GLAST and Ground Based Gamma-ray Astronomy

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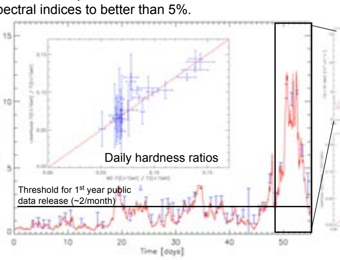
Abstract The launch of the Gamma-ray Large Area Space Telescope (GLAST) next year together with the advent of a new generation of ground-based gamma-ray detectors such as CANGAROO, H.E.S.S., MAGIC and VERITAS, will usher in a new era of high-energy gamma-ray astrophysics. GLAST and the ground-based gamma-ray observatories will provide highly complementary capabilities for spectral, temporal and spatial studies of high-energy gamma-ray sources. Joint observations will cover a huge energy range, from 20 MeV to over 50 TeV. The LAT will survey the entire sky every three hours, allowing it both to perform uniform, long-term monitoring of variable sources, and to detect flaring sources promptly. Both functions complement the high-sensitivity pointed observations provided by ground-based detectors. Finally, the large field of view of GLAST will allow a study of gamma-ray emission on large angular scales and identify interesting regions of the sky for deeper studies at higher energies. In this poster, we discuss the science returns that might result from joint GLAST/ground-based gamma-ray observations and illustrate them with detailed source simulations.

MeV to TeV Gamma-Ray Astrophysics

There is a remarkable lack of overlap between the objects detected at high energies (HE, E < ~30 GeV) by spaceborne experiments and those detected at very high energies (VHE, E > ~150 GeV) by ground-based detectors. Understanding the differences and the relationship between HE and VHE emission requires complete coverage of the gamma-ray spectrum. Such coverage will be possible for the first time with the launch of GLAST in late 2007. The importance of joint observations goes beyond a simple overlap in energy coverage, there is an additional synergy between HE and VHE instruments provided by their complementary capabilities in sky monitoring, source resolution and localization and variability studies (see table at right). In this poster, we explore some selected science topics that will benefit from joint observations between GLAST and ground-based gamma-ray observatories.

Active Galactic Nuclei

AGN are the most populous and best studied known class of high-energy gamma-ray sources. One of their most distinctive features is extreme variability down to sub-hour timescales (Gaidos *et al.* 1996), and measurements of AGN spectra on short timescales provide a crucial tool for understanding AGN physics. Below we investigate the LAT's sensitivity to short-term variability. In the main plot, a model light curve (*red line*) is shown with an unbinned likelihood analysis of 24-hour exposures (*blue points*). The inset shows the hardness ratios (F(E>1 GeV)/F(E<1 GeV)) recovered by a likelihood analysis vs. the Monte-Carlo input. It indicates that hardness ratios can be accurately recovered on daily timescales, even in quiescent states. During moderate flares like the one shown, twelve-hour-exposure fluxes can be measured to better than 10% accuracy and spectral indices to better than 5%.



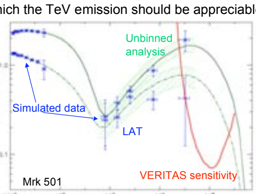
The table below lists the approximate numbers of blazars for which the LAT will measure fluxes and spectral indices to <10% accuracy.

State	Flux (cm^{-2} s^{-1}, >100MeV)	Time res.	No. sources
Low	< 10^{-6}	≥ 24 hr	1000s
Medium	10^{-6} – 10^{-5}	~12 hr	~100
High	> 10^{-5}	~6 hr	~10

With this level of performance, the flux and peak of high-energy emission can be determined in a time-resolved manner for dozens of sources.

Time-averaged SEDs of blazars

As indicated in the table above, the LAT will measure the time-averaged spectra (exposures of days to months) for thousands of blazars. Although a substantial fraction of these will be flat-spectrum radio quasars with little emission in the TeV band, many will be high-energy-peaked BL Lacs (HBLs) for which the TeV emission should be appreciable.

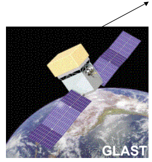


In this figure we use leptonic models of Markarian 501 in high and medium states from Petry *et al.* (2002) (*black lines*) to predict the LAT counts from a week of observations in survey mode. The blue points show predicted LAT and X-ray counts from a binned likelihood analysis, and the green band indicates the 3σ error from an unbinned likelihood analysis.

The red line indicates the VERITAS sensitivity expected from 15 hours of observations. For HBLs like Markarian 501, **joint observations between TeV observatories and GLAST are needed to completely cover the high-energy part of the SED, allowing the peak to be tracked even if it shifts in energy with flux level. Measuring the full shape of the high-energy peak reveals the overall energy budget and the relative contributions of the SSC and SC cooling mechanisms.**

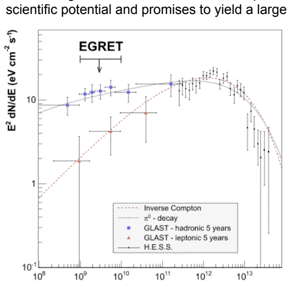
High Energy Gamma-ray Detectors

Parameter	GLAST LAT	IACTs	Ground Arrays
Energy Range	20 MeV - >300 GeV	~100 GeV - >50 TeV	200 GeV - >100 TeV
Energy Resolution	<10%	15%	50%
Duty Cycle	100%	12%	100%
Field of View	2.2 sr	2.4 10-2 sr (5 deg)	2 sr
Angular Resolution	0.1 deg @ 10 GeV	0.1 deg	0.5 deg
Effective area	~1 m^2	~10^5 m^2	5 10^3 @ 1 TeV
Point Source sensitivity	1.5×10^{-10} cm^{2}s^{-1} E>10 GeV	10^{-11}cm^{2}s^{-1} E>100 GeV	2×10^{-13}cm^{2}s^{-1} E>12 TeV



Galactic Gamma-ray Sources

The study of Galactic sources will form an important part in the investigations of the GLAST gamma-ray sky. While EGRET found a large number of sources located along the Galactic plane, only a handful of those could be identified in other wavebands through their characteristic variability pattern -- **the pulsars.** Several other sources were noticed for intriguing spatial coincidences with potential gamma-ray emitters: **OB-associations, Supernova remnants (SNRs) and Pulsar Wind Nebulae (PWNe), Wolf-Rayet stars, pulsars too weak to find with a convincing gamma-ray periodicity, Active Galactic Nuclei shining through the Plane, etc**. Source confusion caused by rather poor angular resolution prevented individual identifications for the remainder of the EGRET sources. Recent advances in the VHE gamma-ray band above ~100 GeV by atmospheric Cherenkov telescopes such as H.E.S.S. have revealed a somewhat different blend of gamma-ray sources in our Galaxy. These include PWN, SNRs, and microquasars, as well as Giant molecular clouds acting as passive material illuminated by cosmic rays. The identifications of these sources, made possible by the good angular resolution of Cherenkov instruments, provide a clean way of predicting flux levels in the GLAST-LAT regime above ~100 MeV if viable multi-frequency models can be found for the individual sources. In the light of these predictions and the large number of EGRET Galactic sources, it is evident that the study of Galactic sources together with VHE instruments represents a large and yet unexplored scientific potential and promises to yield a large scientific return.



Left: Spectral energy distribution (SED) of the shell-type SNR RX J1713.7-3946 above 100 MeV. Existing measurements with H.E.S.S. above ~100 GeV are shown (*black points*) along with simulated GLAST-LAT data assuming different mechanisms for the gamma-ray emission that can be tested with future observations in the GLAST range (*blue*: hadronic interactions and subsequent decay of neutral pions; *red*: inverse-Compton scattering of ultra-relativistic electrons off background photon fields).

The areas in which cooperation will be most advantageous are:

Broad spectral coverage to help in modelling the source and the emission processes, such as differences between hadronic and leptonic acceleration models in shell-type SNRs,

Contemporaneous light-curves for variable objects such as microquasars,

Cross-calibration of the energy determination using common sources such as the Crab Nebula or shell-type SNRs like RX J1713.7—3946,

Help in the identification of GLAST sources through the high sensitivity and superior angular resolution of current VHE gamma-ray telescopes, and

Population studies in two consecutive energy bands, which enable not only individual but spatial/statistical measurements that can be used to understand the transition of source populations through the regime of GeV-cutoffs as already evident in numerous EGRET sources.

Gamma-Ray Bursts

GLAST observations will provide groundbreaking measurements of the high-energy emission up to a few hundred GeV during both the prompt and afterglow phases of a large number of gamma-ray bursts (GRBs). Ground-based gamma-ray detectors can extend the measurements up to the TeV range, allowing the properties of the highest-energy emission from GRBs to be understood and providing information on the bulk Lorentz factor, acceleration physics, UHECRs, and hadronic processes (π^0 cascades, synchrotron, etc.).

An important consideration for planning is to understand the frequency of GRB observations. The GBM will detect ~215 GRB/year. Information on bursts detected onboard by either the LAT or GBM will be promptly released via GCN

Rate of observable GRB = total rate × duty cycle × observable sky fraction

~40 GRB/year for ground arrays

~4 GRB/year for each IACT, including 1-2 within the LAT FoV

Ground arrays are likely to observe enough GLAST GRBs to allow a systematic study of prompt GeV-TeV properties of GRBs.

IACT observations of a GRB detected only by the GLAST Burst Monitor will require an observing mode that covers the few-degree location uncertainty. In contrast, bursts detected by the LAT will be well-localised. A GRB detected onboard the LAT within an IACT FoV will be an uncommon (~1/year) opportunity. Follow-up observations of such GRBs will be extremely valuable and should be accorded high priority.

IACTs can also provide sensitive observations of GRB afterglows. For these observations, the GRB location does not need to be within the observable sky at the time of the burst, it just needs to be observable that night. Assuming a LAT GRB detection rate of 50 GRB/year, this implies that 5-10 GRB per year could be followed up by IACTs for afterglow observations.

IR-Optical-UV background radiation

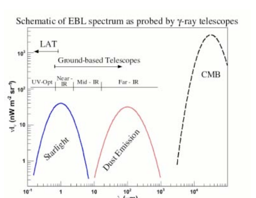
Gamma-rays with energy E > 10 GeV interact via pair-production with photons from the Extragalactic Background Light (EBL). So far, only Very High Energy (VHE) observations of low-redshift BL Lacs have been available to look for these attenuation effects. The future partnership of the LAT and ground-based telescopes will bring important advances in the understanding of the EBL.

1. Different regions of the EBL spectrum will be probed: The pair-production cross section for γ-rays with energy E_γ is maximized when the EBL photon wavelength λ_{EBL} is given by λ_{EBL}= 1.33 μm (E_γ / 1 TeV).

In the case of γ-rays detected by the LAT in the 10 GeV < E < 300 GeV energy range, the EBL attenuation occurs with ***UV-optical*** photons from the EBL.

Meanwhile, γ-rays detected by ground-based instruments with energies above E > ~ 100 GeV are absorbed by ***optical-infrared*** EBL photons.

Therefore, LAT and ground-based observations complement each other by measuring different parts of the EBL.



2. Independent studies of EBL attenuation: Statistical analysis of the large sample of blazars (>1000) that GLAST is expected to detect will be a powerful tool to study EBL absorption and to distinguish extragalactic attenuation from intrinsic peculiarities in individual blazar spectra. Independently, blazar-emission models will continue to be used to predict the intrinsic spectrum of individual blazars through fitting of multi-wavelength data and to calculate then, by comparison, the EBL attenuation. These two independent analyses would validate and reinforce each other.

3. Extended source spectrum: The LAT, with a threshold well below 10 GeV, has access to the region of the gamma-ray spectrum that is not attenuated by the EBL (at any redshift). Observations in this range could be particularly useful for sources observed also at very high energy (E > 100 GeV), since it would lead to a more educated expectation for the intrinsic spectrum of the source.

Right: In this example we consider two scenarios for a γ-ray source at z = 0.2 :
(i) a soft power-law intrinsic spectrum (Γ =2.2) with nominal EBL absorption (Primack *et al.* 2005).
(ii) a hard spectrum (Γ=2.0) with the EBL absorption increased by 20%.
Both scenarios are impossible to distinguish with data above 100 GeV only, but observations by the LAT could tell the two scenarios apart.