Swift TOO OBSERVATIONS OF FLARING BLAZARS TRIGGERED BY *GLAST*

The *GLAST* LAT Collaboration

With the imminent (Sept 2007) launch of the *GLAST* observatory, we will soon have at hand a formidable opportunity to study the physics of blazar jets with unprecedented sensitivity at GeV gamma-rays, a key part of NASA's Strategic Sub-goal 3D: Discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets. Because of the multifaceted activity of these sources, the best constraints on the physical parameters can only be acquired via simultaneous multiwavelength observations and modeling of time-resolved Spectral Energy Distributions (SED). Because of its broad-band coverage and scheduling flexibility, *Swift* is ideal to ensure optimal synergy with *GLAST*. Thus, we propose *Swift* ToO observations of up to 3 blazars with a $>$ 100 MeV flux $\gtrsim 2 \times 10^{-6}$ ph/cm^2/s. Our observation strategy is optimized to sample the SED before, during, and after the GeV flare, in order to study the evolution of the underlying jet physical parameters.

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1. Introduction and Motivation

One of the main legacies of the EGRET experiment onboard CGRO was the discovery of bright and variable GeV gamma-ray emission from blazars, the subclass of AGN most dominated by non-thermal emission from a relativistic jet closely aligned with the line of sight. The rapid ($\sim$ day) variability of the GeV emission, coupled with the large measured luminosities, provided a model-independent argument for relativistic beaming in these sources (Maraschi et al. 1992, ApJ, 397, L5; Mattox et al. 1993, ApJ, 410, 609) and indicated an origin for the gamma-rays at hundreds of Schwartzschild radii from the central black hole (Ghisellini 1998, astroph/9810230).

Despite intensive studies, blazar gamma-ray emission processes remain controversial. In the class of leptonic models, where the jets are filled with relativistic electrons emitting the radio through UV/X-rays via synchrotron (Ulrich et al. 1997, ARA&A, 35, 445), the gamma-ray continuum is generated via inverse Compton scattering of the synchrotron photons themselves (SSC), or of ambient photons (EC). The various models make different predictions for the amplitude of the variability as a function of wavelength. For example, in a first-order scenario quadratic variations of the gamma-ray flux with the optical are expected in the context of SSC, while a linear dependence is predicted by EC models (Ulrich et al. 1997 and refs therein). Moreover, the shape of the GeV flare and its correlation with longer-wavelength emission provide a diagnostic for the acceleration and cooling processes of the emitting particles (Böttcher & Dermer 1998, ApJ, 501, L51).

Thus, *the key to unraveling the origin of the gamma-ray emission from blazars is provided by simultaneous multiwavelength observations.* Detailed multiwavelength observations of the broad-band SEDs, coupled with constraints from timing analysis, is a formidable tool for measuring the jet physical parameters (Doppler factor δ, magnetic field B, region size R, particle injection height H, and radiation densities). This knowledge is a precursor to constraining jet formation models (e.g., Tavecchio et al. 2000, ApJ, 543, 535).

So far our studies of blazar jets have been severly impaired by 1) the limited EGRET sensitivity, and 2) the scarcity of simultaneous broad-band monitoring. Nevertheless, the available data provide tantalizing clues. Multiwavelength observations of a handful of bright and well-studied sources show that the gamma rays vary on timescales typically of days (Wehrle et al. 1998, ApJ, 497, 178) and possibly hours (Fig. 1b; Mattox et al. 1997, ApJ, 476, 692). The GeV flux is correlated with the optical flux, with both quadratic and linear variations observed (Fig. 1a; Maraschi et al. 1994, ApJ, 435, L91). Modeling of time-resolved SEDs indicates that both SSC and EC components can contribute to the gamma-ray emission at one time (Fig 1c; Ballo et al. 2002, ApJ, 567, 50; Hartman et al. 2001, ApJ, 553, 683; Mukherjee et al. 1999, ApJ, 527, 132).

The situation for blazar multiwavelength studies will dramatically improve next year with the launch of *GLAST* in September. The main instrument on *GLAST*, the Large Area Telescope (LAT), will have broader energy coverage (20 MeV–300 GeV) and sensitivity >30x better than EGRET. Most importantly, the large field of view (over 2 steradians) allows survey observations where the LAT will scan the entire sky every two orbits. This will be the default observation mode during the first year of operations. Time-resolved blazar spectroscopy on timescales of days will become a reality, with far-reaching implications for theoretical models. In this mode, spectra and light curves of multiple bright sources anywhere in the sky will be obtained at one time.

Our extensive experience with past multiwavelength blazar campaigns showcased the intrinsic difficulty in coordinating observations from space- and ground-based observatories, so that multi-wavelength data that are truly simultaneous to the gamma rays were rare (e.g., Wehrle et al. 1998). Fortunately, in the *GLAST* era this problem will be greatly alleviated by *Swift*, whose broad-band coverage coupled with its flexible scheduling make it ideal for blazar campaigns. Crucially, *Swift* covers the UV wavelengths where signatures of thermal seed photons (from accretion disk and/or BLRs) can be detected (e.g., Pian et al. 1999, ApJ, 521, 112; Koratkar et al. 1998, ApJ, 492, 173). The *Swift* diagnostic power was recently illustrated by our campaigns for J0746 (Sambruna et al. 2006, ApJ, 646, 23) and 3C 454.3 (Giommi et al. 2006, A&A, in press). *The synergy between Swift and GLAST holds the future of multiwavelength monitoring of blazars.*

This Proposal: We propose *Swift* ToOs during the months of *Swift* and *GLAST* overlap (November 2007 – April 2008) of up to 3 blazars observed by the LAT to be brighter than 2×10^{-6} photons (E> 100 MeV)/cm^2/s. The total requested exposure is 105 ks with the XRT and the UVOT per activation, with a sampling as described below. We will also procure additional monitoring at radio, IR, hard X-rays, and TeV energies to maximize the science return of the *Swift* time.

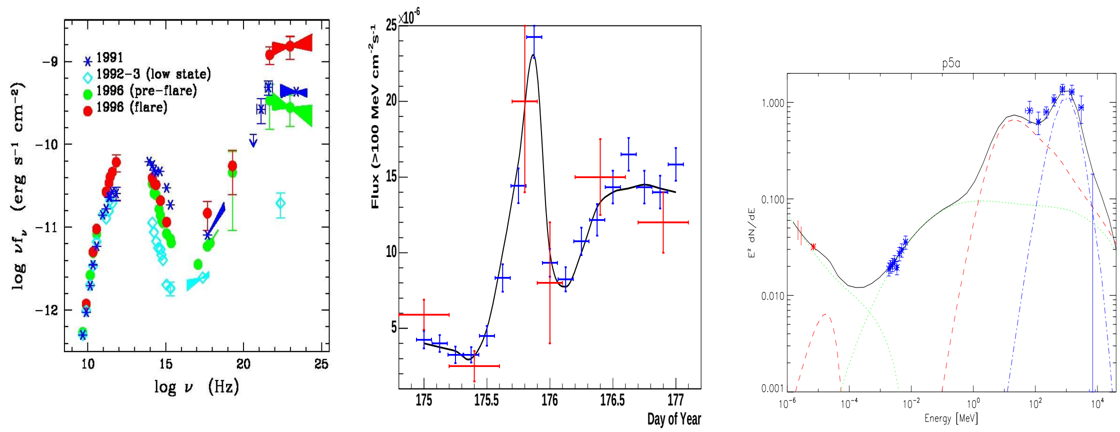

Figure 1: *(a, Left)* Observed SEDs of 3C 279 at various epochs, illustrating the large-amplitude GeV spectral variability correlated with the IR/optical flux (Wehrle et al. 1998). *(b, Middle)* EGRET observations (red points) of a rapid GeV flare observed in 1995 from PKS 1622-297 (Mattox et al 1997). The black curve is a lightcurve consistent with the EGRET observations and the blue points are simulated LAT data. *(c, Right)* Simulated LAT (week-long integration) and *Swift* data for 3C 279 in a bright flaring state (blue points). The model (Hartman et al. 2001) includes contributions from the accretion disk (red), Sy/SSC (green), and EC (blue).

2. Proposed Observations

Sample Selection: We will consider as targets for this program all blazars undergoing a flaring event at GeV energies, as detected by the LAT. To this end, the targets were based on the list of AGN whose LAT data will be made public during year 1; see
`http://glast.gsfc.nasa.gov/ssc/data/policy/LAT_Monitored_Sources.html`. This list includes some of the brightest GeV blazars from the 3rd EGRET catalog, plus a few TeV sources. From this sample, we selected a subset of X-ray bright blazars that we deemed likely to be of interest.

Because of the rapid variability at gamma rays and the large LAT coverage of the sky, it is reasonable to expect that blazars previously undetected by EGRET or other gamma-ray experiments will be seen by the LAT in a flaring mode, or with a flux meeting the trigger criterion below. This includes previously unknown sources serendipitously detected by the LAT. To take this into account, we request an open slot in the target list for “Unknown gamma-ray bright AGN”. The final list, provided in the electronic forms, includes 7 sources.

Trigger Criterion: We propose to consider a ToO observation with the *Swift* XRT and UVOT when the following condition is satisfied: **the > 100 MeV flux of the source as given by**

the LAT increases to a value brighter than 2×10^{-6} photons (E> 100 MeV)/cm^2/s. The choice of this flux threshold is motivated by the following: 1) It is the threshold for release of the LAT data during year 1. Thus, if this proposal is accepted and the ToO(s) activated, the blazar community will be provided immediately with extensive multiwavelength data sets to allow independent analyses. 2) We expect a manageable frequency by meeting this threshold.

The trigger probability is estimated as follows. Based on the 3rd EGRET catalog, in the 53 months of CGRO operations during Cycles 1–4, EGRET detected four blazars with a $>$ 100 MeV flux $\gtrsim 2 \times 10^{-6}$ photons (E> 100 MeV)/cm^2/s (3C 279, 1406−076, 0528+134, and 1622−297), yielding a rate of 0.075/month. However, EGRET covered only 1/24 of the sky. Therefore, LAT should see flares at 24 times the rate EGRET did, or $\sim$ 2/ month. Thus, in the 5 months of operational overlap with *GLAST*, we expect $\sim$ 10 flaring sources in the LAT field of view. This is likely to be a lower limit, since the LAT will be sensitive to large flare on timescales shorter than EGRET. In these cases, we will be able to sample the SED at and after the flare peak, at a minimum, providing important constraints on the models.

Observational Strategy: For the first year of the *GLAST* mission, the LAT will perform a sky survey. In this observation mode, the LAT will sweep across the entire sky every two orbits ($\sim$ 3 hours). During this time every region of the sky will be monitored for around 30 mins; Fig. 1b shows an example of a light curve we would obtain (blue data). For spectral studies a reasonable integration time for a bright source will typically be one day. During very bright periods an integration as low as hours may be used, allowing us to discriminate changes in photon index $\Delta\Gamma \gtrsim 0.3$.

During the first few months, it will likely take a couple of days to process and reduce the LAT data. Combined with the needed integration times, this suggests that a *Swift* sampling pattern of once per 6-12 hours for 1-2 weeks would be well matched to the LAT data. Given these constraints and our science goals (§ 3), we propose the following sampling strategy for *Swift*: **1) two visits per day as evenly separated as possible each day after the trigger for one week; 2) one visit per day for an additional week.** The requested exposure for each XRT visit is 5 ks (see § 4), for a total exposure of 105 ks (70 ks for first week, plus 35 ks for second week) for each ToO. With the UVOT, we request the use of all the optical and UV filters with the exposure time equally divided among them. The reason is the following. As shown in Fig. 1a,c, the optical-to-UV continuum in GeV blazars lies on the synchrotron component, at or above the synchrotron peak. Accurate knowledge of the optical-to-UV continuum is essential to constrain the peak frequency, which in turn constrains the electrons energy.

Previous experience with EGRET taught us that typically, a strong GeV flare lasts a few days and occurs 3–10 days after the initial brightening of the source (e.g., Wehrle et al. 1998). The above *Swift* observing strategy will thus allow us to sample the SED twice daily during the brightening phase, at the onset and peak of the flare; and once daily during its decay phase. However, in some cases the GeV flare was very short (e.g., PKS 1406-076) and the flux barely crossed the trigger threshold. Thus, in order to save precious *Swift* time, upon receipt of the LAT data we will make an informed decision on whether to trigger a ToO or not. Each case will be evaluated based on the source's past history, real-time LAT data, and the observational constraints of the various space- and ground-based facilities.

Additional observations: We will seek to procure additional observations at complementary wavelengths (radio, IR, optical, and TeV). Through members of the LAT Team we may have access to the WIRO IR camera in Wyoming, several optical telescopes, the *VLA*, hard X-rays (*Suzaku*, *RXTE*), and various ground-based Cherenkov telescopes. While these observatories will provide additional data, only *Swift* has the sensitivity, broad-band coverage, and flexibility to ensure succesfull synergy with *GLAST*.

3. Summary of Science Goals

We propose *Swift* ToO observations of up to 3 blazars with a LAT flux of $\gtrsim 2 \times 10^{-6}$ photons (E> 100 MeV)/cm^{2}s during the 5 months of operational overlap with *GLAST* (November 2007 – April 2008). The primary science goals of the program are:
A. Sample the SED before, during, and after a GeV flare (see above). Time-resolved SEDs and measurements of correlated variability severely constrain physical jet parameters, especially the bulk Doppler factor, the size of the emitting region, and the scale height of injection.
B. Constrain the (dominant) emission mechanism(s) of gamma-ray production in blazar jets. The *Swift* UVOT and XRT data independently constrain the synchrotron and SSC components of the time-averaged SEDs (Fig. 1c). LAT data constrain the contribution from external Compton emission. Together, the combined data sets effectively constrain all of the physical parameters describing the jet and possible external radiation densities;
C. Establish a baseline of coordinated gamma-ray and longer wavelength observations for future studies of long-term variability;
D. Use the superior XRT and UVOT resolutions to confirm the LAT source. For bright LAT sources like these, the LAT error box will be a few arcmin, depending on the source spectrum. If necessary, we will use the superior ($5''$) positional accuracy of the XRT, UVOT ($0.5''$), and other companion optical and radio observations, to identify the emitting source in the *GLAST* box.

4. Feasibility

GLAST LAT: The proposed *Swift* observations will occur in the first several months of the *GLAST* mission. The first 60 days after launch will be spent activating and testing the spacecraft and instruments, and science operations (phase 1) will begin in November 2007. It is likely that LAT calibrations will continue to be refined for several more months and that the time to perform automated science processing (at the LAT Instrument Operations Center at SLAC) will become increasingly shorter during this time. We estimate that it will take a couple of weeks to process the LAT data during the first month of phase 1 (November) but that processing in the subsequent five months (December - April) can be completed within about three days. On discovery of any source with a flux above 2×10^{-6} (not just those in our list), we will consider triggering ToO observations with *Swift*. Furthermore, the LAT team will notify the community of the flare and release time-resolved gamma-ray flux and spectral information.
Swift XRT: Our main science goal for the XRT observations is to determine the shape of the 0.3–10 keV continuum of the source. Previous X-ray observations of GeV sources have shown that their X-ray spectra are well described by power laws with photon indices $\Gamma \approx 1.5$. Little or no excess absorption over the Galactic column density (mostly $< 8 \times 10^{20}$ cm^{-2}) is measured. We simulated XRT spectra assuming $\Gamma = 1.5$ and $N_H = 5 \times 10^{20}$ cm^{-2}, and normalized to a conservative flux in 2–10 keV of 6×10^{-12} ergs cm^{-2} s^{-1} as measured for a lower state of 3C 279. Within an exposure of 5 ks, the photon index is determined within 20%, sufficient for our goal of anchoring the part of the spectrum that is not well determined by the LAT data (Fig. 1c).
Swift UVOT: We request the use of all the optical and UV filters with the exposure time equally divided among them (800 s per filter). As shown in Fig. 1, the optical-to-UV continuum in GeV blazars lies at or above the synchrotron peak. Accurate knowledge of the optical-to-UV continuum is essential to constrain the peak frequency, which in turn constrains the electrons energy.