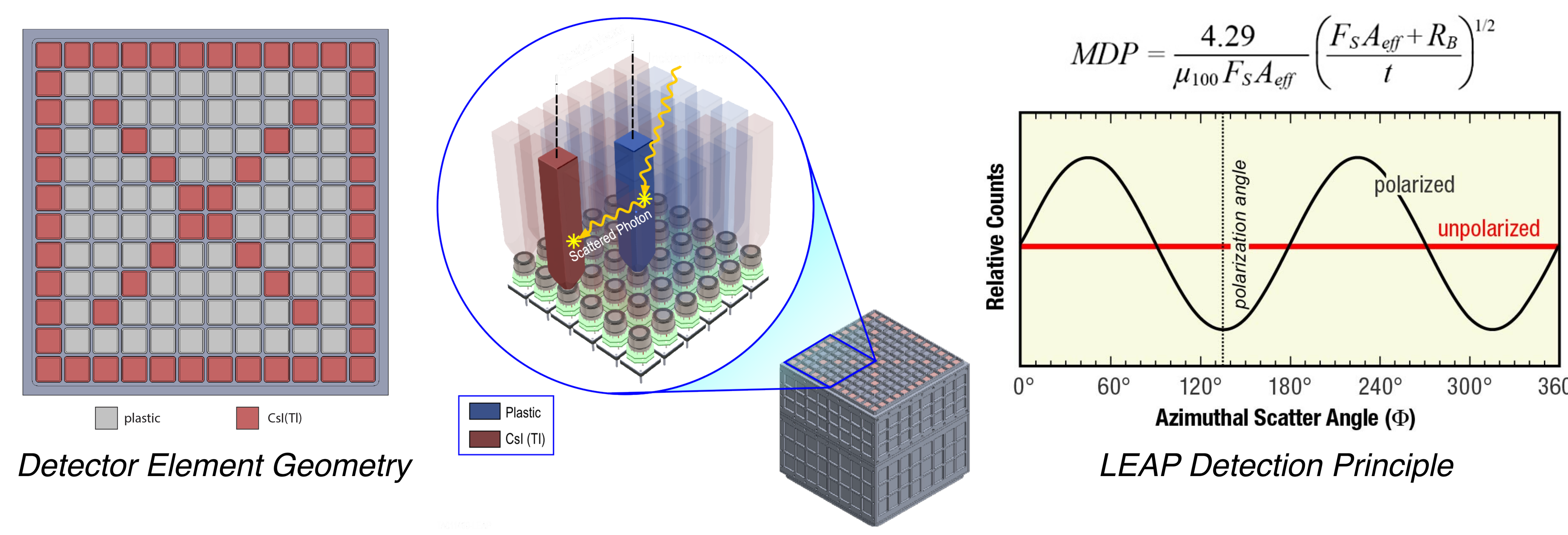


LEAP as mounted at ELC3/3.

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

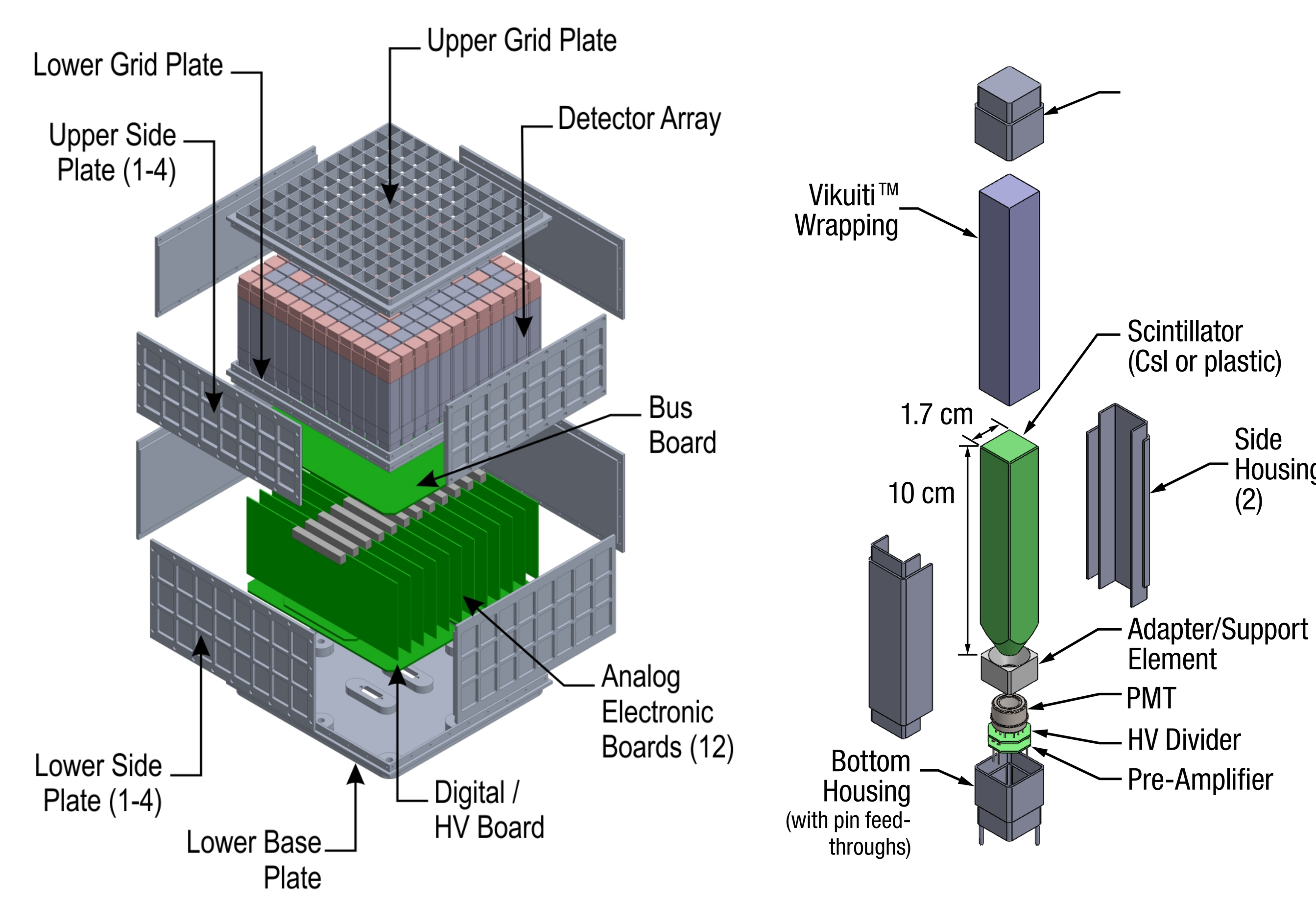
LEAP science objectives are met with a single instrument – a wide FOV non-imaging Compton polarimeter that measures GRB polarization over the energy range from 50-500 keV and performs GRB spectroscopy from ~10 keV up to 5 MeV. The instrument is based entirely on well-established, flight-proven scintillator-photomultiplier tube (PMT) technologies. LEAP self-sufficiently provides the source localization required for analysis of the polarization data using the relative shadowing by adjacent detector elements and module structures of carefully chosen groups of detectors. The LEAP polarization measurement principle relies on detecting photons scattering between two detector elements. Shown here is the arrangement of plastic and CsI(Tl) scintillator elements in a quadrant of an LPM, along with a typical scatter event. 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.



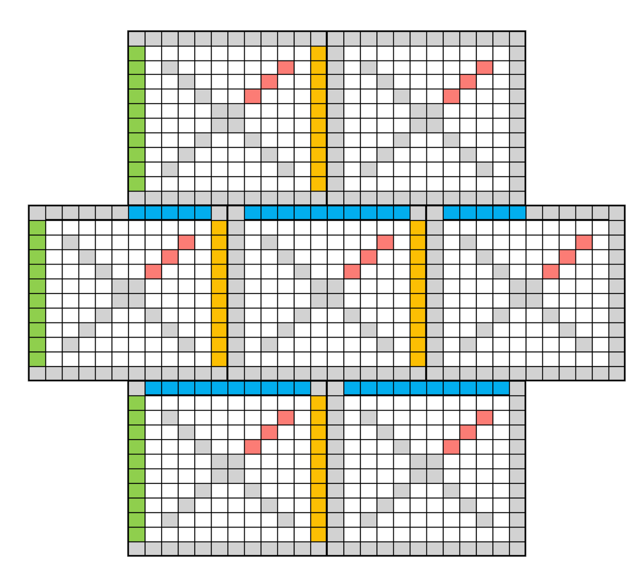
$$MDP = \frac{4.29}{\mu_{100} F_S A_{eff}} \left(\frac{F_S A_{eff} + R_B}{t} \right)^{1/2}$$

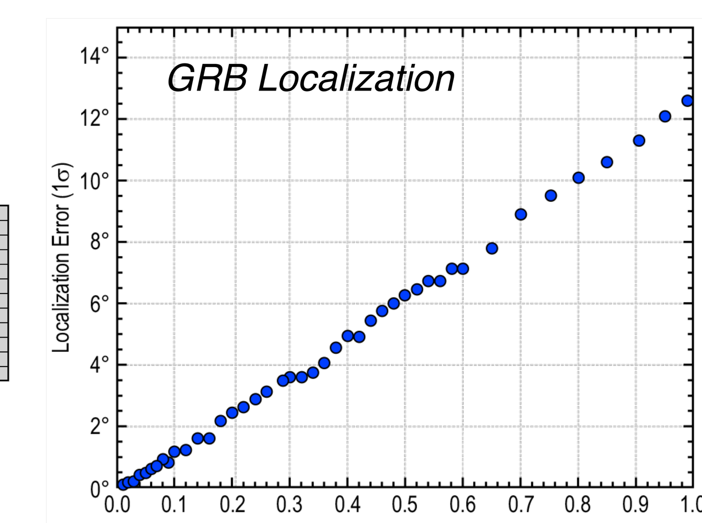
Detector Element Geometry *LEAP Detection Principle*

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.



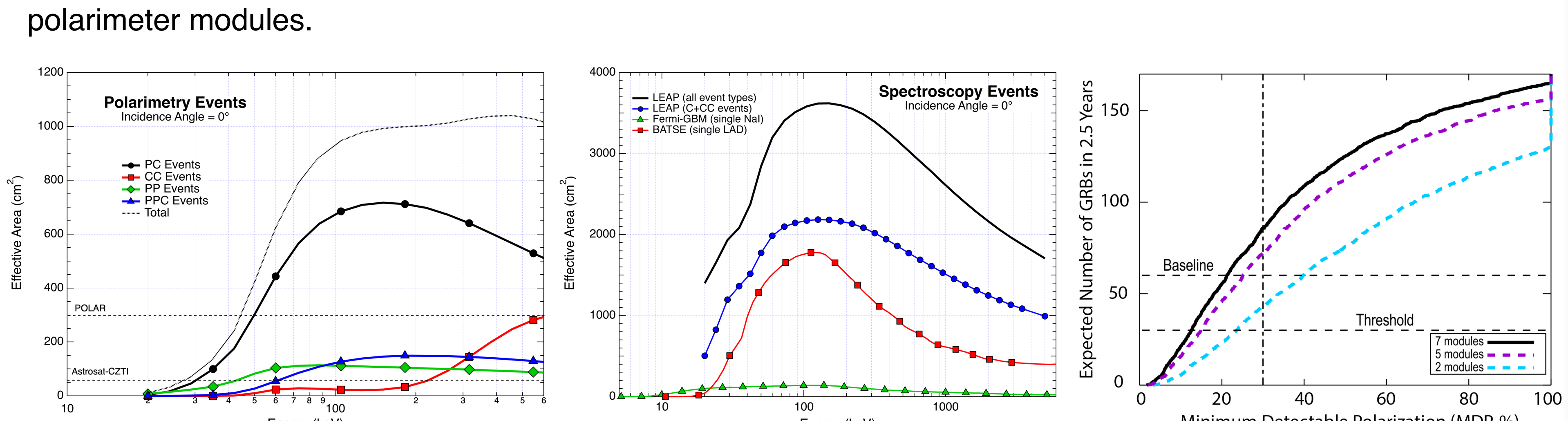
GRB localization utilizes singles events from 32 groups of CsI(Tl) detectors (strategically chosen for having similar sky exposure), whose relative response provides a unique source location. These Virtual Detector Groups (VDGs), some of which are shown here as colored element groups, are selected from across all seven modules. Simulations show a well-defined correlation between the MDP of a burst and the statistical localization uncertainty





Instrument Performance

Detailed simulations have been used to define the instrument characteristics. The effective area (at 0° incidence) for polarimetry (left) and spectroscopy (middle) are significantly better than previous instruments. In both cases, the event types are defined as involving plastic (P) and CsI (C) detector elements. The right-hand plot shows the expected number of events measured less than or equal to a given MDP value during the 2.5 year mission. The baseline goal of 65 GRBs with an MDP < 30% is easily achieved, even with the loss of two polarimeter modules.



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