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GLAST: Status and science simulations

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Abstract. In this talk we will describe the development status of the Gamma-ray Large Area Space Telescope (GLAST). We will also present the most recent simulations of the scientific capability of the mission. The latter includes simulations of the diffuse gamma rays expected from supernova remnants, the Magellanic clouds, and M31.

1 Introduction

The Gamma-ray Large Area Space Telescope (GLAST), a mission for high-energy gamma-ray astronomy, is under development for launch in spring 2006. It is being supported by NASA and the DOE in the U.S. and by institutions in France, Germany, Italy, Japan, and Sweden. The primary science instrument on GLAST will be the Large Area Telescope (LAT, principal investigator P. Michelson, Stanford Univ.), which by a large margin will be the most sensitive high-energy gamma-ray telescope ever flown. (The secondary instrument, not discussed here, is the GLAST Burst Monitor, which will detect gamma-ray bursts over a large solid angle with energy range from the hard X-ray to the lower end of the sensitivity of the LAT.)

Like previous gamma-ray telescopes, the LAT will convert gamma rays into positron/electron pairs for tracking and energy measurement. The LAT will be the first to have a modular, solid state design (see Fig. 1) which offers the advantages of large effective area, good angular resolution, a very wide field of view, very short readout deadtimes, and no consumables (Michelson et al., 1999). The anticoincidence detector for charged particles will be tiled so that photons with very high energies are not vetoed by the backsplash they create in the calorimeter. The minimum specifications and derived performance of the LAT (GLAST Science Req. Doc., 2000) are compared in Table 1 with the Energetic Gamma-Ray Experiment Telescope (EGRET) that was part of the Compton Gamma Ray Observatory, which operated in 1991–2000. The large gain in sensitivity of the LAT relative to EGRET results from the combination of improved angular resolution, much greater effective area, larger FOV, and an observing strategy that maximizes observing efficiency by avoiding Earth occultation (see Sect. 2).

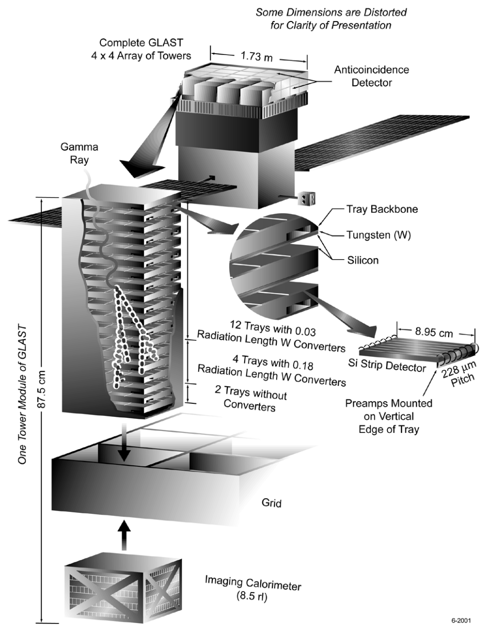

Fig. 1. Exploded view of the LAT showing the modular design of the instrument. Each of the 16 towers has a silicon strip tracker with converter foils interleaved with the detector layers and a hodoscopic calorimeter of CsI. The conversion of a gamma ray, and the tracking of the e^+e^- pair are indicated schematically. The entire assembly is covered by an anticoincidence system of plastic scintillator tiles that are individually read out.

The scientific goals of the GLAST mission are very broad, and include studies of high-energy phenomena ranging in distance from solar flares to gamma-ray bursts at large redshifts. GLAST is expected to detect thousands of gamma-ray

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	EGRET	LAT
Energy Range (MeV)	$20 - 3 \times 10^4$	$20 - 3 \times 10^5$
Peak Effective Area[1] (cm^2)	1500	> 8000
Field of View (sr)	0.5	> 2
Angular Res.[2] @ 100 MeV	$5.8°$	$< 3.5°$
Angular Res.[2] > 10 GeV	$0.5°$	$< 0.15°$
Energy Resolution[3] (%)	10	< 10
Deadtime per Event (μs)	10^5	< 100
Source Location[4]	15′	$< 0.5′$
Flux Lim.[5] (10^{-7} cm^{-2} s^{-1})	~ 1	< 0.06

[1] After background rejection
[2] Single photon, 68% containment, on-axis
[3] 1-σ, on-axis
[4] 1-σ radius, flux 10^{-7} cm^{-2} s^{-1} (> 100 MeV), high $|b|$
[5] > 100 MeV, high $|b|$, 1-year sky survey, photon index -2

Table 1. GLAST LAT minimum specifications relative to EGRET

point sources, principally blazars, and will discover many new gamma-ray pulsars. It will likely permit identification of the large fraction of EGRET sources that remain unidentified, including the source at the Galactic center. And GLAST will be used to search for $\gg 1$ GeV spectral lines from decays of weakly-interacting massive particles, a dark matter candidate, in the halo of the Milky Way. In this paper, we will discuss only the cosmic-ray aspects of GLAST science (Sect. 3), along with some details about the mission and the guest observer program.

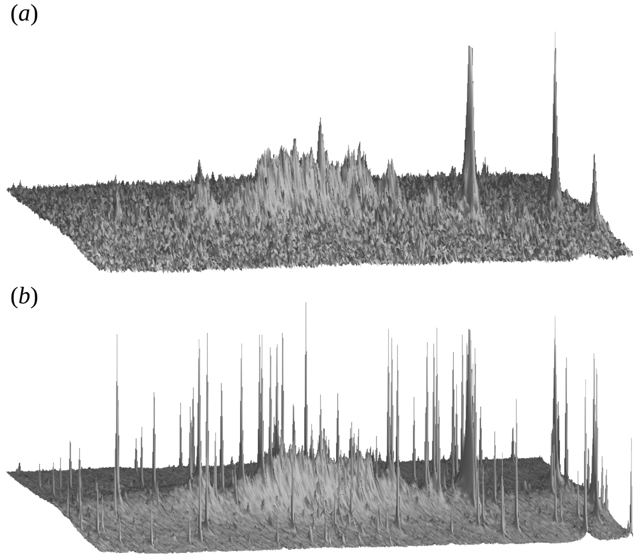

Fig. 2. (a) Gamma-ray intensity (> 100 MeV) observed by EGRET for latitudes $|b| < 20°$ represented as a shaded surface. The broad ridge of interstellar emission along the Galactic equator is evident, along with a number of point sources. The brightest of these are the Vela, Geminga, and Crab pulsars. Data for Phases 1–5 were combined for this figure. (b) Intensity map from a simulated 1-year sky survey with GLAST. The energy range and intensity scaling are the same as in (a). The simulation includes all sources in the 3EG catalog (Hartman et al., 1999) and a distribution of sources below the flux limit of EGRET. Intensities are truncated at 2×10^{-3} cm^{-2} s^{-1} sr^{-1}.

2 GLAST mission plan and guest observer program

After a 30–60 day in-orbit checkout, the science phase of the mission will begin with a 1-year all sky survey. The LAT has a very wide field of view (> 1.6 sr with $> 1/2$ on-axis effective area) and the spacecraft is designed to point anywhere at any time. In order to optimize the exposure to the sky, GLAST will avoid pointing its large FOV toward Earth; during the survey GLAST will nominally be zenith pointed, rocking north and south about the orbit plane in order to obtain full sky coverage every two orbits and uniform exposure on scales of weeks. A catalog of point sources, projected to contain $\sim 10^4$ sources, will be derived from the sky survey data by the LAT instrument team.

At all times, including during the first year, data from transient sources discovered or detected by GLAST will be made public immediately in order to facilitate follow-up observations in other wave bands. During this first year, the survey may be interrupted a few times to follow such transient sources for several orbits to maximize sampling of the time history of the gamma-ray emission.

GLAST will have a robust guest observer program. Some observers will be selected by competitive proposal review to study previously known or suspected gamma-ray sources during the sky survey. Following the survey, the observing program will be science driven, based on peer-reviewed proposals, and no observing time will be reserved for the instrument team. The community will access the GLAST data and analysis software through a GLAST Science Support Center. The design life of GLAST is 5 years and the goal for mission operations is 10 years.

Cosmic-ray researchers will be interested to know that the LAT team will construct a model of the diffuse Galactic emission as part of its responsibility for producing the source catalog. A detailed model is necessary to detect, and obtain accurate positions for, low-latitude point sources. Conversely, the point-source contribution must be carefully determined when analyzing the interstellar gamma-ray emission, especially along the Galactic equator. The Galactic emission model, which will be refined based on LAT observations, is to be publicly released along with the survey data and catalog.

3 Cosmic-ray studies with GLAST

Cosmic-ray collisions with interstellar gas and photons in the Milky Way produce diffuse high-energy gamma-ray emission. For cosmic-ray protons in particular, these interstellar gamma rays are the only way to study their spectra and spatial distribution outside the solar system. With EGRET, many advances were made in the understanding of cosmic rays via interstellar gamma-ray emission. EGRET had relatively large effective area, good angular resolution, and ex-

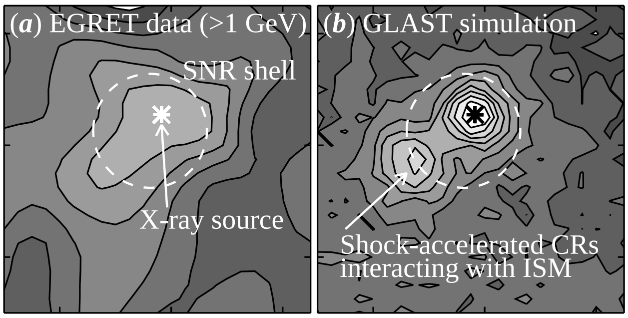

Fig. 3. (a) EGRET observation (Phase 1–4 summed); (b) GLAST simulation (1-year sky survey) of the γ-Cygni SNR. Both images are for energies > 1 GeV. The dashed circle is the location of the shell (Higgs et al., 1977). The spacing of the tick marks is 1°. See text for discussion of the γ-Cygni model.

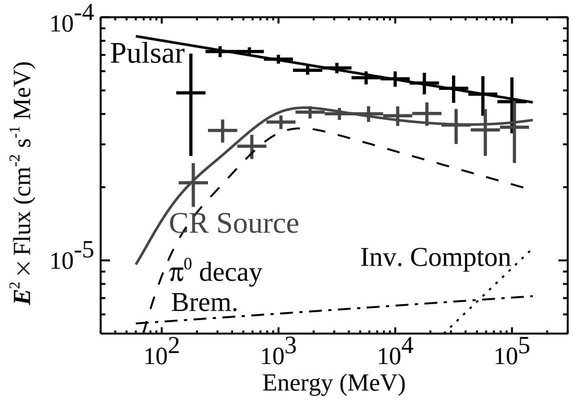

Fig. 4. Simulated measurements with GLAST of the spectra of the pulsar and CR source for a 1-year sky survey.

cellent charged particle background rejection, qualities necessary for studying diffuse emission. Figure 2, which compares EGRET observations of the Milky Way with simulated data from the GLAST sky survey, gives a qualitative sense of the potential for advances with the LAT, especially regarding potential confusion of point sources with diffuse emission. Some topics are explored more quantitatively below.

3.1 Cosmic-ray production

Supernova remnants (SNR) have long been suspected to be the acceleration sites of cosmic rays, and for cosmic-ray electrons the detections of X-ray (synchrotron) and TeV gamma-ray (inverse Compton) emission from some SNR (e.g., Koyama et al. 1995) have confirmed the suspicion. For cosmic-ray protons, however, the proof will likely have to come from gamma-ray observations of π^0 decay emissions in the energy range of GLAST from collisions in adjacent interstellar clouds.

The evidence from EGRET for production of cosmic-rays in SNR is inconclusive. Several unidentified EGRET sources are coincident with SNR associated with dense interstellar clouds (e.g., Romero et al., 1999). But the angular resolution and photon statistics are insufficient to determine whether the sources are spatially extended or point-like (e.g., pulsars) and whether the spectra have the characteristic shape of π^0 decay emission.

GLAST should be able to determine the natures of some of the EGRET source/SNR associations. Figures 3 and 4 illustrate how GLAST could spatially resolve the γ-Cygni SNR (angular diameter $\sim 1^\circ$) and measure the π^0 component of the spectrum of an interstellar cloud at the edge of the shell. An X-ray source with the characteristics of a pulsar has been discovered within the shell, and has been proposed as the gamma-ray source that EGRET detected in γ-Cygni (Brazier et al. 1996). For the GLAST simulation, it was assumed that the flux that EGRET measured could be assigned in a 60:40 ratio to the X-ray source and to a source at the edge of the shell in the direction suggested by the EGRET intensity map. The spectrum of the CR source was chosen to be consistent with models for the gamma-ray emission of SNR (Gaisser et al. 1998). The diffuse emission of the Milky Way was also included in the model; for more details of the γ-Cygni model, see Allen et al. (1999). The simulation shows that GLAST could spatially resolve the SNR at energies > 1 GeV and measure the spectral components separately at energies as low as ~ 200 MeV.

3.2 External galaxies

With GLAST, study of cosmic rays via interstellar gamma-ray emission will not be limited to the Milky Way. EGRET detected only one external galaxy in diffuse emission, the Large Magellanic Cloud (LMC), and could not resolve it from a point source. GLAST will map the interstellar emission of the LMC (Fig. 5) as well as its fainter companion, the Small Magellanic Cloud. It will likely spatially resolve the diffuse emission of M31 and detect as point sources several other local and starburst Galaxies (Blom et al., 1999) as well. Observations of external galaxies will test models of cosmic-ray production and propagation, including coupling of cosmic rays to the interstellar gas, without the disadvantages suffered by studies of the Milky Way from our in-plane perspective.

4 Conclusions

The LAT instrument on GLAST will be by far the most sensitive high-energy gamma-ray telescope yet flown and promises a number of advances for the study of cosmic rays. Within the Milky Way, GLAST will resolve embedded point sources from interstellar emission and may detect evidence of the production of cosmic-ray protons by SNR. GLAST will extend to external galaxies the use of interstellar emission as a tool for studies of cosmic rays. A competitive guest observer program will be implemented to maximize the scientific return from the great potential of GLAST.

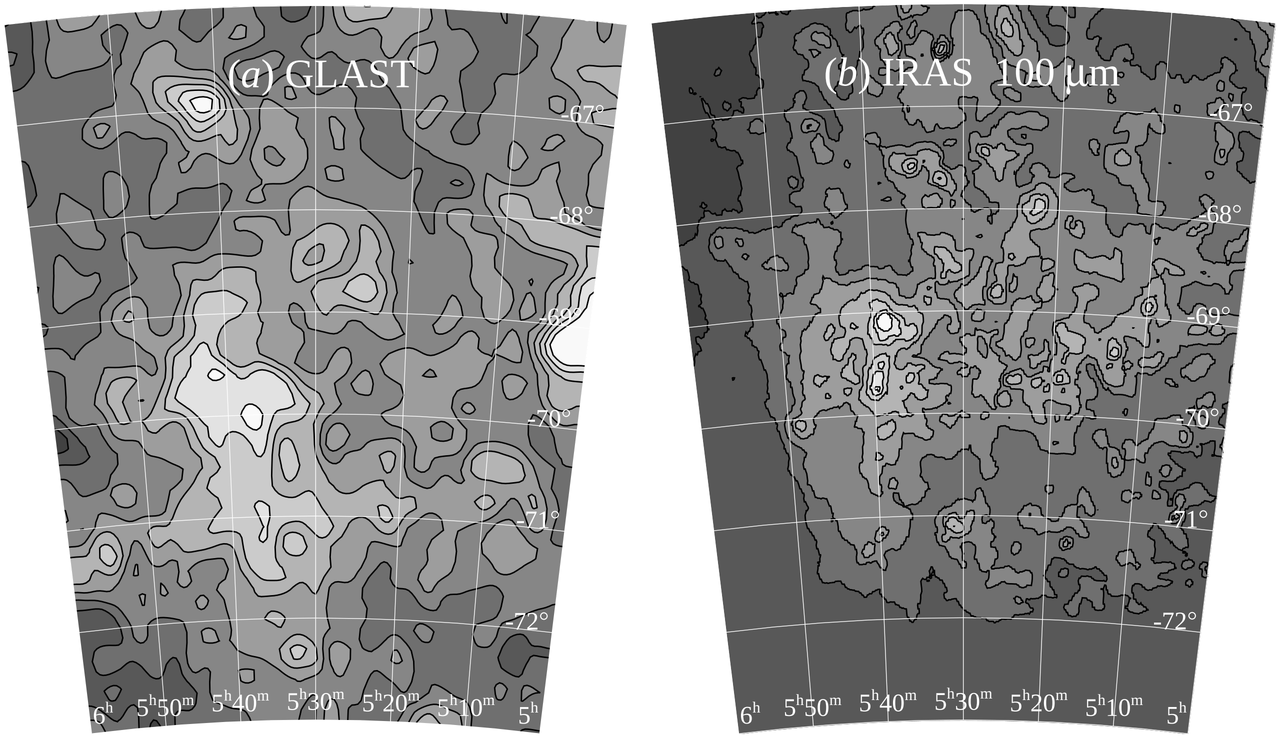

Fig. 5. (a) Gamma-ray intensity map (> 100 MeV) of the LMC from a simulated 1-year sky survey with GLAST. The diffuse emission of the LMC is assumed to be described by the model of Sreekumar (1999) and the simulation also includes the foreground interstellar emission from the Milky Way along with a distribution of background point sources. The latter, several of which are apparent in the image, have an integrated intensity consistent with the extragalactic isotropic emission observed by EGRET but are all fainter than the EGRET flux limit. The image has been smoothed to reduce statistical fluctuations, and the contours are spaced by 7.5×10^{-6} cm^{-2} s^{-1} sr^{-1} from 2.5×10^{-6} cm^{-2} s^{-1} sr^{-1}. (b) Infrared intensity map of the LMC (IRAS 100 μm), showing the extent of the dense interstellar medium and star formation. The diffuse emission at this wavelength traces the dust in the interstellar medium. The most intense areas are regions of massive star formation. The contours are logarithmic from 1 MJy sr^{-1} to 800 MJy sr^{-1}.

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