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GLAST: physics goals and instrument status

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Abstract. The Gamma-ray Large Area Space Telescope (GLAST) is a space-based observatory scheduled to launch in October 2007 with two instruments: (1) the GLAST Burst Monitor (GBM), sensitive to photon energies between 8 keV and 25 MeV and optimized to detect gamma-ray bursts, and (2) the Large Area Telescope (LAT), sensitive to gamma rays between 20 MeV and 300 GeV and designed to survey the gamma-ray sky with unprecedented sensitivity. We describe the LAT and the GBM. We then focus on the LAT's capabilities for studying active galactic nuclei.

1. GLAST

The Gamma-ray Large Area Space Telescope (GLAST) is scheduled to be launched in October 2007 and will operate for 5-10 years in a low-earth orbit. Unlike its predecessor, the Compton Gamma-ray Observatory (CGRO), GLAST is not intended to make pointed observations. Instead, it will operate primarily as an all-sky monitor in which it continuously scans the sky, rocking $\pm 35^\circ$ about the zenith every 90-minute orbit. GLAST will carry two instruments:

(i) the Large Area Telescope (LAT), the main GLAST instrument, sensitive to gamma rays between 20 MeV and 300 GeV, and
(ii) the GLAST Burst Monitor (GBM), dedicated to detecting gamma-ray bursts (GRBs) between 8 keV and 25 MeV.

Both instruments have completed all environmental testing and are currently being integrated onto the spacecraft.

The GBM [1] consists of twelve NaI crystal detectors with sensitivity from 8 keV to 1 MeV and two BGO crystal detectors with sensitivity from 150 keV to 30 MeV. The instrument has a field of view of 9.5 sr (the entire sky not occulted by the Earth) and $\sim$12% energy resolution at 511 keV. The GBM is capable of on-board localizations of $< 15^\circ$ in 1.8 seconds and $2 - 3^\circ$ within several seconds to a few minutes. It is anticipated to detect $\sim$200 GRBs per year, > 50 of which will be in the field of view of the LAT.

The LAT [2] is a pair-conversion instrument. In each of 16 precision trackers, 14 layers of tungsten foil facilitate pair conversion and 18 layers of X-Y pairs of single-sided silicon strip detectors measure the pair tracks. The pair-initiated shower deposits its energy in a calorimeter, composed of 1536 CsI crystals located at the bottom of the LAT. A segmented array of plastic scintillators surrounding the instrument detects charged particles as they enter and is used to veto background events depending on energy and on the correspondence of the hit scintillator tiles with tracks found in the tracker.

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Table 1 [3] summarizes the LAT performance. With a field of view of 2.4 sr, the LAT will "see" 20% of the sky at any instant and will scan the entire sky once every two orbits, or three hours. The predicted one-year sensitivity is $F(E > 100\mathrm{MeV}) > 3 \times 10^{-9}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for a point source with a differential photon spectrum proportional to E^{-2} observed at high latitude. The brightest point sources will be localized to $\sim 0.4'$ and the weakest sources to several arcminutes. The LAT will be much more sensitive than its predecessor, the EGRET instrument aboard CGRO; in one day, it will detect (at 5σ) the weakest sources that EGRET detected during the entire CGRO mission. The LAT is projected to detect thousands of gamma-ray sources over the lifetime of the GLAST mission.

Table 1. LAT capabilities.

Parameter	Present Design Value
Peak Effective Area	$10,000\mathrm{cm}^2$ at 10 GeV
Energy Resolution, 100 MeV, on-axis	9%
Energy Resolution, 10-300 GeV, on-axis	$< 15\%$
PSF, 68%, on-axis, 10 GeV (100 MeV)	$0.09^{\circ}(3.4^{\circ})$
Field of view	2.4sr
Source Location Determination	$< 0.4'$

2. Blazar physics with the GLAST LAT

The LAT is expected to advance the scientific understanding of all types of gamma-ray emitting objects, including Solar System sources like the Sun and Moon, Galactic sources like supernova remnants and pulsars, and extragalactic sources such as active galaxies and GRBs. It will map the structured diffuse emission from the Milky Way and will detect, or perhaps resolve, the diffuse extragalactic emission as well. The LAT may also detect gamma rays from dark matter annihilation and will almost certainly find new catagories of gamma-ray sources. Each of these topics is covered in [2]. Here we have chosen to concentrate on one type of gamma-ray emitter, blazars, a population with significant scientific overlap with ground-based TeV telescopes. We explore the potential of LAT observations for understanding the physics of AGN jets.

2.1. Monitoring variability

The frequency and uniformity of the sky coverage of the LAT will allow sensitive, evenly-sampled monitoring of AGN variability across the sky. Figure 1 shows a 55-day synthetic light curve that includes stochasic variability and a moderately bright flare (solid line). The data points indicate fluxes derived for one-day intervals from simulated LAT data. The data were analyzed using an unbinned maximum likelihood technique that is being developed as a standard analysis tool. The inset shows the hardness ratios ($F(E > 1$ GeV$)/F(E < 1$ GeV$)$) recovered from the likelihood analysis vs. the true hardness ratios, indicating that hardness ratios can be accurately measured on daily timescales, even in low states. The horizontal line indicates the threshold for a public data release in the first year; fluxes and flux ratios on any object whose flux above 100 MeV exceeds $2 \times 10^{-6}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ will be released to the community for follow-up observations and monitoring [4]. The right-hand plot in Figure 1 shows a close-up of the flare with 12-hour time intervals. During moderate flares like the one shown, fluxes can be measured to better than 10% accuracy and spectral indices can be measured to better than 5% on 12-hour time scales. Over the duration of the GLAST mission, the LAT is expected to measure daily fluxes from thousands of sources with this level of accuracy. Twelve-hour and hourly spectra can be measured for approximately 100 and ten sources, respectively.

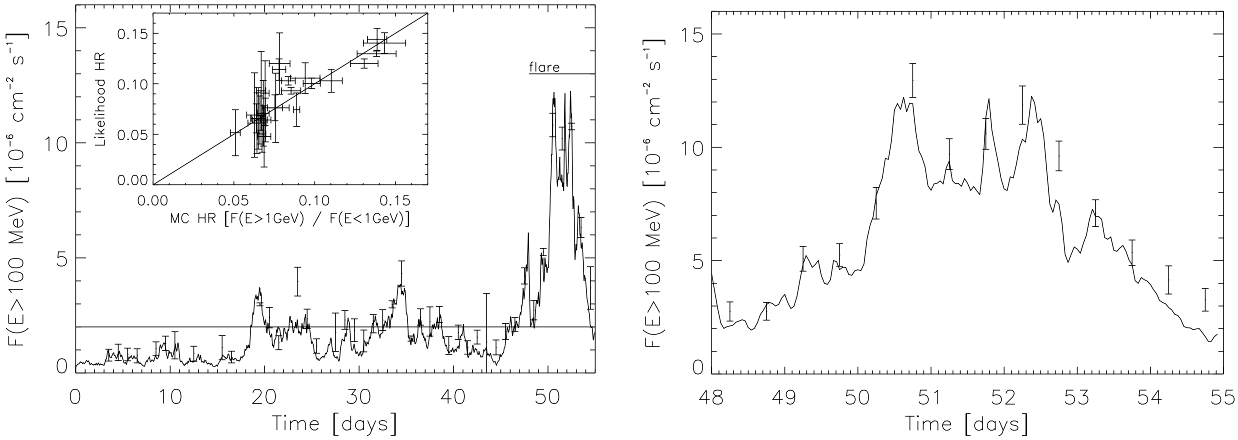

Figure 1. *left*: A 55-day synthetic blazar light curve (solid line) plus one-day LAT exposures (data points). The inset shows the recovered vs. true hardness ratios. *right*: Close-up of the flare indicated in the left panel, with LAT data in 12-hour exposures.

2.2. Time-resolved spectral energy distributions

The level of performance indicated in Section 2.1 suggests that the LAT will be able to measure the high-energy emission from dozens of blazars on timescales of several hours. The synchrotron cooling timescale for a population of relativistic electrons in the inner jet can be several days for reasonable choices of the jet parameters [5]. Therefore, within the context of leptonic models, 12-hour LAT spectra represent snapshots of the particle distribution as it cools, and the LAT can track changes in the gamma-ray spectral index as the highest-energy electrons preferentially lose their energy to inverse-Compton scattering. In the simplest SSC models, the free parameters are the magnetic field B, the particle spectral index p and upper- and lower- energy cutoff γ_1 and γ_2, respectively, the size of the emitting region R, and the bulk Lorentz factor Γ. Each LAT snapshot constrains B, p, γ_1, and γ_2. If, in addition, simultaneous X-ray observations that resolve the shortest variability timescales are available, then these measure R and Γ. The X-ray spectral energy distributions (SEDs) also independently constrain B, p, γ_1, and γ_2. We would expect the constraint on B to be particularly severe with such a set of observations, if indeed it remains constant as the electron population cools.

2.3. Time-averaged SEDs

The estimated number of blazars that GLAST will detect ranges from at least a thousand [6] to several thousand [7, 8, 9]. The majority of these will be faint, and long integration times will be required to build up a reasonable high-energy SED. Here we explore the physics that can be probed with SEDs that measure only the time-averaged properties of the jet. In particular, we consider the case of a week of observations of Markarian 501 (Mrk 501). In 1997, Mrk 501 was monitored by radio, optical, X-ray ($2 < E < 12$ keV, $20 < E < 200$ keV), and TeV ($E > 800$ GeV) telescopes simultaneously, and two week-long epochs in medium and high states of activity were used to fit SSC models [10]. The modeling was realistic in that it evolved the electron population self-consistently as it cooled. Unfortunately, because no data existed on the rising edge of the inverse-Compton peak, the models could not constrain B or γ_1, and so these parameters were fixed at nominal values. In Figure 2, we show the models for the 1997 medium-and high-state epochs (solid lines). The X-ray points in Figure 2 represent 25.2 ks (or 1 hour per day for a week) from a BeppoSAX-like instrument; these cover the low-energy peak of the SED. The gamma-ray points assume a week's worth of sky survey observations with the LAT.

As Figure 2 shows, joint LAT and and VERITAS observations of Markarian 501, and of other high-frequency-peaked BL Lac objects, will cover the entire high-energy peak of the SED. This is an extremely powerful measurement for understanding the origin of the high-energy emission, and such broad high-energy coverage will not be possible until the launch of GLAST. In the context of leptonic models, the LAT coverage of the low-energy half of the SED can constrain B and γ_1, unlike the previous modeling of [10]. If simultaneous X-ray data are also available that cover the low-energy peak of the SED, then the overall energetics of the inner jet are known. We can directly measure the relative contributions of synchrotron and inverse-Compton cooling in the jet. This type of complete, simultaneous coverage constrains all of the parameters of simple SSC models: B, p, γ_1, γ_2, Γ, and R.

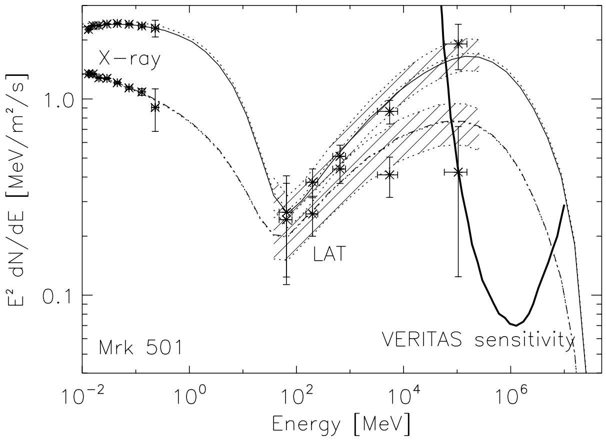

Figure 2. The SSC models in high and medium states from [10] (solid lines) are used to predict the LAT counts from a week of observations in survey mode. The points show the predicted LAT and X-ray counts from a binned likelihood analysis, and the shaded band indicates the 3σ LAT error from an unbinned likelihood analysis. The U-shaped line indicates the VERITAS sensitivity expected from 15 hours of observations (courtesy of R. Ong).

3. Conclusions

We have described the two GLAST instruments and explored the constraints that LAT observations can make on leptonic emission models of AGN jets. We emphasize that none of the results shown require pointed LAT observations; they are all achievable with the all-sky scanning mode of observing. Of course, the most interesting findings may be from sources where the LAT data rule out a simple SSC picture. In these cases, either more complicated leptonic modeling or hadronic modeling must be invoked. Finally, it is clear from the examples here that in order to optimize the scientific return of GLAST for blazars, simultaneous multi-wavelength data are essential, especially from X-ray satellites and from TeV instruments such as VERITAS and H.E.S.S.

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