

# Multiwavelength Opportunities for GeV and TeV Telescopes

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**Abstract.** With AGILE and *Fermi* now in orbit and TeV telescopes continuing to improve their performance, a variety of multiwavelength opportunities is increasingly available. One goal of such programs is to take advantage of the complementary capabilities of the two types of telescopes: the wide field surveys of the satellite detectors and the high sensitivity and resolution of the ground-based telescopes. Some aspects of these multiwavelength efforts will be carried out in near-real-time but must be anticipated with advance preparation. These include gamma-ray burst follow-ups and flare campaigns. Other projects such as long-term variability studies and gamma-ray source identification require deep observations and cooperative work with astrophysicists at longer wavelengths, along with the theoretical studies that tie the observations together.

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## INTRODUCTION – THE VALUE OF MULTIWAVELENGTH STUDIES

Gamma-ray astrophysics is inherently a multiwavelength effort. Above 100 MeV, photons are produced by interactions of high-energy charged particles with other particles, photons, or magnetic fields. Such nonthermal processes are seen over broad energy ranges, and multiple processes involving the same particles can produce radiation in different parts of the electromagnetic spectrum. A typical example is longer-wavelength synchrotron radiation originating from the same electrons that Compton scatter photons to X-ray and gamma-ray energies. For this basic reason, understanding the objects that are seen with gamma-ray telescopes can best be done in the context of multiwavelength studies that involve all relevant forms of radiation.

Empirically, the classes of objects seen at the highest energies are also seen over much of the spectrum. Blazars, pulsars, and pulsar wind nebulae are bright not only in gamma rays, but also generally in X-rays and radio and sometimes in the optical and infrared bands. One of the real challenges in modern astrophysics is obtaining enough multiwavelength observations to learn about phenomena taking place in some of the most exotic and powerful objects in the Universe.

The new generation of ground- and space-based gamma-ray telescopes offers greatly improved capabilities compared to previous instruments. AGILE [1] and *Fermi Gamma-ray Space Telescope* [2] operate at MeV to GeV energies, while CANGAROO, H.E.S.S., MAGIC, and VERITAS measure TeV photons (see [3] for a recent review). The combi-

nation provides:

- A huge energy range – 9+ orders of magnitude
- All-sky coverage, from both ground and space (*Fermi* sees the entire sky every three hours)
- Excellent sensitivity compared to previous instruments (*Fermi* LAT is about 30 times more sensitive than EGRET on the Compton Gamma Ray Observatory)
- Good source locations – 1 arcmin in many cases, especially for TeV sources.
- High time resolution for individual photons and flux variations
- Imaging for some extended sources

Even with all this information, however, astrophysical research demands yet more than gamma-ray telescopes can provide on their own. Some of these other requirements are:

- Distance – redshift, Dispersion Measure, parallax, proper motion, column density
- Composition – spectroscopy
- Precise source locations and imaging
- Velocities
- Polarization
- Magnetic fields
- Theories to connect the observations to physical models

These additional needs imply that gamma-ray astrophysicists must work not only with each other but with observers and theorists in a wide variety of astronomical and astrophysical settings.

## **PRACTICAL ASPECTS OF GEV – TEV COOPERATION**

### **How the *Fermi* LAT Team Handles Multiwavelength Campaigns**

The LAT team uses three approaches for multiwavelength programs:

- Monitoring studies are ongoing in radio, optical, and X-ray bands.
- Planned Intensive Campaigns (PICs) are detailed studies attempting to maximize multiwavelength studies by choosing a time based on availability of resources
- Target of Opportunity (TOO) campaigns react to something seen in LAT or at other wavelengths.

Information about planning resources is largely public. The sections below describe some of the sources.

## *Monitoring Programs*

Monitoring programs are used to track behavior such as timing or flux that can be correlated with LAT data. Some of the monitoring programs include:

- Pulsar timing for more than 200 known pulsars is being carried out by a consortium of radio and X-ray astronomers [4]. The list of timed pulsars can be found at <http://confluence.slac.stanford.edu/x/n4Do>.
- Radio AGN studies in cooperation with *Fermi* LAT are summarized at <http://pulsar.sternwarte.uni-erlangen.de/radiogamma/>.
- Optical/IR Monitoring is carried out at a wide variety of installations around the world.
- High-energy monitoring includes work by Swift, which watches the 23 LAT monitored sources, and INTEGRAL, where key proposals monitor a number of blazars.

## *Planned Intensive Campaigns – PICs*

Planned Intensive Campaigns – PICs are pre-set, major campaigns covering the electromagnetic spectrum for sources expected to be of special interest. Their schedule is set by availability of telescope facilities and observing time. The most complete recent example, the Mkn 501 pre-launch campaign, led by David Paneque, is described at <http://confluence.slac.stanford.edu/x/bwBs>.

These campaigns are generally advertised in advance, with an invitation for any observers to join. Below is a list of completed or planned campaigns.

- Completed: BL Lac, PKS 2155–304
- In Progress or Starting Soon: 1ES1959+650, PKS 0528+134
- Mkn 421: January – March, 2009
- 3C279: January, 2009
- LSI +61 303: January/February, 2009

If you have a suggestion for such a campaign, please contact the LAT team.

## *Targets of Opportunity – TOOs*

TOOs are similar to Planned Intensive Campaigns but started ad hoc by a transient event. All Gamma-ray Bursts fall into this category. An example of a non-burst TOO was the 3C454.3 campaign of 2007, led by Matthias Kadler and Ann Wehrle. See <http://confluence.slac.stanford.edu/x/K5>.

Other recent non-GRB examples include flares of PKS 1454–354, 3C273, PKS 1502+106. A campaign on 3C66A was recently announced by the VERITAS group, <http://www.astronomerstelegam.org/?read=1753>. The LAT team is interested in joining such campaigns. These campaigns are generally announced by

Astronomer's Telegrams (ATel) or e-mail distribution lists, with a contact person noted. LAT ATels include the name of a contact person who is a "friend of the source."

The LAT team (or friends) have a number of TOO proposals, often based on GeV or TeV flares, to facilities such as:

- XMM AGN flare (Tagliaferri)
- INTEGRAL AGN flare (Pian)
- Chandra high-latitude source flares (Madejski)
- Chandra Galactic source flare (Corbel, Grenier)
- VLA Galactic source flare (Reimer, Cheung)
- OVRO rapid response for Galactic flare (Readhead)
- ESO/ATCA proposals for southern flares (Chaty, Corbel)

The Swift Project has been extremely cooperative in granting TOO requests, which can be made on the Web, at <http://www.swift.psu.edu/too.html>.

RXTE can also carry out TOO observations. The contact person is Jean Swank at Goddard.

TOOs can go the other way, too. If an extraordinary event occurs, the *Fermi* spacecraft can be re-pointed to track that event. Contact <http://fermi.gsfc.nasa.gov/ssc/resources/observations/too.html>.

The LAT team maintains a list of upcoming proposal opportunities at <http://confluence.slac.stanford.edu/x/WTw>.

## **MULTIWAVELENGTH COOPERATION BETWEEN GEV AND TeV COMMUNITIES**

A key issue is: how do we make the best use of the complementary capabilities of GeV and TeV telescopes? LAT sees the full sky every three hours [5]. TeV Telescopes have huge collecting areas and excellent angular resolution.

A Basic GeV – TeV Strategy can be outlined as follows:

- LAT (and AGILE) map the GeV sky, noting possible targets for TeV telescopes - new sources, flares, GRBs with high energies, etc.
- TeV telescopes observe with high timing and spatial resolution at the higher energies.
- The GeV telescopes provide information before, during, and after the times of TeV observations.
- The GeV - TeV communities work together with longer-wavelength observers to build a more complete picture.

The key to making this approach work is communication. The LAT team has agreements with the four major TeV telescopes. They are posted at <http://confluence.slac.stanford.edu/x/YQw>.

## Some frequently asked questions about working with the *Fermi* GBM and LAT teams.

Q. Where is there information about *Fermi*'s Multiwavelength Program?

A. <http://fermi.gsfc.nasa.gov/science/multi/> is a good starting point. In addition, <http://confluence.slac.stanford.edu/x/YQw> is the public Web site used by the LAT team for MW, including campaigns.

Q. How will the *Fermi* instruments send out information about gamma-ray bursts?

A. GCN has become the standard. Both the GBM and the LAT will use GCN for announcements about gamma-ray bursts.

Q. How quickly can the LAT team tell us if one of our TeV sources is flaring?

A. At least half a day is required before an Automated Science Processing run is done to search for such flares.

Q. How can I find out when *Fermi* will be looking at my favorite source?

A. *Fermi* will view your favorite source every day under most circumstances. Because both the GBM and LAT have huge fields of view and the satellite's nominal operating mode is scanning, the entire sky will be viewed every 3 hours (with very limited exceptions for Targets of Opportunity).

Q. If I plan a major campaign on my favorite source, can I get LAT data?

A. Yes. All the LAT data will be public at the end of Cycle 1, about one year after start of operations. If you would like access to LAT data sooner, contact the LAT team. They are very interested in cooperative efforts.

Q. You mentioned a gamma-ray multiwavelength mailing list. What is it and how do I get on it?

A. HEASARC at Goddard maintains this list as a service to the gamma-ray community. It is an e-mail exploder aimed at sending general announcements to anyone interested in multiwavelength gamma-ray studies. Sending an e-mail to [gam-mamw@lists.gsfc.nasa.gov](mailto:gam-mamw@lists.gsfc.nasa.gov) distributes that mail to the list and puts a copy in the archive at <https://lists.nasa.gov/mailman/private/gammamw/>. The location to sign up for this mailing list is <https://lists.nasa.gov/mailman/listinfo/gammamw>

Q. Can a LAT team member tell me whether LAT sees my favorite source?

A. Not in general. The LAT team simply lacks the manpower to respond to individual requests in most cases.

Q. I would like to help identify LAT gamma-ray sources. How do I go about that?

A. About six months after the start of science operations, the LAT team will release a preliminary list of bright sources. Many of these may be sufficiently well localized that you can start looking for and modeling candidate MW counterparts.

Q. What other LAT results will be public in the first year?

A. A list of 23 likely gamma-ray sources will be monitored, with public release of fluxes and energy information, during Cycle 1. The list is at [http://fermi.gsfc.nasa.gov/ssc/data/policy/LAT\\_Monitored\\_Sources.html](http://fermi.gsfc.nasa.gov/ssc/data/policy/LAT_Monitored_Sources.html). Any source that flares above  $2 \times 10^{-6}$  ph(>100 MeV)/cm<sup>2</sup>s will be added to this list until/unless its flux falls below  $2 \times 10^{-7}$  in the same units.

A. What about weaker flares? Can you tell me when one happens so I can compare with flares I see with my instrument?

Q. Early in the mission, the LAT team will only release information about the brightest flares. Weaker flares will be added to public announcements as the system matures. The LAT team is still discussing the possibility of sharing information about the weakest flares.

Q. Whom do I contact about cooperative efforts?

A. If you know a member of the LAT collaboration, you can contact him/her. He/she will contact the appropriate LAT science group. As an alternative, David.J.Thompson@nasa.gov is the LAT Multiwavelength Coordinator and will be glad to pass along information about multiwavelength opportunities.

Q. Can I avoid losing LAT data during my multiwavelength campaign?

A. If you have a planned campaign that might benefit from LAT data, use the following FSSC form to tell the *Fermi* Project your plans: <http://Fermi.gsfc.nasa.gov/ssc/resources/multi/reporting/list.php>.

Q. How will the LAT team know what is of interest to the TeV groups?

A. The LAT team includes a number of scientists who are also affiliated with TeV telescopes. Those scientists will be watching the LAT results for TeV-related results, such as HBL or other low-*z* AGN flaring, unidentified transients, and sources with hard spectra. If something interesting is happening, they will encourage the LAT team to take action to tell the TeV telescope teams.

Q. Why should I care about the *Fermi* Cycle 2 Guest Investigator Program, <http://fermi.gsfc.nasa.gov/ssc/proposals/>, when the data will all be public?

A. There are three reasons for scientists to be interested in the program:

- Cooperative programs with NRAO and NOAO. Radio and optical telescope time is available through this proposal process.
- Proposals can determine the *Fermi* operations plan, e.g. pointed observations (although such observations require very strong justification).
- Money is available to U.S. proposers.

## SUMMARY

Multiwavelength studies are critical to maximizing the scientific return from GeV and TeV telescopes. GeV and TeV telescopes offer complementary strengths for high-energy studies. Opportunities for cooperation are available now.

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