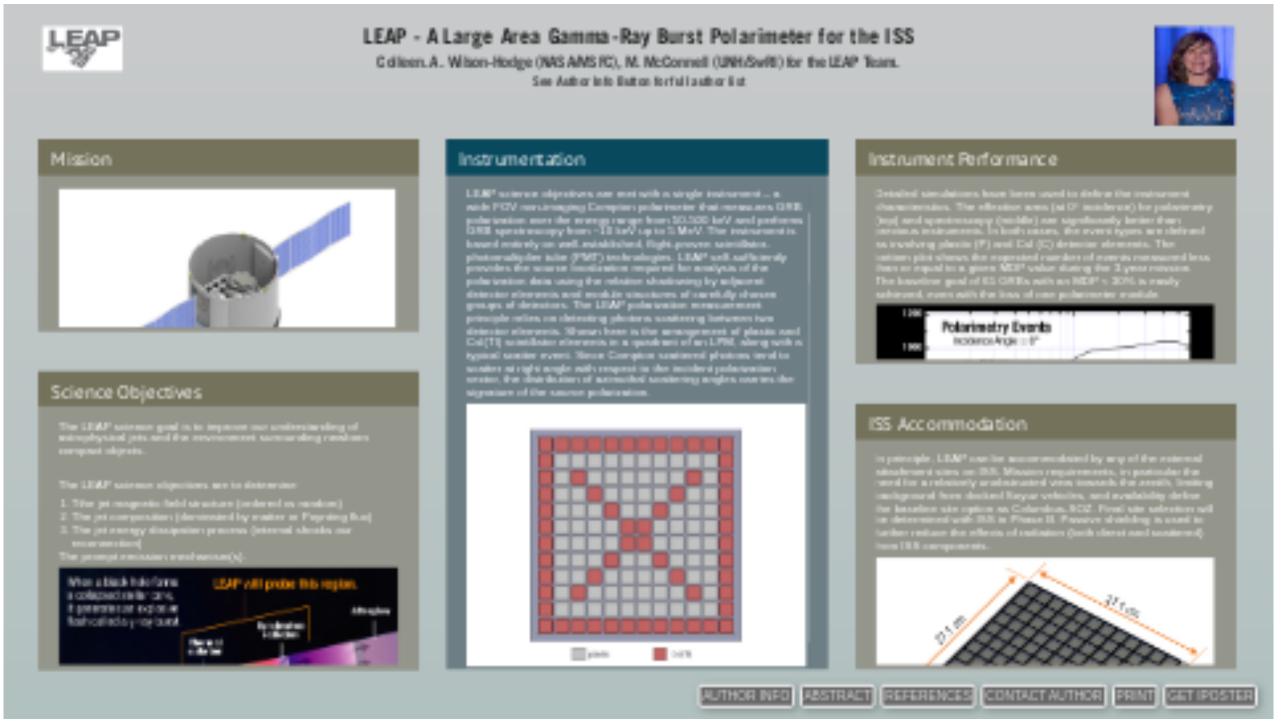
LEAP - A Large Area Gamma-Ray Burst Polarimeter for the ISS



Colleen. A. Wilson-Hodge (NASA/MSFC), M. McConnell (UNH/SwRI) for the LEAP Team.

See Author Info Button for full author list

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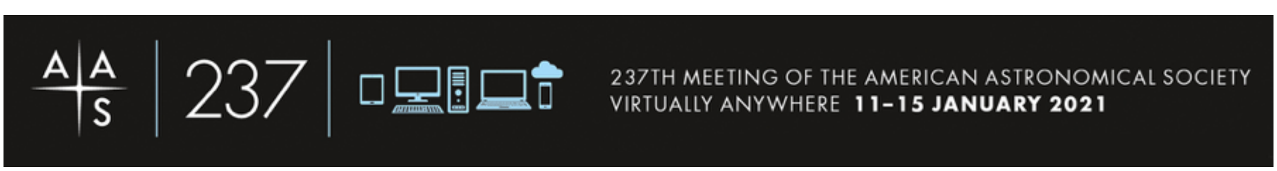

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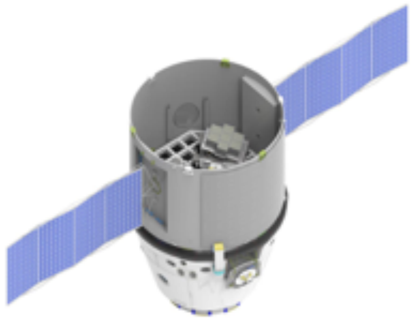

LEAP is shown in the Dragon trunk.

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Deputy Principal Investigator: Jessica Gaskin (NASA/MSFC)

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

- LEAP is a low-cost, low risk mission of opportunity designed to provide polarization measurements of the prompt emission from gamma-ray bursts (GRBs)
- Launch Readiness Date is September 2025
- The integrated payload will be launched on a Dragon (or equivalent) spacecraft for delivery to and integration onto the ISS
- The total mission duration necessary to achieve the proposed science objectives is 3 years.

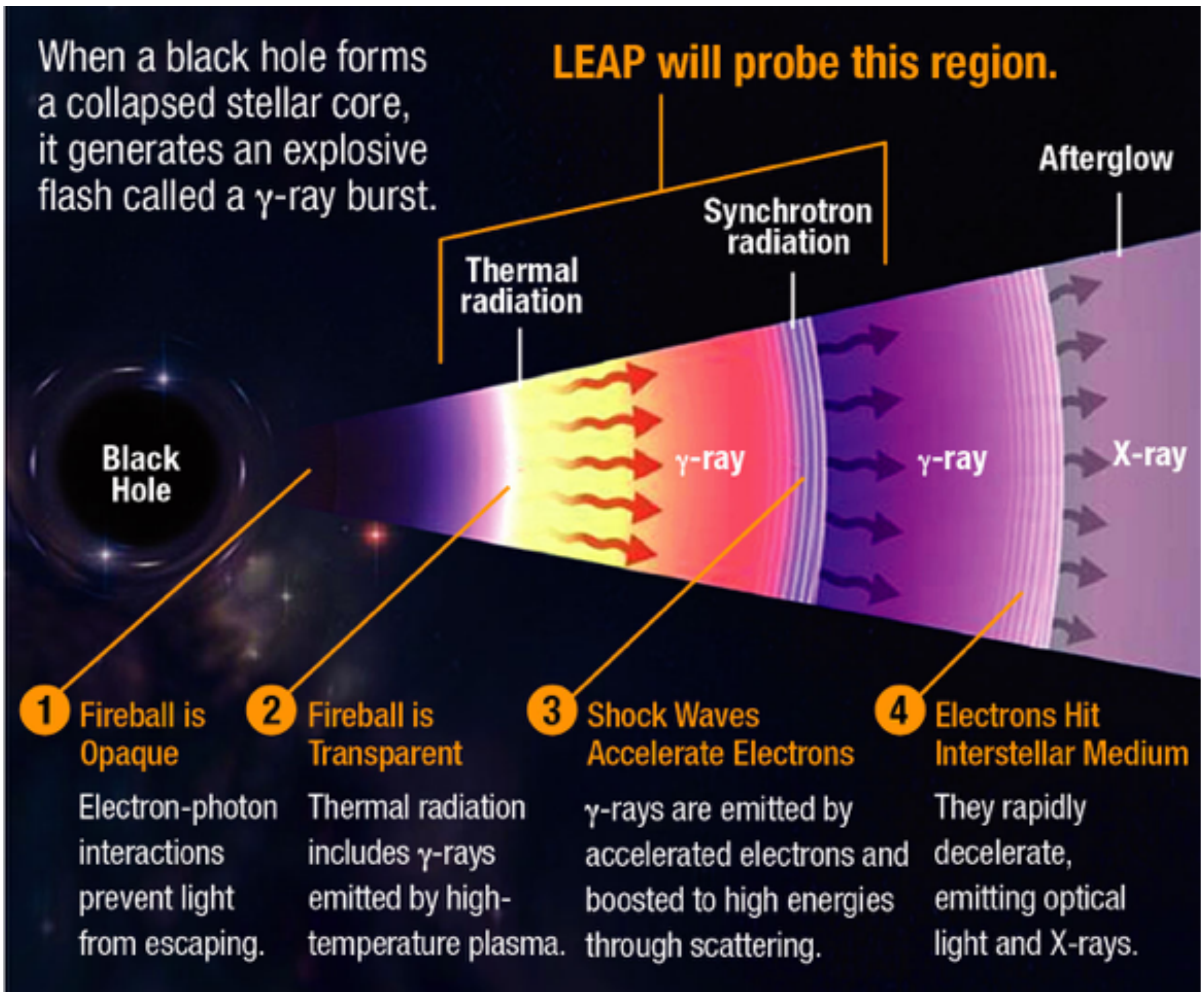
SCIENCE OBJECTIVES

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. Tthe 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)

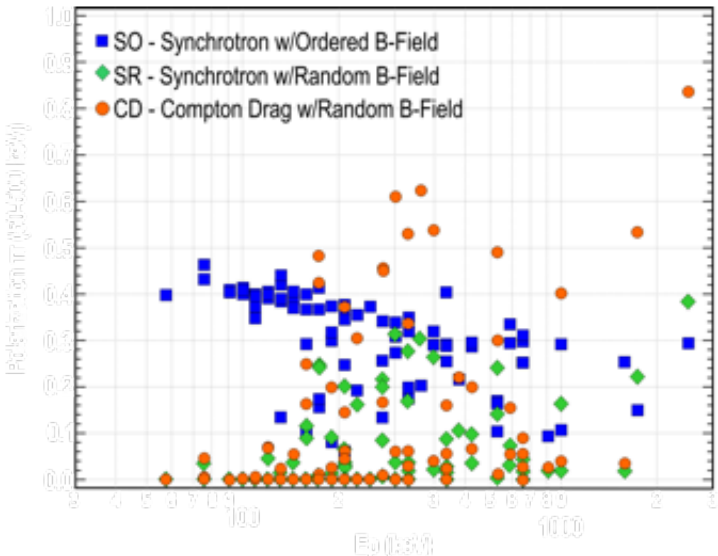
The prompt emission mechanism(s).



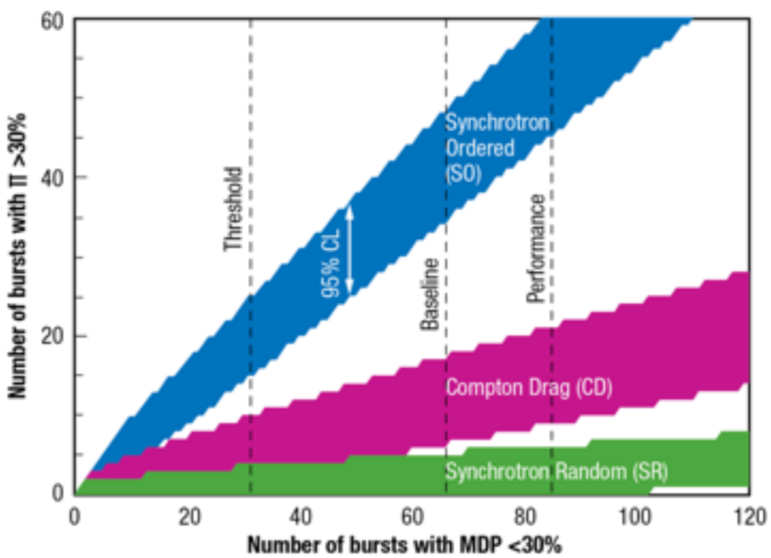
LEAP is designed to distinguish amongst three basic model classes for GRBs (Toma et al 2009)

- Synchrotron Ordered (SO) model - Synchrotron emission with ordered magnetic fields
- Synchrotron Random (SR) model - Synchrotron emission with random magnetic fields

- Compton Drag (CD) - Inverse Compton emission with random magnetic fields, requiring a narrow range of observing and viewing angles.



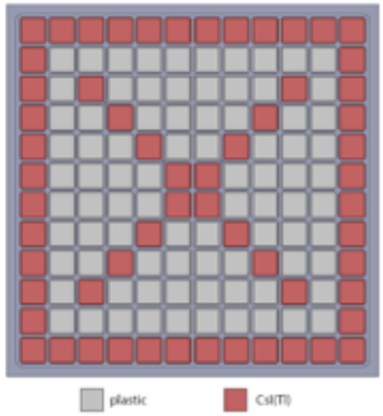
The three model classes (SO, CD, and SR) show distinctive differences when the polarization degree (Π) is plotted vs E_P). Prompt emission spectra of GRBs are often described by an empirical model called a Band function (Band et al. 1993), consisting of a broken power-law with a smooth break at a characteristic energy (E_P), commonly referred to as E-peak.



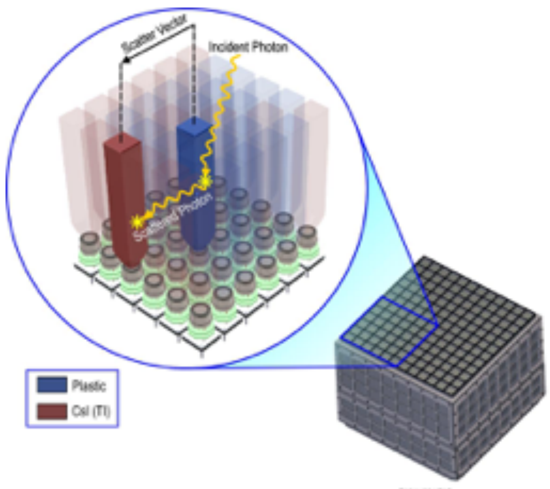
The three model classes can be differentiated using the number of GRBs with measureable polarization with Π>30%. LEAP's sensitivity to polarization is defined by the Minimum Detectable Polarization (MDP).

INSTRUMENTATION

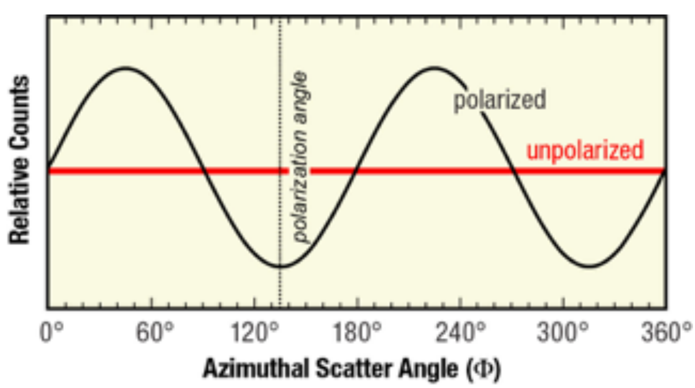
LEAP science objectives are met with a single instrument – a wide FOV non-imaging Compton polarimeter that measures GRB polarization over the energy range from 50-500 keV and performs GRB spectroscopy from ~10 keV up to 5 MeV. The instrument is based entirely on well-established, flight-proven scintillator-photomultiplier 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.



Each LEAP module is a 12 x 12 array of 144 plastic and CsI elements arranged in a pattern that optimizes the polarization sensitivity.



The LEAP polarization measurement principle relies on detecting photons scattering between two detector elements. Illustrated here is the arrangement of plastic and CsI(Tl) scintillator elements in a quadrant of an LPM, along with a typcial scatter event.



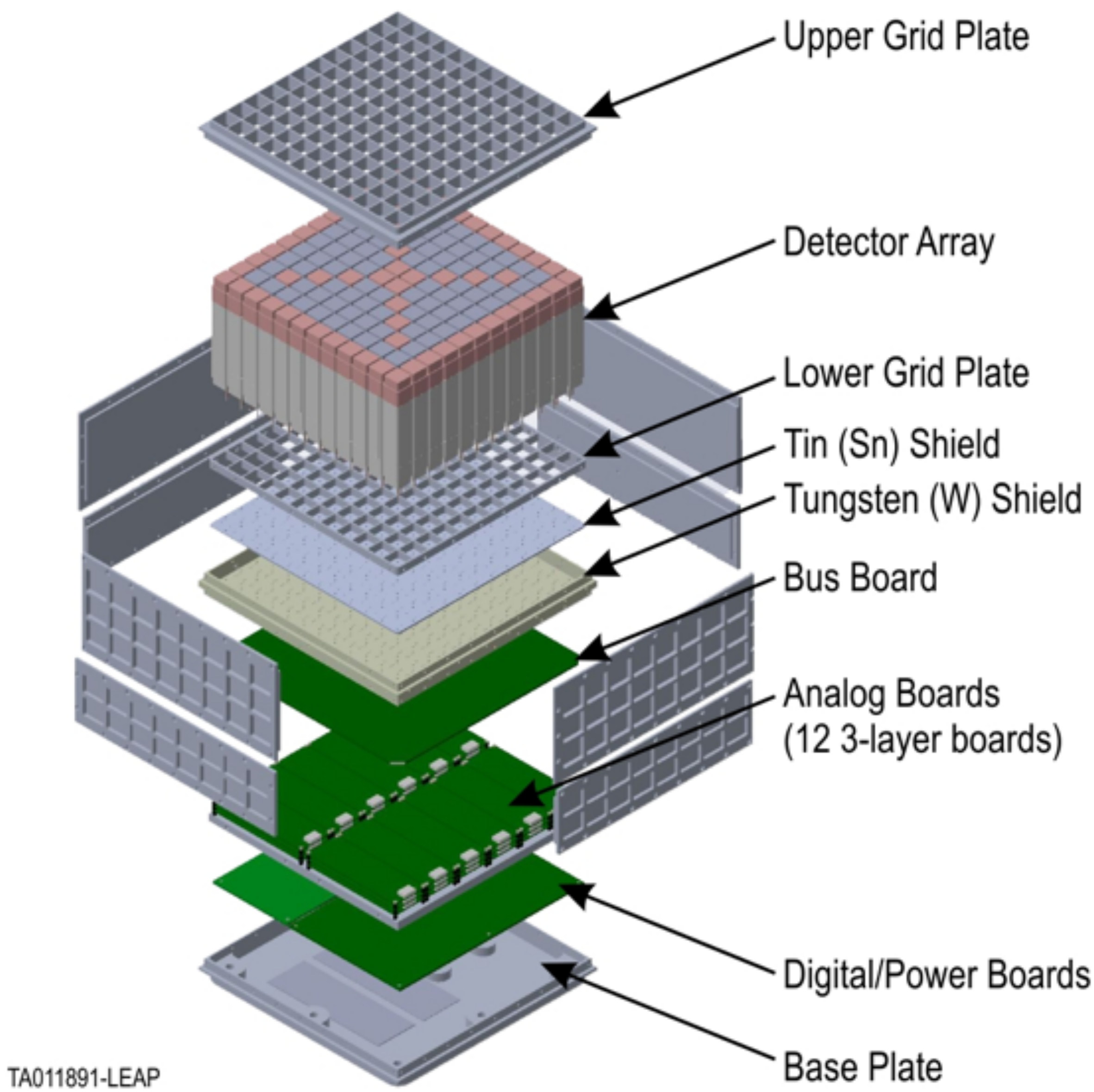
The distribution of photon azimuthal scattering angles carries the signature of source polarization.

The sensitivity of a polarimeter is defined by its minimum detectable polarization (MDP) given by (99% confidence):

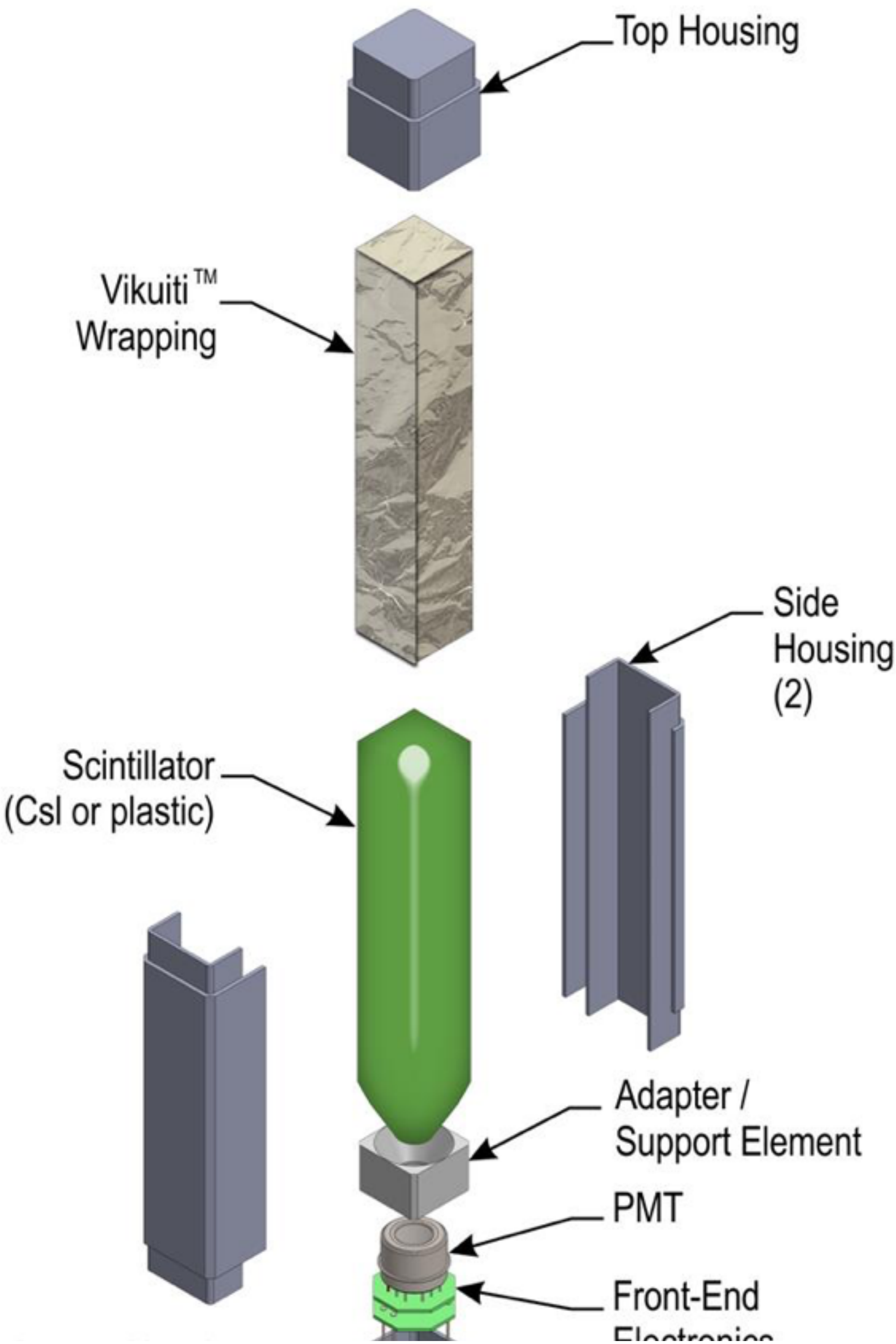
$$MDP = \frac{4.29}{\mu_{100} F_s A_{eff}} \left(\frac{F_s A_{eff} + R_B}{t}\right)^{1/2}$$

where F_S is the source flux in photons $cm^{-2}\ s^{-1}$, Aeff is the polarization effecive area (cm^2), R_B is the total background rate (cts s^{-1}), and t is the observing time (s). The parameter μ_{100} is a figure-of-merit, referred to as the polarization modulation factor, that characterizes the polarization response.

The full LEAP instrument assembly consists of 7 independent LEAP Polarimeter Modules (LPMs) and associated electronics. Each module is a 12x12 array of 144 independent, optically-isolated plastic and CsI(Tl) scintillator elements, arranged in a pattern that optimizes the polarization sensitivity.

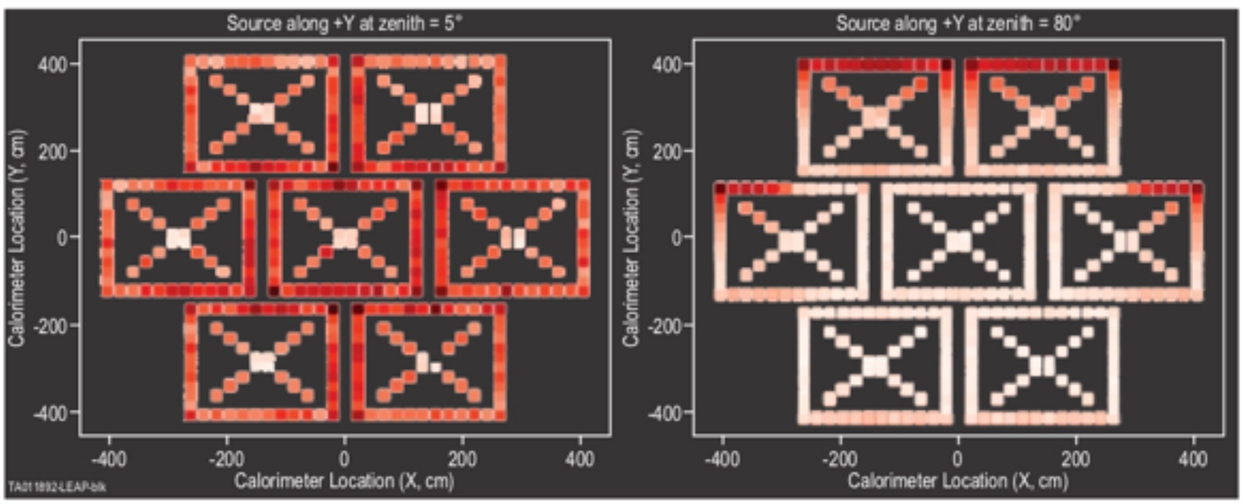


An exploded view of a single LEAP module


Top Housing
Vikuiti ™ Wrapping
Side Housing (2)
Scintillator (CsI or plastic)
Adapter / Support Element
PMT
Front-End

An exploded view of a single LEAP detector element.

GRB localization with LEAP will be comparable to GRB localizations with BATSE or GBM. LEAP on-board localization utilizes singles events from groups of CsI(Tl) detectors selected across all 7 modules (strategically chosen for having similar sky exposure), whose relative response provides a unique source location. Ground-based localizations with LEAP will use all 420 calorimeter detectors. Simulations show a well-defined correlation between the MDP of a burst and the statistical localization uncertainty.

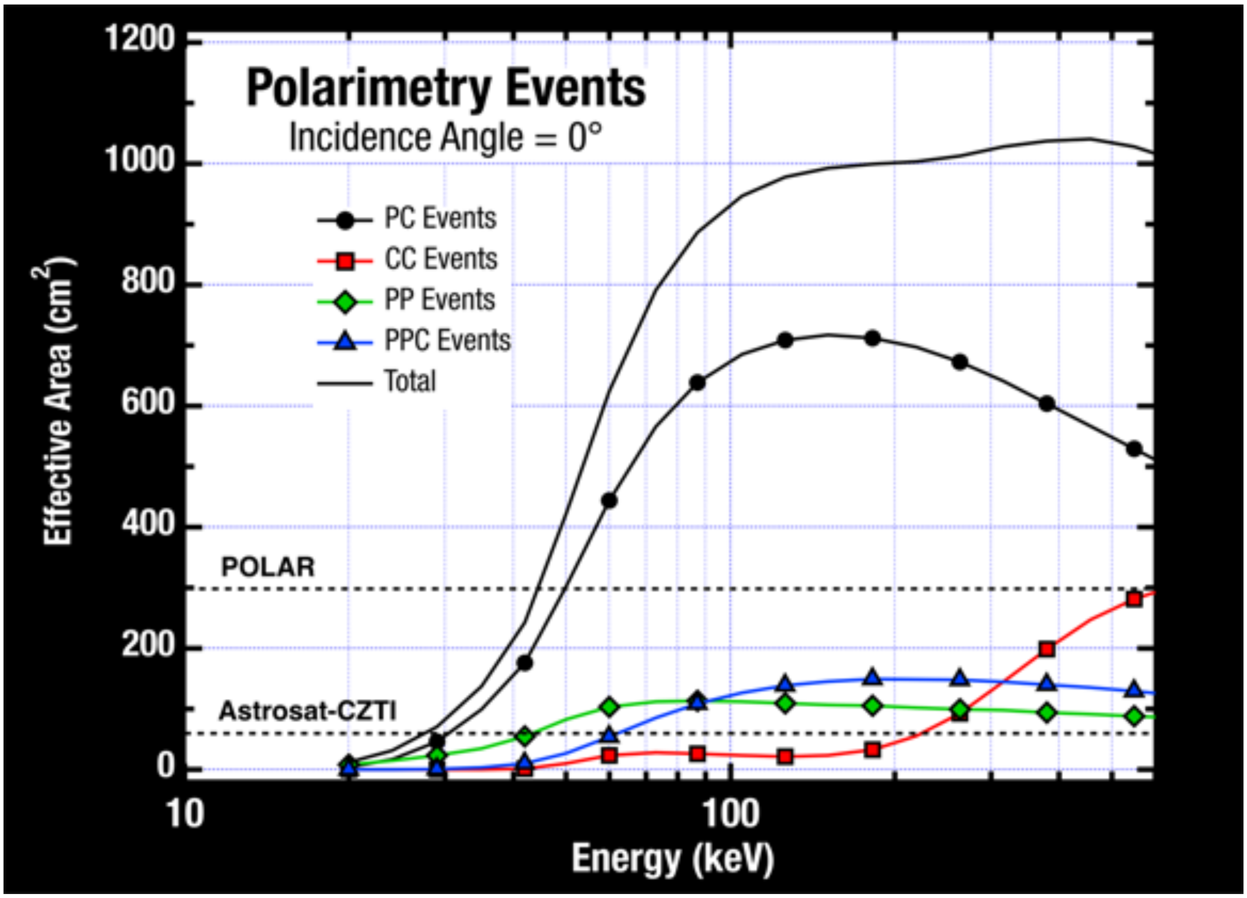


The LEAP localization process is based on the relative number of counts in all 420 CsI(Tl) calorimeter elements, as seen here for two different locations within the field of view.

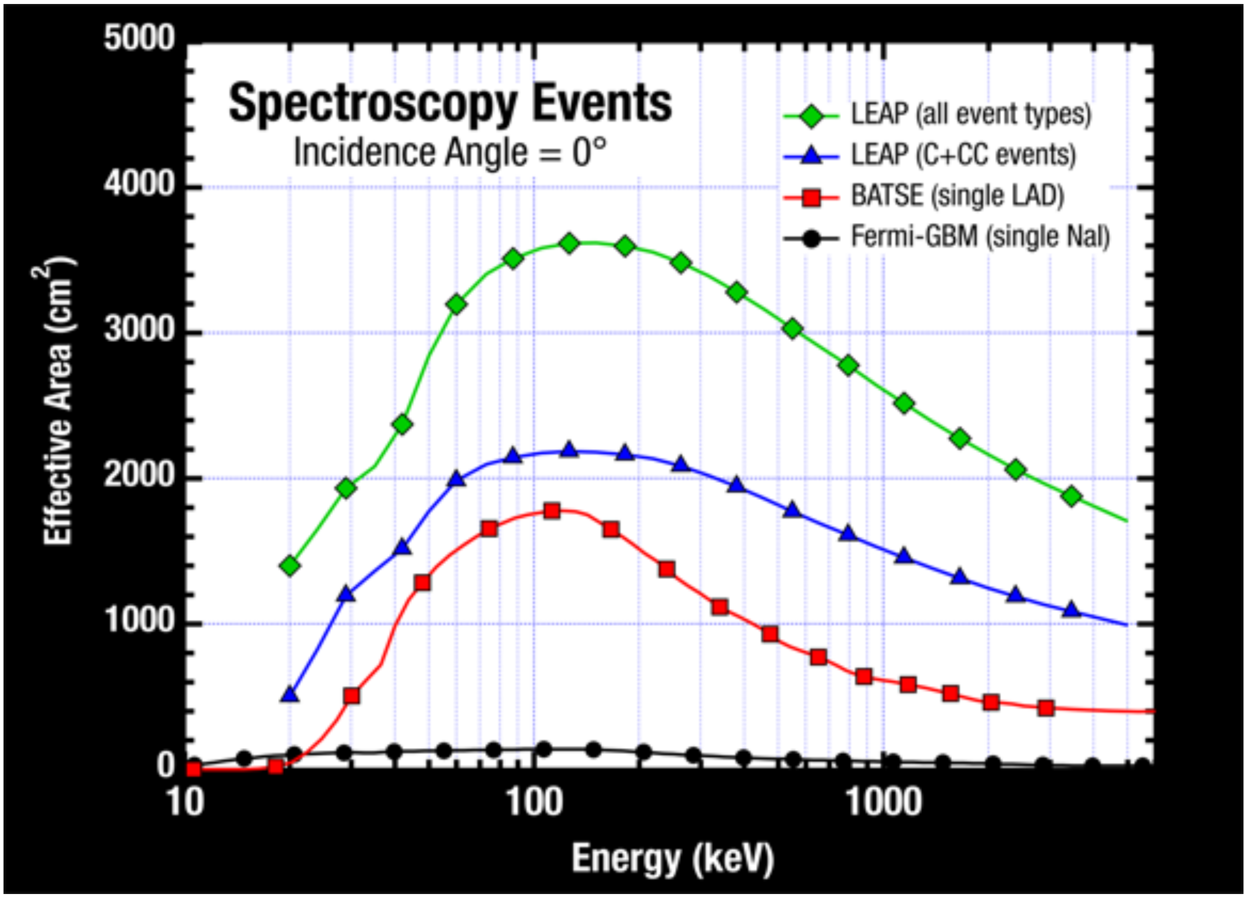
The LEAP statistical localization error is highly correlated with the MDP of a GRB, because both quantities depend strongly on the signal-to-noise for the GRB. The correlation varies with zenith angle.

INSTRUMENT PERFORMANCE

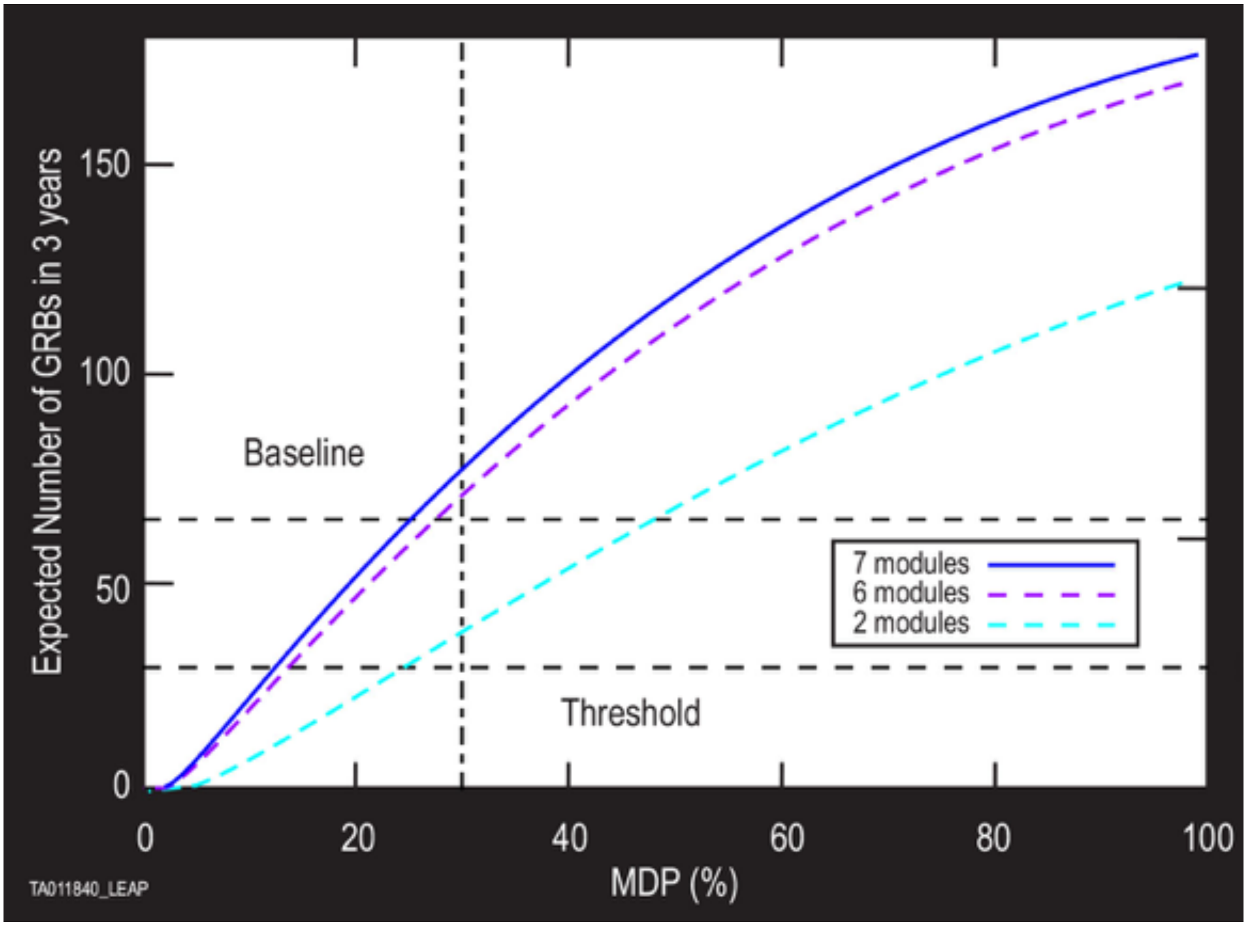
Detailed simulations have been used to define the instrument characteristics. The effective area (at 0° incidence) for polarimetry (top) and spectroscopy (middle) are significantly better than previous instruments. In both cases, the event types are defined as involving plastic (P) and CsI (C) detector elements. The bottom plot shows the expected number of events measured less than or equal to a given MDP value during the 3-year mission. The baseline goal of 65 GRBs with an MDP < 30% is easily achieved, even with the loss of one polarimeter module.



LEAP on-axis effective area for polarimetry events.



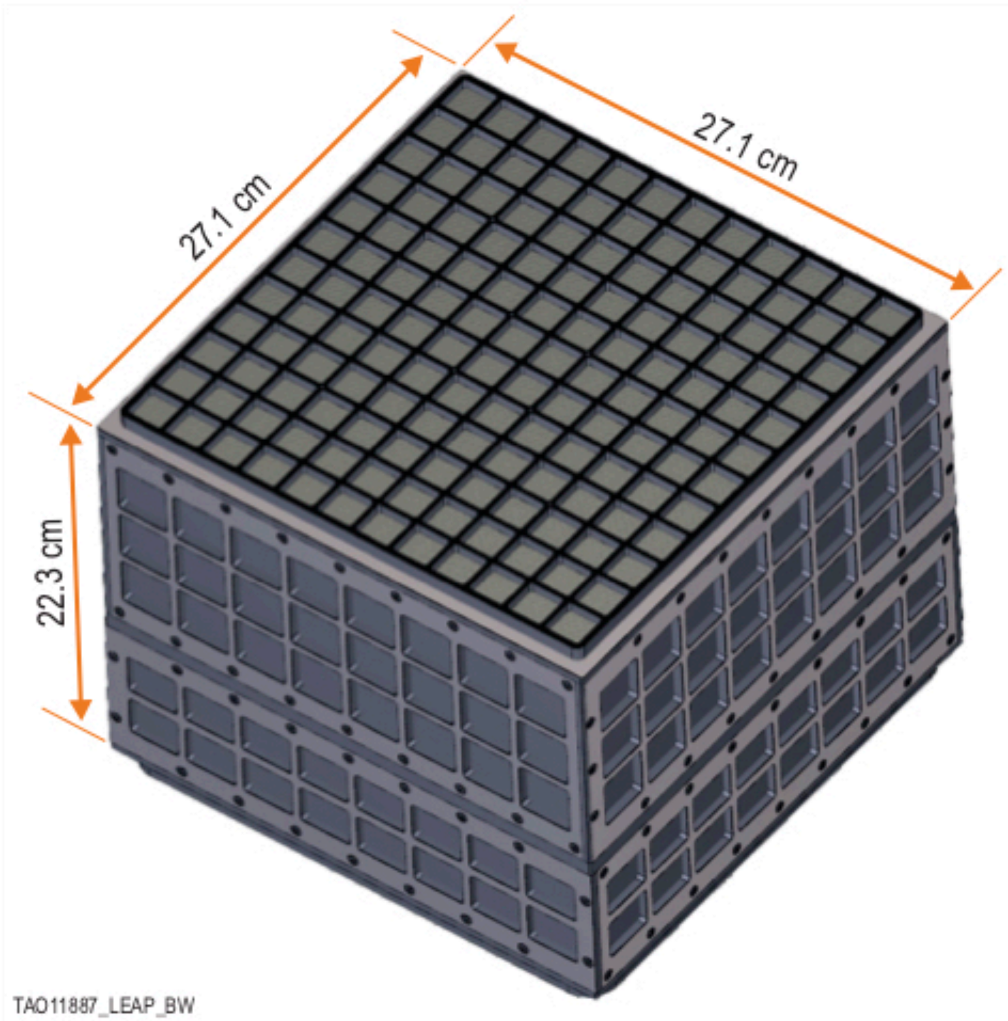
LEAP on-axis effective area for spectroscopy events. The spectrocopy effective areas for BATSE (single LAD) and Fermi GBM (single NaI) are shown for comparison.



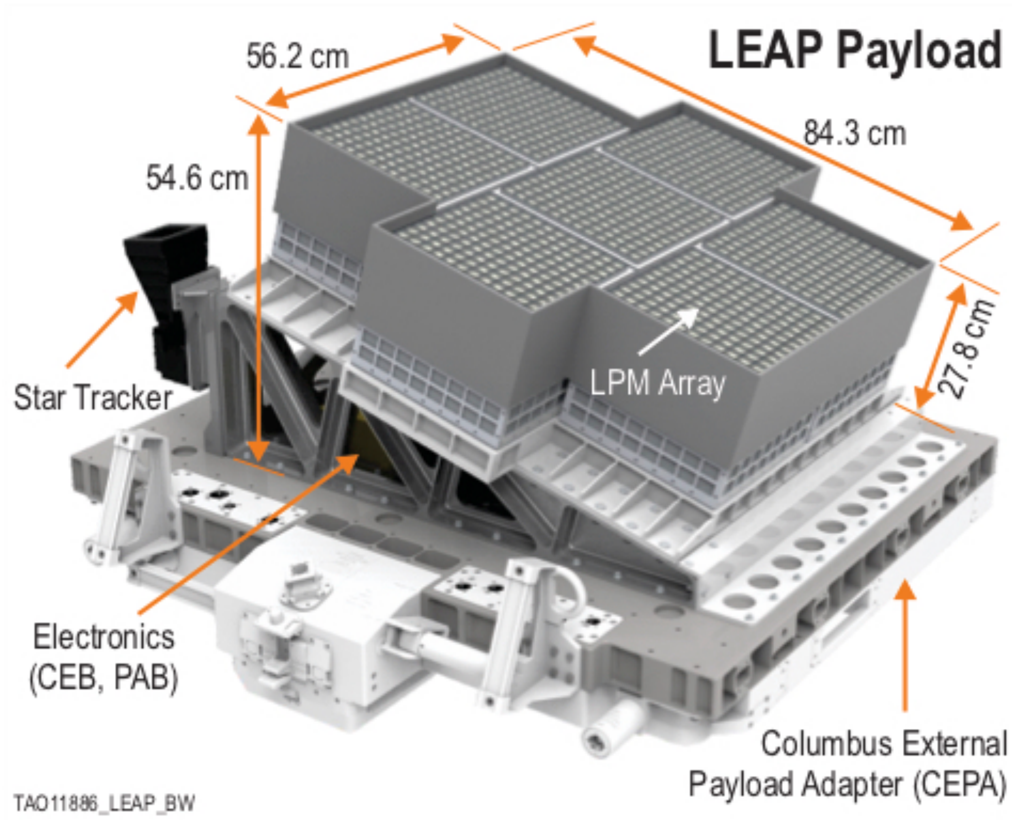
The expected number of GRBs that LEAP will detect at a given MDP during its three year mission. LEAP's baseline mission is acheived by observing 65 GRBs with an MDP of 30% or better. LEAP's threshold mission requires 30 GRBs with an MDP of 30% or better.

ISS ACCOMMODATION

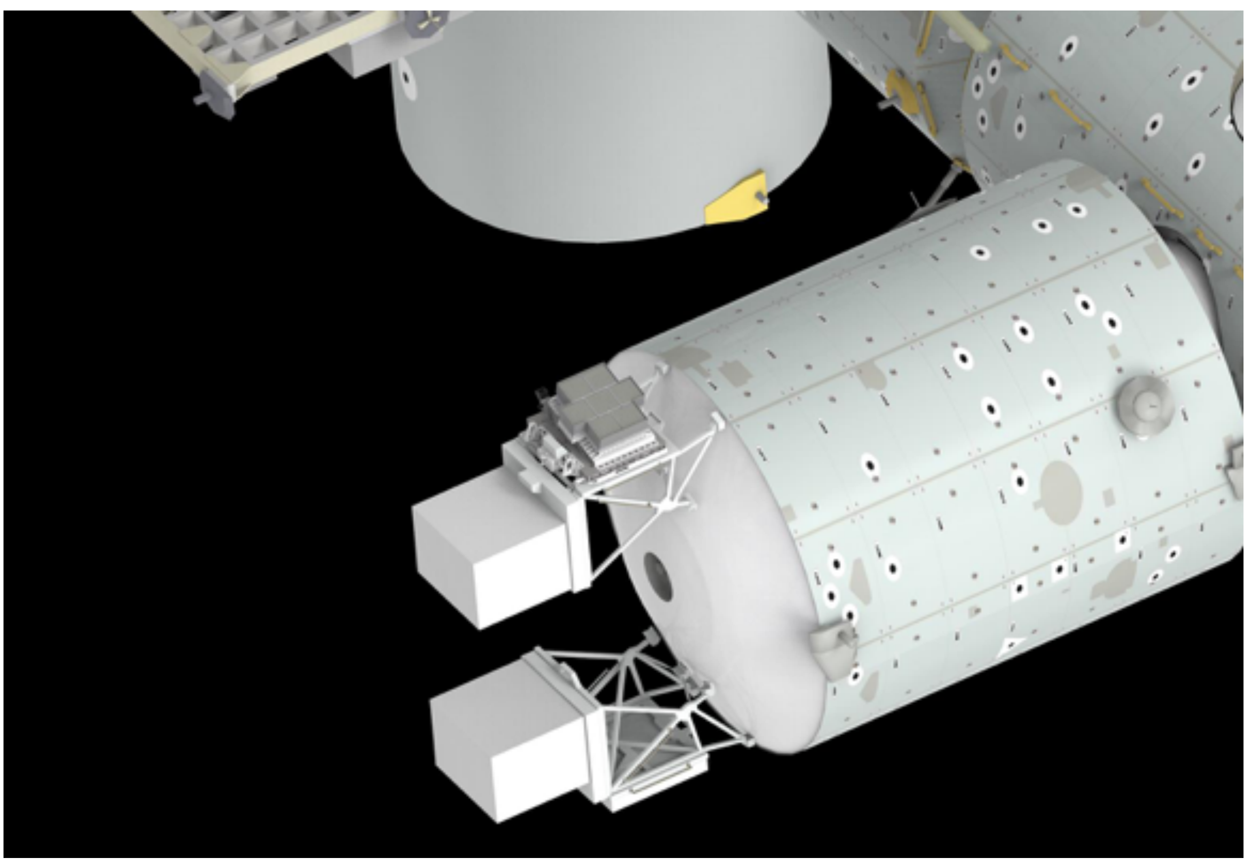
In principle, LEAP can be accommodated by any of the external attachment sites on ISS. Mission requirements, in particular the need for a relatively unobstructed view towards the zenith, limiting background from docked Soyuz vehicles, and availability define the baseline site option as Columbus-SOZ. Final site selection will be determined with ISS in Phase B. Passive shielding is used to further reduce the effects of radiation (both direct and scattered) from ISS components.



The LEAP payload consists of seven LEAP polarimeter modules (LPMs) and two electronics boxes, the Central Electronics Box (CEB) and the Power Adapter Box (PAB).



The full LEAP payload is shown, mounted on the Columbus External Payload Adapter (CEPA), which connects to the Columbus-SOZ module on ISS.



LEAP (center of image) is shown mounted on ISS on the Columbus-SOZ module.

The Central Electronics Box (CEB) inclues the Central Data Processing Unit (CDPU) and provides the electrical interfaces for each LEAP Polarimeter Module (LPM). and the data/command interfaces for the ISS. The Power Adapter Box (PAB) converts the 120 V ISS power t 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 dissemenation of GRB data (localization and time histories) to ground-based observers.

AUTHOR INFO

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ABSTRACT

Polarization studies of the prompt emission from Gamma-ray bursts (GRBs) provide crucial information about the magnitude and coherence of magnetic fields carried by the astrophysical jets powering them. Polarization studies of GRBs to date present limited significance and conflicting results. The LargE Area burst Polarimeter (LEAP) will provide a large sample of high sensitivity polarization measurements, including time-resolved polarization measurements, required to understand GRB jets and their geometry. LEAP was proposed as an International Space Station external payload, launching in 2025, and was selected by NASA for a Phase A concept study. LEAP consists of an array of both plastic and CsI scintillation detectors to identify Compton scatter events from prompt GRB emission. The source polarization is measured from the azimuthal distribution of the Compton scattered photons. Since GRBs can come from any part of the sky, LEAP has a wide field-of-view and is a non-imaging instrument. It has a total geometric scintillator area of ~3000 cm^2 and an effective area for polarization measurements (double scatter) of ~1000 cm^2. LEAP will provide high sensitivity polarization measurements from 50-500 keV, a range that covers the bulk of observed Epeak values. The large effective area will simultaneously provide broad-band spectral data from 20 keV to 5 MeV and enable time- and/or energy- resolved polarization measurements for the brightest GRBs. During its nominal 3 year mission lifetime, LEAP will trigger on ~400 GRBs, including ~320 long and ~80 short GRBs, and will provide polarization results on >100 GRBs. LEAP can self-sufficiently determine GRB localization, with an accuracy that depends on fluence. Typically localization errors (1-sigma) are 2-3 deg. LEAP enables exciting science beyond GRB polarization studies, including but not limited to, polarization studies of solar flares and observations of GRBs coincident with gravitational waves.

REFERENCES

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Toma, K. et al. 2009, "Statistical Properties of Gamma-Ray Burst Polarization," ApJ, 698, 1042, doi:10.1088/0004-637X/698/2/1042.