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GLAST Status and Prospects for Microquasars

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The Gamma-ray Large Area Space Telescope (GLAST) is a next generation high energy gamma-ray observatory due for launch in early 2008. The primary instrument is the Large Area Telescope (LAT), which will measure gamma-ray flux and spectra from 20 MeV to > 300 GeV and is a successor to the highly successful EGRET experiment on CGRO. The LAT will have better angular resolution, greater effective area, wider field of view and broader energy coverage than any previous experiment in this energy range. An overview of the LAT instrument design and construction is presented which includes performance estimates with particular emphasis on how these apply to strudies of microquasars. The nature and quality of the data that will be provided by the LAT is described with results from recent detailed simulations that illustrate the potential of the LAT to observe gamma ray variability and spectra.

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1. Introduction

GLAST is a next generation high-energy gamma-ray observatory designed for making observations of celestial gamma ray sources in the energy band extending from 20 MeV to more than 300 GeV. It follows in the footsteps of the Compton Gamma Ray Observatory EGRET experiment, which was operational between 1991-1999. The GLAST Mission is part of NASA's Office of Space and Science Strategic Plan, with launch anticipated in 2008. The principal instrument of the GLAST mission is the Large Area Telescope (LAT) that is being developed jointly by NASA and the US Dept. of Energy (DOE) and is supported by an international collaboration of 26 institutions led by Stanford University.

The GLAST LAT is a high-energy pair conversion telescope that has been under development for over 10 years with support from NASA, DOE and international partners. It consists of a precision converter-tracker, CsI hodoscopic calorimeter, plastic scintillator anticoincidence system and a data acquisition system. The design is modular with a 4x4 array of identical tracker and calorimeter modules. The modules are approximately 38 x 38 cm. Figure 1 shows the LAT instrument concept.

The LAT science instrument consists of an Anti Coincidence Detector

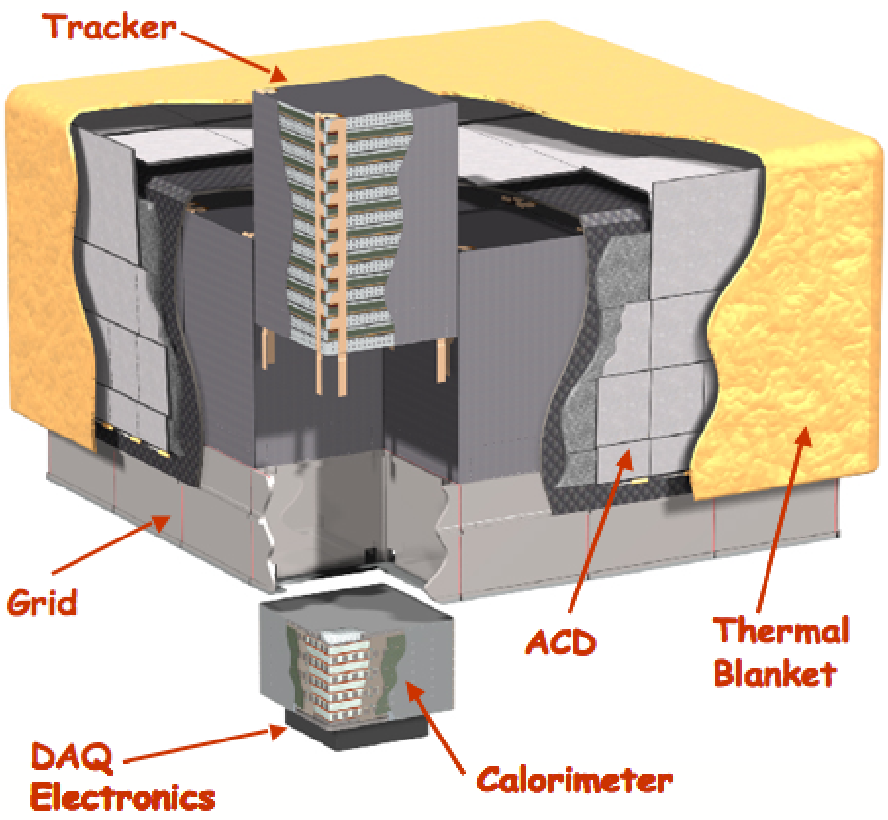

Figure 1: Large Area Telescope. Composed of 16 modules containing Tracker and Calorimeter elements, all surrounded by a scintillator anti-coincidence shield.

(ACD), a silicon-strip detector Tracker (TKR), a hodoscopic CsI Calorimeter (CAL), and a Trigger and Data Flow system (T&DF). The principal purpose of the LAT is to measure the incidence direction, energy and time of cosmic gamma rays while rejecting background from charged

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cosmic rays and atmospheric albedo gamma rays and particles. The data, filtered by onboard software triggers, are streamed to the spacecraft for data storage and subsequent transmittal to ground-based analysis centers. The Tracker provides the principal trigger for the LAT, converts the gamma rays into electron-positron pairs, and measures the direction of the incident gamma ray from the charged-particle tracks. The first 12 layers of converter are about 3% X_0, while the next 4 layers (back) are about 18%. This was done to optimize efficiency for photons interacting near the calorimeter. The tracker is crucial in the first levels of background rejection for providing track information to extrapolate cosmic-ray tracks to the ACD scintillator tiles, and it is important for further levels of background analysis due to its capability to provide highly detailed track patterns in each event.

In normal operations the LAT will continually scan the sky, obtaining essentially complete sky coverage every 3 hours (two orbits). This uniformity of sky coverage together with the large effective area and good angular resolution should permit many advances in the study of microquasars in the GeV range. The performance properties of the LAT are summarized in Table 1. The most current LAT performance specifications are kept online[1].

Table 1: LAT Energy and Angular Resolution

Energy Resolution	≈10% (≈5% off axis)
PSF (68%) at 100 MeV	3.5^0 front; 5^0 total
PSF (68%) at 10 GeV	0.1^0
Field of View	2.4 sr
Point Source Sensitivity (> 100 MeV)	$3\text{x}10^{-9}$ cm^{-2} s^{-1}

A second intrument on GLAST, the Glast Burst Monitor (GBM) provides complementary observations of gamma-ray bursts from 8 keV to 30 MeV. The GBM alone will provide excellent prompt spectral observations of hundreds of bursts per year. The GBM plays a crucial role in connecting the ground-breaking high-energy measurments made by the LAT to the better studied low-energy regime. The GBM will provide real-time burst locations over a wide field of view with sufficient accuracy to allow repointing the GLAST spacecraft. Time-resolved spectra of many bursts recorded by the LAT and the GBM will allow the investigation of the relation between the keV and MeV-GeV emission from GRBs over an unprecedented seven decades of energy.

1.1 Mission Status

At the time of writing, the GLAST observatory is on track for launch in early 2008. The instruments have been integrated onto the observatory with remarkably few serious problems. The LAT has been thoroughly tested in the integration process. The major steps remaining prior to launch are dynamics testing (acoustic and vibration) and TVAC (thermal-vacuum).

In the meantime, the ground system has been exercised with End to End tests, sending data from the observatory up to the geo-synchronous TDRSS satellites and then back through the ground elements: White Sands ground station; Mission Operations Center at Goddard Space Flight Center; the instrument operations centers at SLAC and Marshall Space Flight Center; and then finally back to the Science Support Center at Goddard for release to the public.

Table 2: Properties of the Simulated Microquasar Sources

Source	flux $(ph/s/m^2)$	spectral index	Comment
LSI +61 303	0.09	-2.21	full orbital modulation; uncrowded region
LS5039	0.046	-2.19	full orbital modulation; crowded region
Cyg X-3	0.02	-2.	short period
Cyg X-1	0.06	-3, -3.5	extension of X-ray spectra for 2 states
GRS 1915+105	0.12	-2.75	on 3 hours of every 12
GX 339-4	0.02	-2	on 25 days 3 times in a year
XTE J1118+480	0.06	-2.	model as two sources one degree apart

2. Feasibility Study for Microquasar Observations

EGRET provided the most recent window to the GeV sky, with most of its sensitivity in the 0.1-10 GeV range. The ground air Cerenkov telescopes are now providing the main observations into the high energy sky, revolutionizing the field and providing GLAST with indicators of where to look.

Up until now, the high energy catalogue for microquasars (X-ray binaries) was limited to two high mass X-ray binaries (HMXRB), LS5039 and LSI +61 303; no low mass (LMXRB) candidates have been observed above 100 MeV.

It is entirely possible that the two LS candidates are in fact, pulsars. Fortunately, MAGIC has recently observed[3] a high energy outburst from Cyg X-1 in conjunction with an X-ray flare. With any luck, the micro quasar class of sources will continue to provide surprises, so exploiting GLAST's all sky survey capability to continuously monitor candidates will be pursued.

This paper describes simulations of a variety of possibilities for how microquasars might manifest themselves, ranging from steady sources with orbital modulation to flaring sources with different duty cycles. Table 2 tabulates the source models and their motivations.

GLAST's Data Challenge 2 (DC2) provided a detailed simulation of the sky and the LAT's response. Five X-ray binaries were included with flux and spectra from EGRET measurements and known orbital periods. Fifty-five days of simulated orbit were created using a full GEANT4 simulation of LAT response, with full time dependence in the simulations for AGN, solar flares, GRBs. It took some 200k CPU hours to produce this rendition of the sky. This simulation demonstrated that the residual backgrounds, due to leakage of charged particle backgrounds into the photon sample, are negligible for point source analyses, and that the backgrounds are dominated by the galactic diffuse emission.

Given this realization, we have proceeded using fast observation simulations to study the sources. These simulations use parameterizations of the instrument response functions and effective area. This allows us to easily perform simulations for a range of parameters; full simulations for months to a year of orbit data are major undertakings and provide a comparison for one or two choices.

All sources are modeled as power law energy distributions. For as-yet undetected sources, we have set the spectral index to -2 and set the flux to EGRET's sensitivity of $2x10^{-6} ph/s/cm^2$. All simulations cover one orbit-year of operation.

2.1 HMXRBs

2.1.1 LSI +61 303

LSI +61 303[2] was chosen primarily as one of the famous microquasars and as an example of a relatively long orbital period with full modulation of its flux.

2.1.2 LS5039

LS5039 has a much shorter period, and is in a much more confused region of the sky than LSI +61 303, both in terms of much more diffuse background and nearby sources. Unlike at higher energies, no spectral index dependence on orbital phase is expected, so none were included, in contrast to the HESS[4] observations in the TeV range.

2.1.3 CygX-1

CygX-1 ironically was chosen as the example of extending[5] X-ray fluxes to 500 MeV. The high soft and low hard states were simulated as independent outbursts in time, with different, soft spectra.

2.1.4 Cyg X-3

CygX-3 is a short orbital period example.

2.2 LMXRBs

Since no high energy LMXRB candidates are known, we postulate that any emission would be correlated with radio jets during the disk-jet cycles that have been observed in these systems when they are in outburst. Typically this is a relatively short fraction of the full disk cycle. In the simulations we fluctuate the durations of all parts of the cycles, so start times and durations are randomized to avoid any artificial periodicities. Due to the relatively weaker stellar field densities, no significant orbital modulation of the flux is expected.

2.2.1 GRS 1915 +105

This source is one of the most famous radio/X-ray microquasars and has been remarkably reliable for being active. For this simulation, we have set the gamma ray emission to be active for three hours every half day.

2.2.2 GX 339-4

GX339-4 has been active[6] in recent times with outbursts lasting on the order of a year. We have modeled the gamma ray emission period as being on for 25 days three times in a year.

2.2.3 XTE J1118+480

A speculative model[7] for emission is from collision of the jets with clouds in the interstellar medium. For XTE J1118+480, the jets are modeled as extending 10 pc, with the source being about 1 kpc distant from earth, resulting in an approximately 1 degree separation of the sources for back to back jets. The test was to see if the observed source could be distinguished from a point source.

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3. Simulation Results

For initial studies into GLAST's capabilities in observing microquasars we concentrated on the two which have been measured in TeV gamma rays, by HESS[4] and MAGIC[2]. This work has been reported previously and illustrates the variation in detection difficulty with location on the galactic plane due to magnitude of diffuse background and nearby sources. Also demonstrated is the sensitivity to orbital modulation of the flux.

In this study, we are examining the effects of the diffuse background on the observability of our model sources, hence any other sources surrounding the candidate source have been suppressed artificially in the analysis.

3.1 HMXRBs

Fig 2 shows an l vs b distribution for LS5039 for the nominal flux as well as a fit to the energy distribution in a 5 degree cone about the source and for E > 100 MeV. At one year, LS5039 is clearly observable. This is in contrast to the previous study in which a higher energy cut was required together with a tighter angular cut. This indicates that the confusion from other sources in the vicinity significantly degrades our the ability to resolve this source.

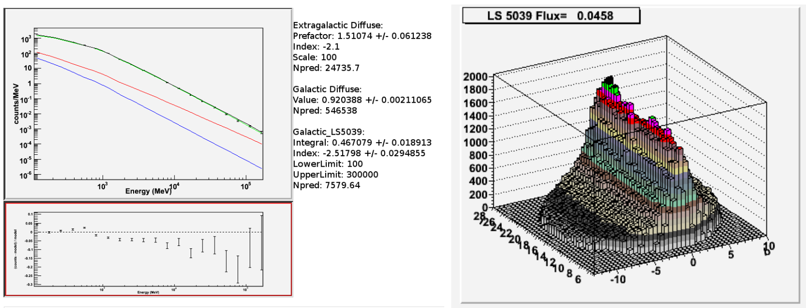

Figure 2: Left: Maximum likelihood fit and residuals to the LS5039 region, excluding other sources except for the diffuse backgrounds. Green: galactic diffuse; Red: extragalactic diffuse; blue: LS5039. Right: l vs b for this region, showing that LS5039 is just visible above the diffuse in this one year simulation.

Not surprisingly, as seen in Fig 3, the extension of the X-ray spectrum in Cyg X-1 is lost in the diffuse background for any reasonable estimate of the flux.

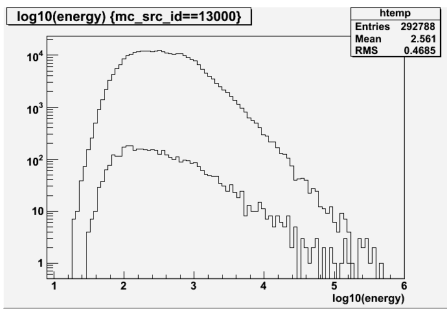

Figure 3: Counts vs $\log_{10}$E for diffuse and Cyg X-1 sources. Cyg X-1 is unobservable in this scenario.

Table 3: Expected Observable Fluxes for the Simulated Microquasar Sources

Source	min flux $(ph/s/cm^2)$	ratio to nominal	Comment
LSI +61 303	0.006	1/8	minimal diffuse
LS5039	0.046	1	full orbital modulation; crowded region
Cyg X-3	0.005	1/4	short period
GRS 1915+105	0.96	8	still must account for "on" time
GX 339-4	0.04	2	marginal at nominal flux
XTE J1118+480	0.008	1/8	minimal diffuse and confusion

3.2 LMXRBs

Fig 4 shows the l vs b distribution of events for GX339-4 for three fluxes bracketing nominal by a factor of two. After suppressing counts during quiescent periods, it can be seen that the source can only be resolved at twice nominal flux.

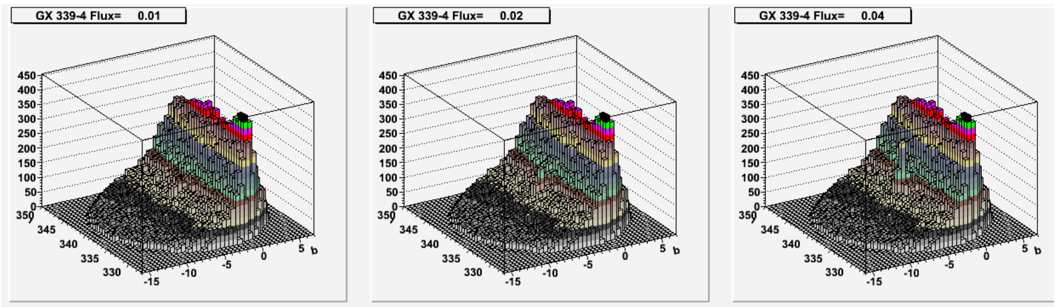

Figure 4: l vs b for three flux values bracketing nominal, by factors of 2. GX339-4 is just visible to the eye at nominal flux (middle plot).

Fig 5 shows the l vs b distribution for XTE J1118-480 for the emission lobes being at the same location and separated by one degree. The 2-site case is clearly resolvable from a point source.

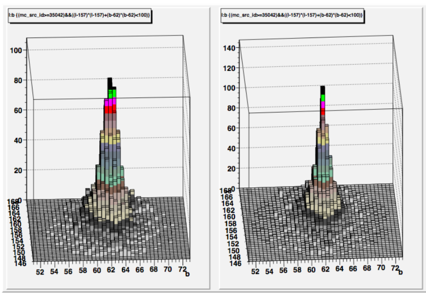

Figure 5: Left: l vs b for the source with 2 emission sites separated by one degree. Right: l vs b for this region,with one emission site.

Results of a systematic study of all the sources (except Cyg X-1) vs flux are shown in Table 3.

4. Conclusions

GLAST will launch in mid 2008 and provide a unique view of the gamma ray sky over the

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0.1-300 GeV energy range. The Observatory has been integrated at the time of writing and will undergo final TVAC testing before moving to Kennedy Space Flight Center for launch. The large field of view and survey mode of the LAT will allow us to monitor all the microquasar candidates on a continuous basis. At the time of writing, only Cyg X-1 has been observed at high energies; LSI +61 303 and LS5039 may be handed over to the pulsar camp.

For isolated sources in the galactic plane, with typical spectral indices around -2, we should expect observability from fluxes of $4.5x10^{-6} ph/s/cm^2$ near the galactic center, dropping to $0.5x10^{-6}$ $ph/s/cm^2$ far away from the center.

We expect sources with spectral indices greater than 3 will be very difficult to find above the diffuse background.

For a nearby spatially extended source far from the galactic center, we should be able to distinguish a one degree offset of emission centers from a point source.

Prior to launch we plan to extend our full simulations to a full year of orbit data and develop the machinery to observe all the microquasar candidates. We will develop strategies for multi-wavelength campaigns. The analysis machinery is nearly in place to find the surprises microquasars will have to show us.

5. Acknowledgements

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