Science of Compact X-Ray and Gamma-ray Objects: MAXI and GLAST

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Abstract

The Monitor of All-sky X-ray Image (MAXI) and Gamma-ray Large Area Space Telescope (GLAST) observatories will be surveying the sky simultaneously. Compact objects that may show variability will be excellent targets for coordinated multiwavelength studies. Gamma-ray bursts (and afterglows), pulsars, high-mass X-ray binaries, microquasars, and active galactic nuclei are all objects whose X- and gamma-ray relationship can be explored by such observations. Of particular interest will be variable unidentified gamma-ray sources, whose contemporaneous observations by MAXI may prove decisive in identifying the source of the high-energy emission.

Key words: X-rays — gamma rays — variability

1. Introduction

One of the clearest characteristics of the high-energy (X-ray and gamma-ray) sky is variability. Bursting, flaring, and periodic variability are seen on timescales ranging from milliseconds to years. Monitoring the changing cosmos therefore provides a valuable resource for scientific analysis and interpretation.

With the launch of GLAST, which took place during the MAXI workshop, and the upcoming launch of MAXI itself, the scientific community will have for the first time sensitive all-sky monitors covering a broad portion of the high-energy electromagnetic spectrum. The goal of this paper is to outline some of the scientific topics that can be addressed by cooperative efforts between these two missions.

2. GLAST Mission and Operating Plans

GLAST (Figure 1) is a successor to the successful Compton Gamma Ray Observatory (CGRO) that operated during the 1990's. GLAST is an international mission, involving the U.S. NASA and Department of Energy as well as contributions from many astrophysics and particle physics institutions and agencies in Japan, France, Germany, Italy, and Sweden. The GLAST Observatory (Michelson, 2003) includes two scientific instruments:

- The GLAST Burst Monitor (GBM) is a successor to BATSE on the Compton Observatory. It uses sodium iodide (NaI) and bismuth germanate (BGO) wide-field detectors to monitor the sky for transients in the 10 keV – 30 MeV energy range (Meegan et al 2008). The GBM field of view is large enough to view the entire sky except for the part occulted by the Earth.
- The Large Area Telescope (LAT) is a pair-production high-energy telescope successor to EGRET on CGRO. It uses a combination of detector subsystems (silicon strip tracker, cesium iodide calorimeter, plastic scintillator anticoincidence detector) to measure the properties of gamma-ray pair production events and to separate such events from the much larger background of charged particle cosmic rays (Atwood et al 2008).

Some important characteristics of the GLAST LAT are:

- Huge field of view (approximately 2.4 steradians).
- Broad energy range (20 MeV - >300 GeV, including the largely unexplored 10 - 100 GeV range).
- Good source location accuracy (1 arcmin for bright sources).
- Large effective area (factor >4 better than EGRET).
- Single photon absolute time accuracy better than 10 microseconds.

This combination of improvements results in a factor >30 improvement in sensitivity compared to EGRET, with an even larger factor at energies above 10 GeV.

GLAST was launched on June 11, 2008, into a 565 km circular orbit with inclination 25.5°. For comparison with MAXI, the most important operating feature

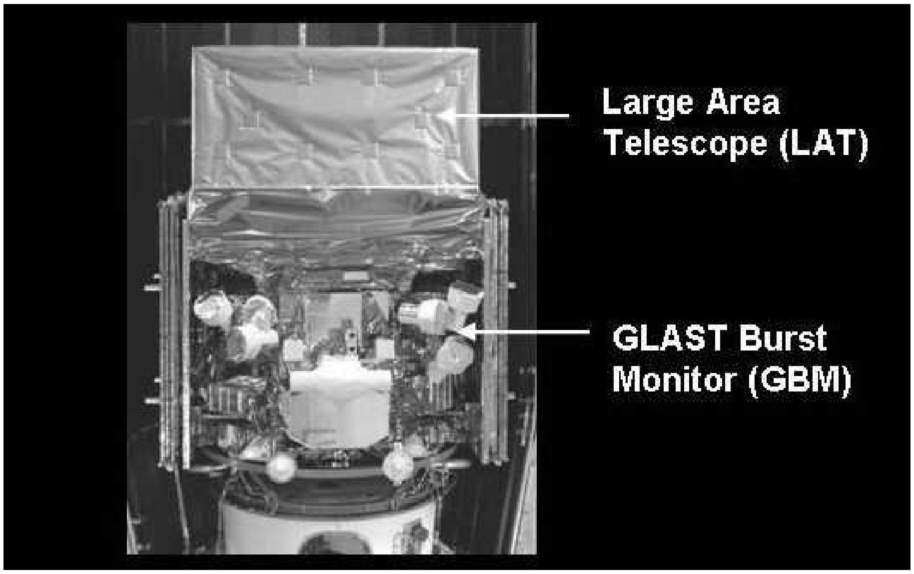

Fig. 1. GLAST on its launch vehicle.

of GLAST is its planned scanning mode. Taking advantage of the large instrument fields of view, the spacecraft will continually point away from the Earth. By rocking 35° north of the zenith for one orbit and 35° south of the zenith on the following orbit, both the LAT and the GBM will survey the entire gamma-ray sky every two orbits (192 minutes). For the first time, high-energy gamma-ray astrophysics will have an all-sky monitor.

Following a checkout period of about 60 days, GLAST will spend most of the next year in scanning mode, with a few exceptions for pointing mode operation triggered by unusual phenomena such as bright gamma-ray bursts. Results from bright sources and transients will be made public quickly, including Gamma-ray Burst Coordination Network (GCN) notices. At the end of approximately one year of normal science operations, all the data, including the first-year data, will become public as quickly as they can be processed. The GLAST Science Support Center (GSSC) at Goddard Space Flight Center (http://glast.gsfc.nasa.gov/ssc/) will be providing software and support for analysis of both GBM and LAT data.

3. GLAST, MAXI, and Multiwavelength Studies

Modern astrophysics has become a multiwavelength enterprise, reflecting the realization that many astrophysical sources reveal their properties across broad ranges of the electromagnetic spectrum. Gamma-ray telescopes, for example, provide little or no information about distances, composition, velocities, magnetic fields, or polarization of detected objects. Determining these other parameters requires identification and study at other wavelengths. For this reason, GLAST scientists are strongly interested in cooperative efforts with other observatories such as MAXI.

MAXI and GLAST have enough similarities that they have a particularly strong potential for working together:

- Both MAXI and GLAST survey the whole sky regularly.
- Both have good time resolution.
- Both cover a wide range of energies.

Two likely areas of cooperation between MAXI and GLAST are:

- Construction of broad-band Spectral Energy Distributions (SEDs) to help determine physical processes (such as particle acceleration and interaction) that are important in specific sources; and
- Study of correlated time variability to help examine relationships between the X-ray and gamma-ray emission processes.

4. Sensitivities and Potential Targets

Although MAXI and GLAST are in principle good candidates for cooperative efforts, the practical question is whether the time-dependent sensitivities of the two instruments are matched to potential sources. One way to address this question is shown in Figure 2, which plots the SED for the Crab along with the approximate energy ranges and sensitivities of the MAXI SSC, the MAXI GSC, and the GLAST LAT for a one week observation in their standard operating modes. These values are approximate because performance is estimated based

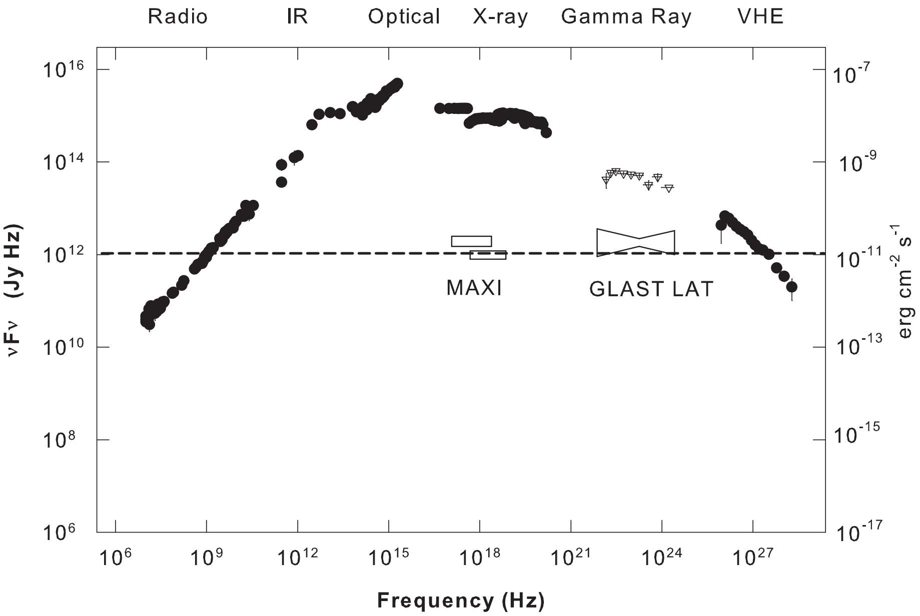

Fig. 2. Data points: Broadband energy spectrum of the Crab (nebula and pulsar). MAXI open rectangle upper left: SSC sensitivity in one week. MAXI open rectangle lower right: GSC sensitivity in one week. See other MAXI papers in these proceedings for details. GLAST LAT "bowtie": sensitivity in one week.

on pre-launch calibrations, not from in-flight conditions. The GLAST GBM is primarily sensitive to shorter transients and so is not shown on this figure. It is clear from this figure that a source like the Crab would be easily visible to both MAXI and GLAST in less than one week. Both telescopes can add data to gain sensitivity. For weaker sources, the integration time required for a measurement would be longer.

The horizontal dashed line on this figure provides a useful reference for comparing MAXI and GLAST LAT sensitivities. The level 10^{-11} erg cm^{-2} s^{-1} or 10^{12} JyHz is one that can be reached by either MAXI or GLAST LAT in one to two weeks.

Other than the Crab, what sorts of sources might be of interest to both MAXI and GLAST? Thermal sources are not good candidates; they might be visible to MAXI but not to GLAST. Conversely, nuclear sources would be more likely to be gamma-ray sources than X-ray sources. The best possibilities would seem to be nonthermal sources (involving accelerated particles) with some combination of synchrotron radiation (more likely in X-rays) and Compton radiation (more likely in gamma rays). Sources that combine both types of emission may yield information about the particle populations and acceleration processes, the magnetic fields, and photon fields in and around the source. Those with pronounced time variability (i.e. compact objects) are clearly of greatest interest, in order to take advantage of the monitoring capability of the two observatories. Some examples of potential astrophysical targets are discussed below.

4.1. Blazars and Other Active Galactic Nuclei

Active Galactic Nuclei (AGN), particular blazars, in which the jet is pointed toward the Earth, are primary targets for both X-ray and gamma-ray telescopes. They can have broad, nonthermal spectra and strong time variability. Figure 3 illustrates one example, blazar 3C279 as observed in 1993 during a moderately bright state. The data require time-dependent modeling, and this example from Hartman et al (2001) shows some possible components to the emission. If observed simultaneously, the MAXI data would constrain the synchrotron self-Compton component, while the GLAST LAT data would measure the Compton components arising from interactions of the same particles with external photon sources. Optical and radio observations would help constrain the synchrotron contribution, allowing a fairly complete model of the source as a function of time. Note that for this 1993 observation no X-ray data were available.

Blazars in particular are seen with a wide distribution of luminosities and spectra. 3C279 is a Flat Spectrum Radio Quasar with high luminosity and SED peaks at relatively low energies. High-Peaked BL Lac objects such as Mkn 421 have lower luminosities but SED peaks at higher energies. For such sources, MAXI would measure

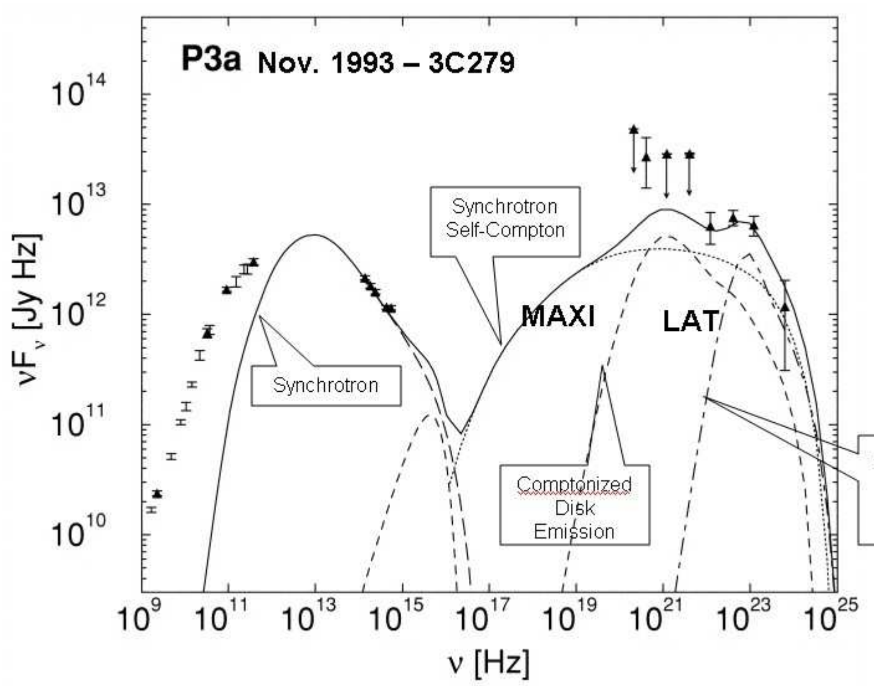

Fig. 3. Data and models for the 3C279 SED, adapted from Hartman et al (2001). The approximate one-week sensitivities of MAXI and GLAST LAT are shown by their names.

the synchrotron component directly, while GLAST LAT would measure the synchrotron self-Compoton component.

4.2. Gamma-ray Bursts

The GLAST GBM, along with other observatories such as Swift, will provide trigger information for gamma-ray bursts (GRBs). Both MAXI and GLAST LAT have some chance of seeing bursts directly, and both will be able to conduct afterglow studies. X-ray afterglows (e.g. Burrows et al 2005) are seen regularly from GRBs, potentially observable by MAXI for hours. Delayed high-energy gamma-ray emission was also seen for a small number of GRBs by EGRET on CGRO (e.g. Hurley et al 1994; Gonzales et al 2003), with components seen up to 90 minutes after the initial flash. The X-ray afterglows were not discovered until late in the CGRO mission, so that none of the EGRET-detected bursts had simultaneous X-ray measurements. MAXI and other X-ray telescopes will provide the first opportunity to determine the relationship, if any, between X-ray afterglows and delayed high-energy gamma-ray emission.

4.3. High-mass X-ray Binaries

Some high-mass X-ray binaries (HMXBs) have powerful winds that can accelerate particles and produce nonthermal emission, including both X-rays and gamma rays. An example is shown in Figure 4. LSI +61 303 has a 26 day period that produces a time-varying signal, although current studies are inconclusive about the nature of the emission. The summary of data and one possible model from Gupta and Böttcher (2006) illustrates the potential for coordinated study with MAXI and GLAST LAT. The X-ray range is likely synchrotron emission, while the gamma rays may be observing a transition between synchrotron and Compton radiation. Having simultaneous monitoring of this source and others like it will be important in resolving the processes important in this binary system.

4.4. Pulsars

Rotation-powered pulsars (as opposed to those powered by accretion) are particle accelerators. They can have nonthermal emission that provides insight into the strong gravitational, magnetic, and electric fields in the magnetospheres of these rotating neutron stars. The good timing capabilities of MAXI and GLAST LAT offer two particular possibilities for working together:

- Discovery of new X-ray and gamma-ray pulsars can be done by searching for short periodicities in sources. Most rotation-powered pulsars have been discovered in the radio band, but some have been found that are radio-quiet. Although MAXI and GLAST LAT have similar sensitivities in terms of energy, MAXI detects far more photons and therefore can potentially find pulse periods that could then be searched for in the LAT data. It is possible,

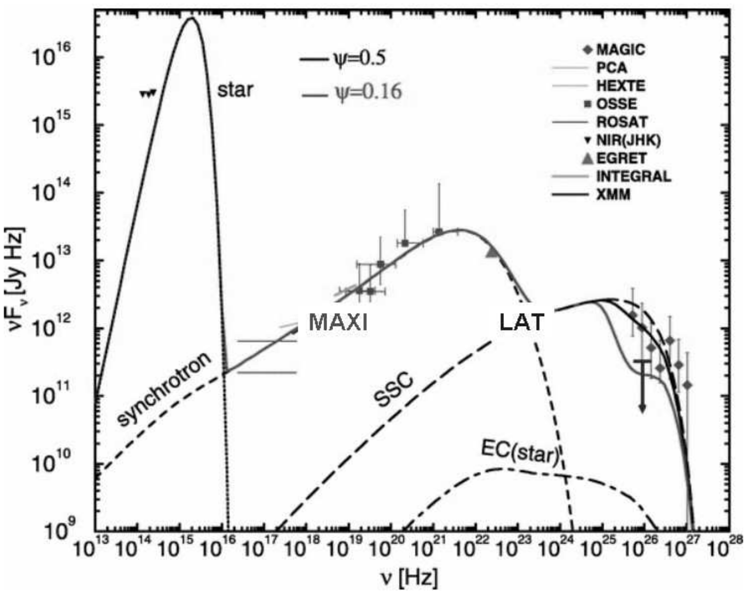

Fig. 4. LSI +61 303 SED, adapted from Gupta and Böttcher (2006). The approximate one-week sensitivities of MAXI and GLAST LAT are shown by their names.

too, that some pulsars could be discovered in the LAT data that MAXI might then search for; and

- For any pulsar seen in both energy bands, a comparison of light curves and energy spectra helps identify where and how the particle acceleration and interaction processes are taking place in the pulsar magnetospheres. An example is shown in Figure 5 (Thompson et al 1999). The X-ray and gamma-ray light curves differ in both shape and phase, suggesting different emission processes and locations.

4.5. Pulsar Wind Nebulae

Although pulsar wind nebulae (PWNe) are not by themselves compact objects, they are powered by pulsars and can exhibit time variability. The summary in Figure 6, from Nakamori et al (2008), shows why having simultaneous MAXI and GLAST LAT data will be valuable for PWNe studies. The X-rays seem well described as synchrotron radiation, implying high-energy electrons, but the gamma-ray origin is far less clear. Finding correlated time variability would be a strong argument in favor of a leptonic (inverse Compton) origin for the gamma rays rather than a hadronic (π°-decay) origin.

4.6. The Unknown - Source Identification and Study

Although the X-ray sky has been surveyed fairly thoroughly, the gamma-ray sky is far less understood. Over half the sources in the third EGRET catalog (Hartman et al 1999) remain unidentified. One of the major challenges for GLAST will be resolving the nature of these and other newly-discovered gamma-ray sources. Even with arcmin positions, spatial association is often inadequate to make a firm identification of a new source. Correlated variability, by contrast, is a high-confidence means of identification. The all-sky monitoring capabilities of MAXI and GLAST are extremely complementary for this type of identification.

5. Summary

With the launch of MAXI to the International Space Station next year and the continued operation of GLAST, astrophysics will have for the first time sensitive all-sky monitors in both both X-ray and gamma-ray bands. For nonthermal processes that are visible to both observatories, the opportunities for cooperation are extensive.

Acknowledgements

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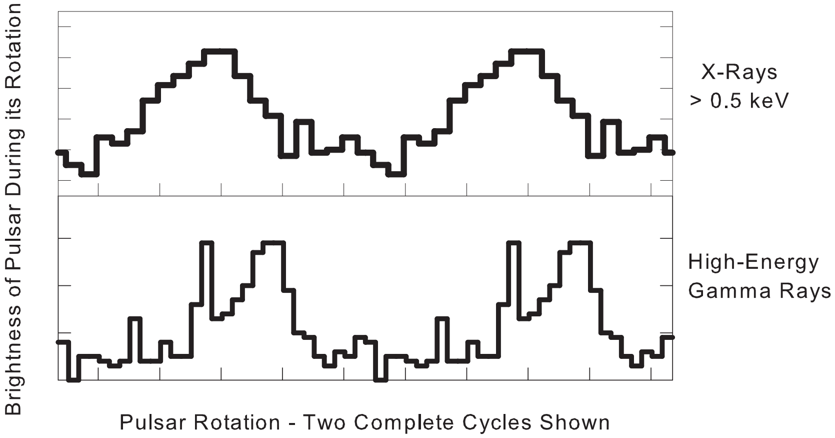

Fig. 5. X-ray and gamma-ray light curves (two cycles shown) of PSR B1055−52 (Thompson et al. 1999).

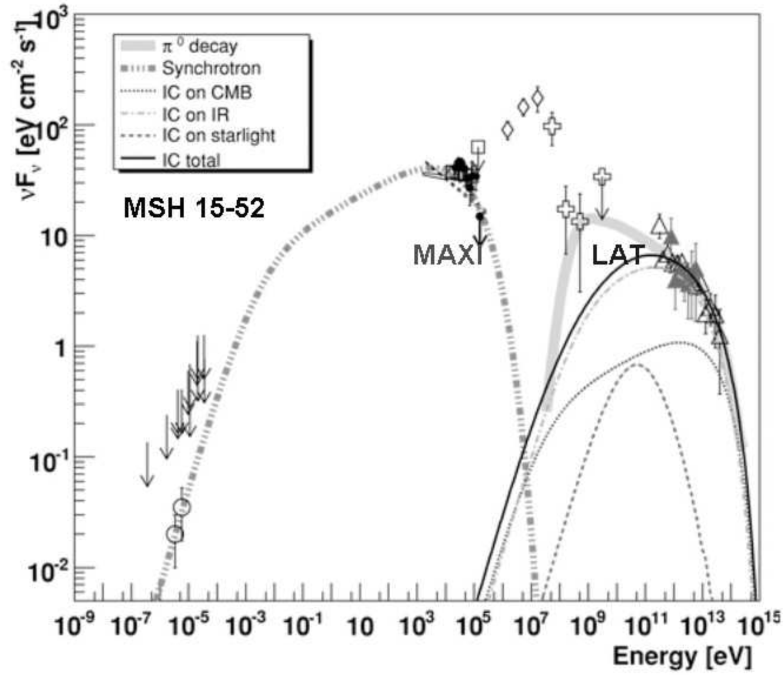

Fig. 6. MSH 15-52 SED, adapted from Nakamori et al (2008). The approximate one-week sensitivities of MAXI and GLAST LAT are shown by their names.