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THE GAMMA RAY LARGE AREA SPACE TELESCOPE

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Abstract. The Gamma-ray Large Area Space Telescope, GLAST, scheduled for launch in early 2008, will measure cosmic gamma-rays in the energy range from 20 MeV to 300 GeV, with supporting measurements for gamma-ray bursts from 10 keV to 25 MeV. Its main instrument, the Large Area Telescope (LAT) is a pair-conversion telescope. With a sensitivity 25 times better than its predecessor EGRET, it will drastically improve our knowledge of the GeV sky, and thus, will shed light on a wide variety of high-energy phenomena. The GLAST mission is described, with particular focus on the LAT. The scientific objectives of GLAST are reviewed, concerning the diffuse emission, AGN, pulsars, GRBs, supernova remnants as well as searches for hypothetical new phenomena such as supersymmetric dark-matter annihilation.

1 The GLAST mission

The Gamma-Ray Large Area Space Telescope (GLAST, http://glast.stanford.edu/) is the next generation high-energy gamma-ray satellite. Its main instrument is the Large Area Telescope (LAT), a wide field of view gamma-ray telescope covering the energy range from 20 MeV to 300 GeV. A burst monitor, the Gamma-ray Burst Monitor (GBM), working in the 8 keV-25 MeV range, complements the payload. GLAST's expected lifetime is 5 years, with possible extension to 10 years. The GLAST collaboration includes agencies and universities from USA (NASA, DOE), France (IN2P3, CEA), Italy (INFN), Japan, Germany and Sweden.

1.1 Instruments description

The LAT consists of a 4 × 4 array of 16 modules as illustrated in Figure 1. Each module is constituted by a *tracker* to determine the direction of the incoming gamma-ray photon and a *calorimeter* which provides the associated energy. The 16 modules are shielded by an *anti-coincidence system* (ACD) to reject the background due to high energy cosmic rays. Each tracker has 18 x,y tracking planes made of single-sided silicon strip detectors. The first 12 planes (the front section of the tracker) are interlaced with tungsten plates to convert the incident gamma-ray into a e^+ e^- pair, each 0.03 radiation lengths (X_0) thick. The next 4 planes are interlaced with 0.25 X_0-thick converters, and the final 2 planes have no converter. The pitch is 228 μm, the total number of electronic channels is 884 736. A calorimeter module is made of 8 layers of 12 CsI crystals, 32 cm × 2.7 cm × 2 cm each, placed in individual carbon-composite cells. Each crystal is read out by 2 PIN diodes : a large one (1.5 cm^2) and a small one (0.25 cm^2). Two electronic chains are associated with each photodiode and therefore allow for 4 different dynamic ranges, up to 100 GeV full scale. Because of the limited weight budget, the calorimeter thickness is only 8.6 X_0. The ACD is based on segmented plastic scintillator tiles associated with photo-multiplier tubes through optical fibers. Its overall efficiency is 99.997%. Thanks to its segmentation, the self-veto due to "backsplash" particles is limited. The latter effect, which considerably affected EGRET performances at high energy, allows the LAT to maintain a good overall efficiency beyond 1 GeV.

The GLAST Burst Monitor includes 12 Sodium Iodide (NaI) scintillation detectors and 2 Bismuth Germanate (BGO) scintillation detectors. While the NaI detectors cover the low energy range (few keV-1 MeV), the BGO scintillators are dedicated to the ∼150 keV- ∼30 MeV energy range. Therefore, the GBM extends the spectral

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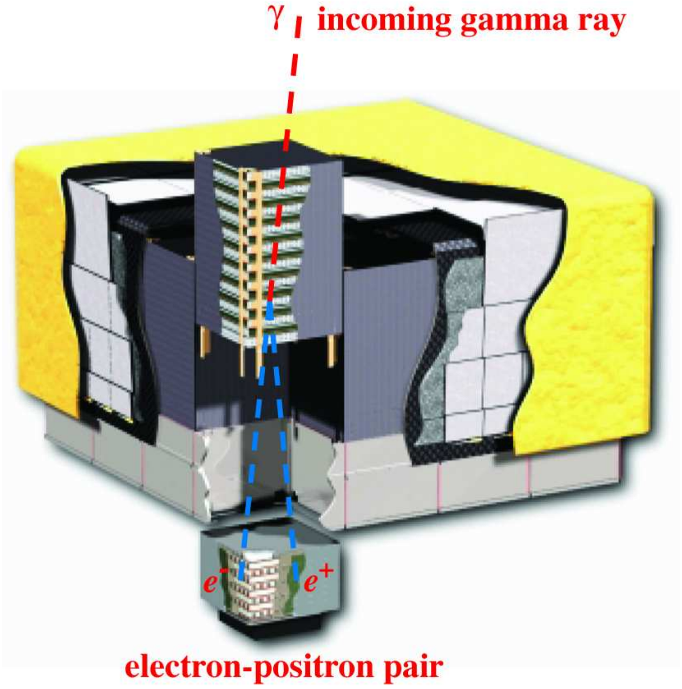

Fig. 1. Schematic view of the Large Area Telescope

coverage of GRBs by more than 3 decades below the LAT energy threshold. A field of view of about 10 sr is reached by spatially distributing the detectors on the spacecraft, without impacting the LAT field-of-view.

Both instruments are currently being integrated onto the platform. The team is now performing tests to accomodate launch date in early 2008.

1.2 Performance

Combining an effective area of almost 1 square meter and a field of view wider than 2 sr, the expected 1-year GLAST/LAT sensitivity (E>100 MeV) is 4×10^{-9} cm^{-2} s^{-1}. This is 25 times better than the limiting flux in the third and last EGRET catalog (Hartman et al. 1999). The GLAST orbit is a low earth orbit, with an altitude of 565 km and 23° of inclination; the resulting orbital time is about 90 min. Since the first year after launch will be devoted to a sky survey, the large LAT field-of-view, ~20% of the sky at a time, ensures the coverage of the full sky in 3 hours. The 1-day sensitivity of the LAT is approximatively equivalent to the point source sensitivity of EGRET for the entire mission.

Table 1 shows a comparison between GLAST/LAT and EGRET performance. A more detailed description of the GLAST/LAT performance is available at :
http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm.

2 Scientific objectives

Thanks to its very good sensitivity, GLAST is expected to detect a very large number of sources, most of them being more precisely located than possible in the EGRET survey. The source identification challenge faced in the EGRET era, mainly because of ambiguity in counterpart assignement, is then substantially different. On the one hand, the better localization capabilities of LAT will surely enable us to identify many more sources, at least for the bright and better located ones. However, this could be balanced by the expected large number of faint -with greater error boxes- sources. One of the challenges in the GLAST era will then be to reliably identify sources among already-known GeV classes, primarily blazars and pulsars, and, hopefully, to establish new classes, e.g. among the ones described in the following sections. The general problem of source identification in the era of deep all-sky coverage is adressed in Reimer & Torres 2007 while the particular efforts that are actually

Table 1. Comparison between GLAST/LAT and EGRET performances

	GLAST/LAT	EGRET
Energy range	20 MeV - 300 GeV	30 MeV - 30 GeV
Energy resolution	10%	10%
Effective area	$\sim$10000 cm^2	$\sim$1500 cm^2
Field-of-view	2.2 sr.	0.5 sr.
Angular resolution (FWHM), E=100 MeV	3.5°	5.8°
Angular resolution (FWHM), E=10 GeV	0.1°	0.5°
Sensitivity* (10^6s, E>100 MeV)	$\sim$4 10^{-9} cm^{-2} s^{-1}	$\sim 10^{-7}$ cm^{-2} s^{-1}
Deadtime	27 μs	100 ms

* LAT: 1yr, EGRET: 4.5 yr

undertaken with regards to the GLAST source identification issue are described in Lonjou & Knödlseder 2007 and Caraveo & Reimer 2007.

2.1 *Diffuse emission*

Generally speaking, the GLAST sky will be composed of a large number of point sources on top of a diffuse emission. In the context of GLAST data reduction, knowing the latter is essential to properly extract the signal from the point sources. On the other hand, the diffuse emission itself is a very important scientific topic linked to cosmology (extragalactic diffuse background) as well as to the cosmic ray origin and propagation (galactic diffuse emission). Both spatial and spectral distributions of the galactic diffuse emission will be measured with a unprecedented accuracy with LAT thanks to its large collecting area. This new measurement will enable us to address fundamental questions left open by EGRET. As an example, comparison with the predictions of the GALPROP model (Strong & Moskalenko 1998), initially developed to fit the EGRET data, will be used to constrain the cosmic-ray diffusion and acceleration in our Galaxy. The long-standing problem of the GeV excess observed by EGRET (Hunter et al. 1997) will be addressed by resolving point source and diffuse contributions to this emission.Diffuse emission will be studied with GLAST in other galaxies than the Milky Way. While EGRET wasn't able to resolve any structure in LMC, GLAST could be able to identify the most prominent emission regions as early as after 1 year of observation, depending on how structured the emission is (Weidenspointner et al. 2007). This could constitute a unique opportunity to the study cosmic rays origin and propagation in another galaxy.

2.2 *Blazars*

Blazars are among the most powerful sources of electromagnetic radiations in the Universe. The observed photons very probably originate from a relativistic jet that is closely aligned to the observer line of sight, in agreement with the unified model of radio-loud AGN (Urry & Padovani 1995). With about 100 sources identified by EGRET, with a majority being FSRQs, blazars constitute the largest known source class in the GeV range. They will largely dominate the GLAST sky too; the number of GLAST blazars is expected to be greater than one thousand when extrapolating the EGRET logN-logS curve down to the LAT 1-year sensitivity (Dermer 2007). This should allow for a major step forward in the understanding of the blazar phenomenon (Lott et al. 2007). In particular, the so-called "blazar sequence" (Fossati et al. 1998), positing a correlation between the position of the synchrotron peak and the source luminosity, and suggesting a possible evolutionary scheme linking FSRQs, LBLs, and HBLs, will be addressed using the GLAST blazar population. Another major scientific objective is to determine the nature of the jet particles as well as the geometry of the emitting region. Two families of models have been proposed: *leptonic* and *hadronic*; see Böttcher 2006 for a recent review. To disentangle these two hypotheses, broad-band modeling of various blazar spectra is required. Along this line, several multiwavelength campaigns are already in preparation- involving instruments working throughout the electromagnetic spectrum -from the radio to the TeV domain. A web page describing the multiwavelength activities involving the GLAST/LAT is available at :
https://confluence.slac.stanford.edu/display/GLAMCOG/GLAST+LAT+Multiwavelength+Coordinating+Group
High redshift blazars will also be used as a tool to determine the evolution of the density of the Extragalactic

Background Light via the attenuation of their high-energy spectra through e^+ e^- pair production.
Several *Radio galaxies* have been associated with EGRET sources. Moreover, highly variable TeV emission in M87 has recently been reported. This makes radio galaxies a good GeV source class candidate to be probe by GLAST.

2.3 Pulsars

With 6 high-condidence identifications and 3 candidates, EGRET has established pulsars as the second most numerous GeV source class. Mainly two competing classes of models, differing in the location of the emitting region, are proposed: namely the *polar cap* (Daugherty & Harding, 1996) and *outer gap* (Zhang & Cheng 1997) models. The predicted spectra exhibit different cutoff energies in the LAT range. Moreover, the emission beam size and the number of pulsars detectable by GLAST is also model-dependent. Using LAT observations, the number of firmly identified pulsars detected in the GeV range will increase significantly. This large high energy pulsar population will then be used to put stringent constraints on the physical processes at work. Among the 9 EGRET pulsars, J0218+4232 is the only millisecond one. LAT observations of this specific object should be able to confirm or revoke this ambiguous detection, and to discriminate between the two competing models, in only a few months (Guillemot et al. 2007). For a recent review of pulsar physics in the context of GLAST, see Harding 2007.

2.4 Gamma-ray bursts

Being the most powerful events in the Universe, gamma-ray bursts constitute an ideal tool for studying physical laws under extreme conditions and probing the Universe at very high redshift. The two GLAST instruments, the LAT and GBM, have been designed to provide a continuous spectral coverage in the 20 keV-300 GeV range. Moreover, a burst alert system will allow associated multiwavelength observations to be carried out promptly. GLAST is expected to discover about 200 bursts per year, of which about 60 will fall in the LAT field-of-view. The high energy emission of a gamma-ray burst contains information on the bulk Lorentz factor and the optical depth for the pair creation in the emission site. The physical origin of the high energy photons can either be synchrotron emission or inverse-Compton upscattering of lower energy photons. EGRET detected only four bursts with gamma-ray energies greater than 100 MeV, all of them having SEDs compatible power laws in that range. Combining a shorter deadtime and a larger collecting area, GLAST is expected to provide burst SEDs in the keV-GeV range with an unprecedented sensitivity. One of the primary goals will then be to determine the spectral energy cutoff in the LAT range and eventually constrain the mechanisms at work in these events.

2.5 Solar flares

EGRET observed gamma-ray solar flares involving photons with energies ranging up to 2 GeV. Several physical processes are considered to explain the observed radiations: Bremsstrahlung emission from energetic electrons, pion decay generated by proton and heavy ion interactions. GLAST will pin down where the acceleration takes place by resolving the acceleration site (spatial resolution down to 5'). On the other hand, the shape of the SED as well as its time evolution will constrain the physical processes responsible for the emission.

2.6 SNR et PWNe

SNRs and PWNs are sources of thermal emission seen at X-ray, GeV (for PWNs : Crab), and TeV energies. GLAST will help establish what the dominant emission process is (Compton scattering or pion decay)). Theoretical as well as observational facts suggest that SNR and PWNe will be new GeV source classes to be established by GLAST. On a theoretical point of view, SNRs are the actual best candidates to produce cosmic-rays with energy lower than the "knee" (10^{15}eV) via diffuse shock acceleration. They would also produce high energy photons via the decay of π^0 generated in p-p interaction. From observations, SNR and PWNe are known to be particles acceleration sites through the detection of hard X-ray synchrotron radiations. More recently, both SNR and PWNe have been established as TeV sources by ground-based Cerenkov telescopes. As a consequence, they are natural GeV source candidates that could be detected by GLAST. Together with X-ray and TeV measurements, GLAST observations will provide complete high energy SEDs of these objects that could help distinguish the possible physical mechanims. Future studies of SNR and PWNe planned with GLAST are reviewed in Funk 2007.

2.7 Others GeV source class candidates

- The nature of *Dark Matter* is one of the longest-standing enigmatic issue in Astronomy. GLAST could help to shed light the problem via the detection of WIMP annihilation in the GeV range. WIMP source candidates potentially detectable by GLAST include the galactic center (Morselli et al. 2007), the Milky Way halo (Sander et al. 2007) and WIMP galactic satellites (Wang et al. 2007). Spectral signatures in the extra-galactic spectrum from WIMP could also be detected (Bergström et al. 2007).
- Because of their similarities with AGN including the presence of accretion disk and sometimes relativistic jets, *binary systems*, and more specifically *microquasars*, are expected to produce high-energy gamma-rays. While these objects are prominent sources in the X-ray sky thanks to thermal emission from very hot plasma, there are observational evidences from non-thermal Synchrotron emission in the radio domain. This demonstrates the presence of relativistic electrons which can potentially emit in the LAT range too. Dubus 2007 summarizes GLAST prospects with regards to binaries and microquasars.
- *Massive stars* are suspected to produce high-energy non-thermal photons via different physical processes happening in their colliding winds. This idea is strengthened by the multiple associations between massive binary systems with EGRET unidentified sources and, more recently, TeV unidentified sources. Reimer et al. 2006 investigates the case of WR+OB system and predicts that WR140 and WR 147 could be detectable by the LAT.
- Millisecond pulsars are believed to emit in the LAT energy through curvature radiations, EGRET having however only marginally detected one of them. A large fraction of radio ms-pulsars are members of *globular clusters*. GLAST may detect their collective emission (Harding et al. 2005).
- One *normal galaxy* has already been detected by EGRET: LMC. Its detection at a high significance level is granted with GLAST. Others normal galaxies could be detected; natural candidates are nearby ones like M31 or SMC. Although *starburst galaxies* are located at larger distances than the latter, their greater star formation rate, and so their secondary cosmic-ray induced GeV emission, are much higher than in normal galaxies. Therefore, some starburst galaxies, like NGC253 and M82, could be within reach of GLAST (Domingo-Santamaria & Torres 2005).
- *Cluster of galaxies* observations in the radio, UV and X-ray domain suggest the presence of non-thermal emission. An average 2σ upper limit from 58 individuals clusters of galaxies of $6\ 10^{-9}$ cm^{-2} s^{-1}, E>100 MeV has been reported by Reimer et al. 2003 using EGRET data. This flux is above the 1-year LAT sensitivity for a single source therefore GLAST will, at least put much more severe constraints on this upper limit, and maybe discover the first cluster of galaxies in the GeV range.

3 Conclusion

Thanks to a sensitivity over an order of magnitude better than its predecessor EGRET, GLAST will revolutionize our view of the high energy sky. Synergy with AGILE and the ground-based Cerenkov telescopes operating at higher energies will be beneficial to the field. The upcoming original LAT data will be used to address fundamental questions left open by EGRET. Among the latter, the most prominent one is very probably the nature of the numerous unidentified gamma-ray sources, an issue closely linked to the establishment of new GeV source classes. On the other hand, substantial progress is expected in the understanding of the already established GeV source classes.

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