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GLAST Large Area Telescope - Daily Survey of High Energy Sky

Tuneyoshi Kamae[a]*

[a]Stanford Linear Accelerator Center, Sand Hill Road,
Menlo Park, California 94025, USA

GLAST Large Area Telescope was proposed to NASA in 1999 as a follow-up of EGRET on-board Compton Gamma-Ray Observatory by an international collaboration. The proposal has been approved as a part of the GLAST observatory mission in its capability to explore a wide range of astrophysics with 5-40 times higher sensitivity and extended energy coverage (20MeV to 300GeV) than EGRET.

The instrument consists of 16 towers of e+e- pair tracker, 16 blocks of segmented electro-magnetic calorimeter, and a set of anti-coicidence plastic scintillator tiles covering the tracker towers. It will have 5-10 times larger on-axis effective area, 6 times wider field-of-view (FOV), and up to 5 times better angular resolution when compared with EGRET.

The Large Area Telescope will cover about 40% of the sky above the Earth's horizon in its FOV at any given time and will scan nearly the entire Universe every orbit ($\sim$ 90min): about 20% of Gamma-Ray Bursts will be observed from the onset of the bursts to the initial after-glow phase; all longer-lasting transients and variabilities will be detected daily at the improved sensitivity.

The instrument has been prototyped twice between 1995 and 2001, designed almost to the Flight Model by the international collaboration of the US (NASA and DoE), France, Italy, Japan, and Sweden. The first prototype consisted of one tower of e+e- pair trackers, one block of segmented calorimeters and a smaller set of anti-coicidence plastic scintillator tiles (Beam Test Engineering Model, BTEM), which was put into e^+, p, and γ beams at SLAC in the winter of 1999-2000. It was subsequently modified for a balloon experiment (Balloon Flight Engineering Model, BFEM) and flown at Palestine, Texas in August 2001. Data collected in the test experiments have been analyzed and compared with predictions of computer simulation codes such as Geant4. These studies have confirmed validity of the basic design, brought up a few issues for further improvement, and gathered data on the cosmic-ray background expected in the orbit.

All subsystems of GLAST-LAT are scheduled to be completed and come to SLAC in 2005 for integration. The integrated instrument will go through a set of tests before being integrated onto the spacecraft. The spacecraft will be put into a Low Earth Orbit (altitude $\sim 450-550$km) in the fall of 2006 and the LAT will begin collecting data after the commissiong phase. The astronomical gamma-ray data collected in the observation will be processed by the LAT team and archived for public use GLAST Science Support Center at Goddard Space Center in Greenbelt, Maryland.

1. Introduction to GLAST Large Area Telescope

The Gamma-ray Large Area Space Telescope (GLAST) Observatory Mission has two instruments aboard the spacecraft: the Large Area Telescope (LAT) and the GLAST Burst Monitor (GBM) (see the websites given in reference [1]). The present paper deals with Large Area Telescope . The GLAST-LAT collaboration consists of scientists, engineers, and technicians from the US, France, Italy, Japan, and Sweden. Funding in the US comes from NASA and Department of Energy.

GLAST-LAT is designed to measure the direction and energy of gamma-rays between 20MeV and 300GeV [2]. This energy coverage is substantially broader than that of EGRET [3] and corresponds to the band where attenuation by Inter Steller Matter (ISM), Extragalactic Background Light (EBL), and Cosmic Microwave Background (CMB) is minimum. It is capable of detecting gamma-rays produced at cosmological dis-

*For the GLAST-LAT collaboration.

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tance by dark matter particles, jets and flares of Quasars and AGN, Gamma-Ray Bursts, and other yet-to-be-discovered sources.

The LAT instrument is different from the typical X-ray astronomy satellite instrument in several respects, as will be described below. The number of independent sensor channels is nearly 10^6 and sophisticated on-board data processing is required to remove high rate of background events. These features pose some challenge: several rounds of prototyping and testing, such as the beam test with Beam Test Engineering Model [4] and the balloon experiment with Balloon Flight Engineering Model [5], and computer simulations have been essential in verifying the instrument design.

1.1. Instrument

GLAST-LAT, as shown in Fig.1, consists of 16 towers of e+e- pair tracker made of 18 sets of X and Y layers of single-sided silicon strip detectors, 16 blocks of calorimeter made of 8 layers of CsI(Tl) logs, and a set of anti-coicidence plastic scintillator tiles. Sixteen tungsten foil converters are inserted between the tracker layers to enhance for $\gamma \rightarrow e^+e^-$ pair conversion. Components on these layers are listed in Table 1. The total radiation length along the axis of the LAT comes out to about $10X_0$.

GLAST-LAT will have $\sim 5-10$ times larger on-axis effective area, $\sim$ 6 times wider field-of-view (FOV), and $\sim 1-5$ times narrower angular resolution than EGRET (see Fig.2). These improvements are expected to bring $\sim 5-40$ times higher sensitivity for point gamma-ray sources,

Combined with transparency of the Galaxy and Universe to gamma-rays of its energy coverage, GLAST-LAT will have unique ability to uncover hidden sources and structures of our Galaxy and reach out to z>>1 to much higher precision than EGRET did in its $\sim$ 10 year life.

Another important strength of GLAST-LAT lies in its wide field-of-view (FOV). The e^+e^- pair tracking was done by a spark chamber in EGRET whereas GLAST-LAT will do by layers of silicon strip detectors covering a total area of $\sim$ 75m^2. This large SSD coverage combined with the large calorimeter will give us nearly 2.5sr of field-of-view. LAT will survey $80-90\%$ of sky every orbit ($\sim$ 90min), reaching EGRET's 1 year sensitivity just in 2 days (see Fig.3). No observatory in the entire photon spectrum has ever done such complete and frequent survey in the past. The LAT will keep vigil for any transients including Gamma-Ray Bursts and AGN flares. It will also detect many interesting longer term variabilities which may reflect varying environment around Black Holes, Supernova Remnants, Pulsars, Binary Systems and AGNs.

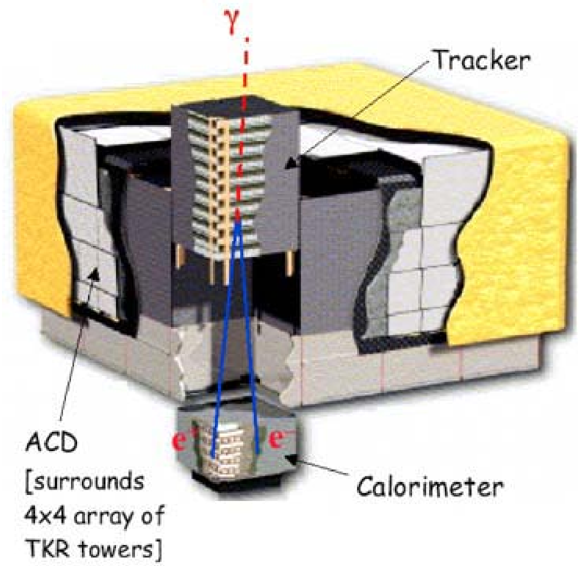

Figure 1. GLAST Large Area Telescope: one corner is cut open to show a tracker tower and a calorimeter.

1.2. Data acquisition, event filtering, and downlink

The data acquisition and subsequent event filtering required aboard the satellite will be quite challenging compared to any previous satellite missions known to the present author.

Data acquisition starts with the Level-1 Trigger which requires one or more hits in contiguous 6 layers in any one of the 16 tracker towers. A

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Table 1
Major dimensions of the LAT tracker, calorimeter and ACD.

Components	No. of units	Unit size ($l \times w \times t$)	Comments
SSD layer	16 SSDs	$89.5 \times 89.5 \times 0.4\text{mm}^3$	384 strips per SSD at 228μm pitch
W converters	16 planes		12: 3%X_0, 4: 18%X_0 2: 0%X_0
Cal. layer	12 CsI logs	$326 \times 26.7 \times 19.9\text{mm}^3$	alternately laid to form 4 X and 4 Y layers
ACD	89 tiles	10 & 12mm thick tiles	4 ribons ($w = 12$mm) of sq. scinti fibers added

cosmic-ray model and Geant4 based simulation of the instrument predict this trigger to be at $\sim 5-10$kHz with the following composition: primary and secondary protons ($\sim$ 40%, see Fig.4 for their model spectrum), primary alpha partilces ($\sim$ 4%), primary and secondary e^+e^- ($\sim$ 20%), seconday muons ($\sim$ 15%), atmospheric gamma-rays ($\sim$ 20%).

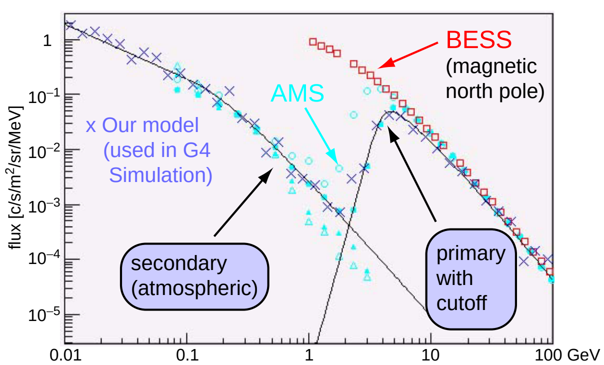

Figure 4. Model spectrum for cosmic-ray protons for the balloon experiment at Palestine, Texas. We expect a similar spectrum in the Low Earth Orbit. Note that the flux depends on the magnetic rigidity of the satellite location.

For all triggers, a set of hit patterns will be read in by the on-board program for initial filtering which will reduce the rate down to $\sim 100-200$Hz. The program will then read in digitized data from the tracker, calorimeter and ACD, and filter out background events down to about $\sim 30-50$Hz. We expect astronomical gamma-ray contribution to the Level-1 Trigger to be at $\sim 5-10$Hz.

These filtered events ($\sim$ 30 $-$ 50Hz) will be transmitted to ground, typically 5 times a day, and will processed by more elaborate reconstruction and filtering programs.

For Gamma-Ray Bursts (GRB) and other prominent transient phenomena, the mission will establish a faster radio link through Tracking and Data Relay Satellite System (TDRSS). When such phenomena are detected, alerts and calculated coordinates will be distributed worldwide through the Internet within $\sim$ 6 sec. of the detections [2].

1.3. Gamma-ray reconstruction and possible background

Despite a large FOV, the LAT will reconstruct photon directions rather accurately. The e^+e^- will be tracked by silicon strip detectors to about its channel pitch (228μm) before they develop to a shower. The segmented CsI(Tl) calorimeter also has tracking capability: the scintillation light from a log will be measured at the two ends by a small and a large photodiodes, allowing the centroid of energy deposition to be calculated to $\sim$ 5mm accuracy. If the reconstructed axis of the shower in the tracker and calorimeter agree, the longitudinal and lateral shower profiles in the calorimeter will be examined. If all come out to be consistent with a gamma-ray coming from above the Earth's horizon, the event will be regarded as a valid astronomical gamma-ray.

Angular resolution or Point Spread Function (PSF) of the directional measurement will be dominated by multiple scattering of the e^+e^- pair at low energies ($E <$ 1GeV: e.g. σ = 3.5deg for 100MeV photons) and by tracking precision of the SSDs at higher energies ($E >>$ 1GeV: e.g. σ = 0.15deg for 10GeV photons). We note

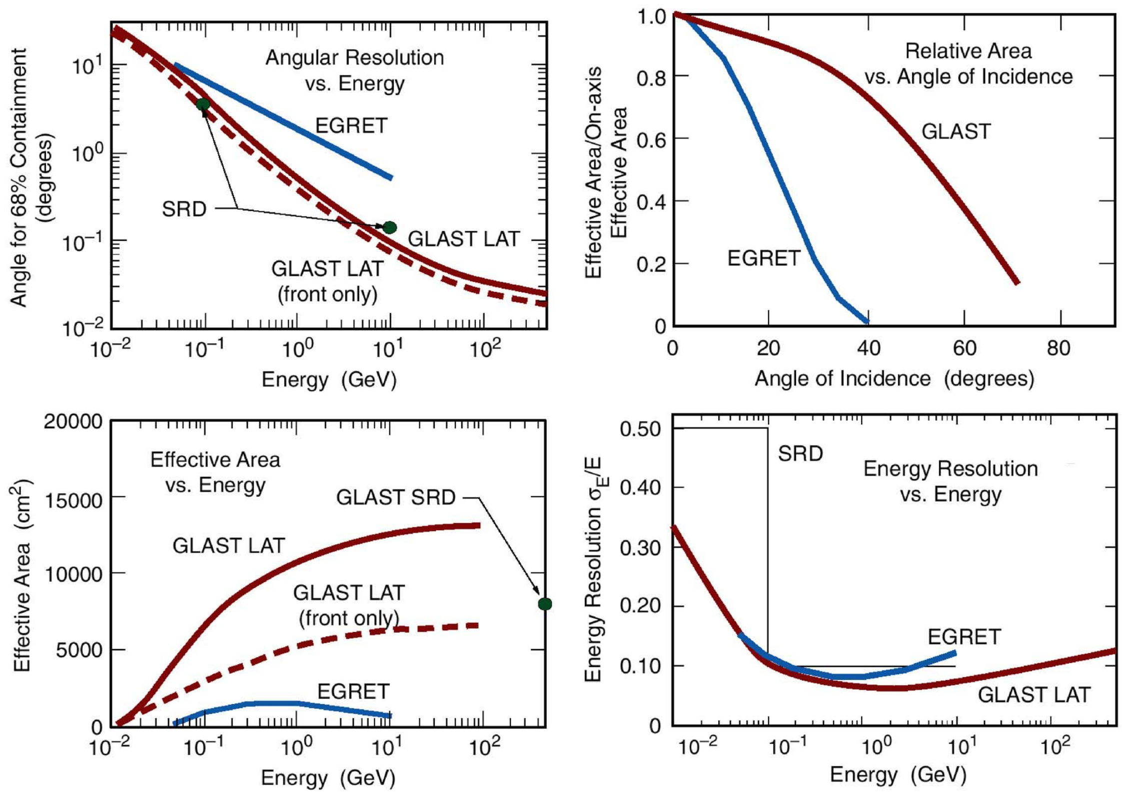

Figure 2. Expected performance of LAT compared with that of EGRET: a) PSF(68% containment); b) Effective area; c) Effective area as a function of incident angle about the LAT axis; d) Energy resolution (rms) as a function of energy.

here that our SSDs give about 5 times finer position measurement compared with the wire spark chamber of EGRET GLAST-LAT, resulting in the improved PSF as shown in Fig.2.

The major challenge for the LAT will be reconstruction of gamma-rays in the lower end of its energy coverage. Gamma-rays will not develope to a well-defined shower below $\sim 200-300$MeV. Multiple scatterings and early bremsstrahlung emissions may confuse the reconstruction program in finding the e^+e^- pair signature nor the EM shower profile. Below $\sim$ 100MeV, this challenge will become even harder while higher confidence will be required on the direction to reduce contamination from abundant Earth albedo gamma-rays . Their angular distribution simulated for the BFEM flight at Palestine, Texas is shown in Fig.5 [6]. They can be eliminated by the reconstructed direction, by identifying a correctly orientated V-shape pattern and by the pulse-height measurement imediately after the e^+e^- conversion point by the time-over-threshold method.

Charge cosmic-ray particles may also pose some challenge: the balloon experiment with BFEM has been demonstrated that straightness of track segments can be quite effective in discriminating charged particles heavier than electrons as shown in Fig.6 [6]. In this regard, we note that the hermeticity and efficiency of our Anti-Coincidence Detector are expected to exceed

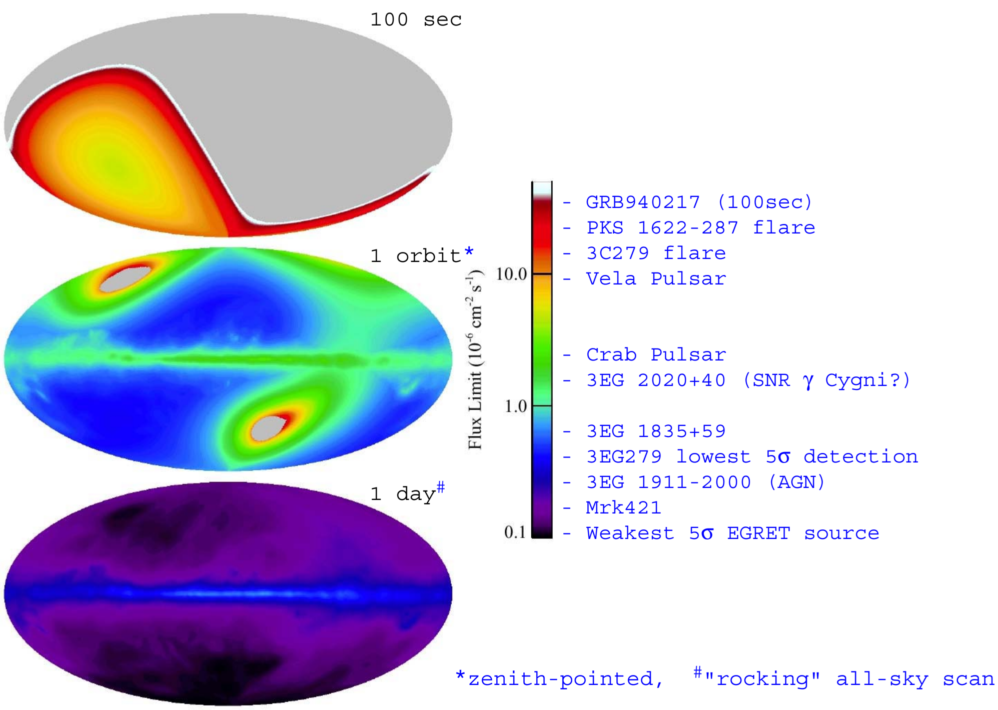

Figure 3. Expected exposure of GLAST-LAT for 100sec, 1 orbit (90min), and 1 day. Color scale on the right shows the detectable integrated photon flux in unit of 10^{-6}cm^{-2}s^{-1}. Astronomical sources are listed at their known integrated photon fluxes.

99.97% in the area of its coverage.

1.4. Design and development activities

The design of the instrument has been mostly completed and reviewed successfully by a series of committees conducted by NASA and Department of Energy between January and August 2002. The instrument team is now constructing Engineering Models of critical subsystems. The Flight Model desing and the test results on the subsystem-level Engineering Models will be reviewed by a committee in spring of 2003 by NASA and DoE.

All subsystem Flight Models will be completed by the end of 2005 and several towers will be assembled for a beam test at SLAC End Station A. The LAT Flight Model will be integrated at SLAC and mounted to the spacecraft with the GBM Flight Model in 2006.

1.5. Orbit and observation modes

The spacecraft will be put into a Low Earth Orbit (altitude $\sim 450-550$km) in the fall of 2006 by a Delta-II rocket. Observation will begin after a short commissiong phase. The nominal mode of observation will be the all-sky survey mode where the LAT will be pointed approximately at the zenith: it is forseen that the LAT axis will be rocked about the zenith by $\pm \sim 30$deg for several orbits a day to make the sky coverage uniform.

When interesting transients are detected or interesting targets of opportunity (TOOs) appear, the LAT may be operated in the pointing mode.

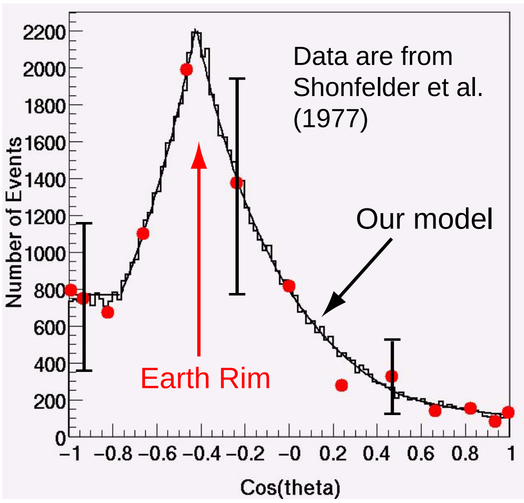

Figure 5. Model angular distribution of atmospheric gamma-rays tuned for the balloon experiment at Palestine, Texas. Note that the flux above the Earth Rim will be absent in the Low Earth Orbit.

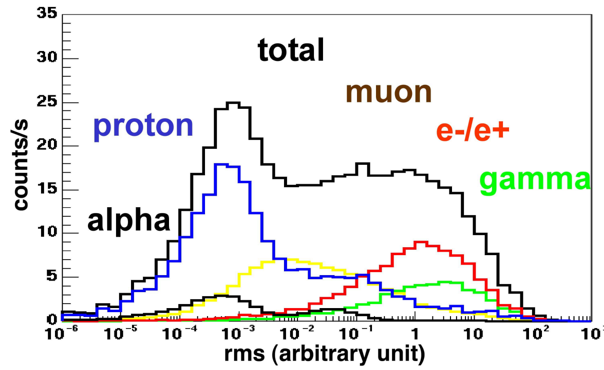

Figure 6. Straightness distribution of tracks in the tracker simulated by Geant4 to fit the observation in the balloon experiment. Note that e^+e^- tracks due to gamma-conversion can be selected by their higher rms deviation from straightness.

2. Science with GLAST-LAT

As has been described in the previous section, the most attractive feature of the GLAST Large Area Telescope, at least to the present author, is its ability to survey the entire sky every day to a sensitivity close to that of the 3rd EGRET Catalog [7].

Many time-variable phenomena will be detected including Gamma-Ray Bursts; flares and jets of AGNs, Microquasars, and Sun; precessions and glitches of Pulsars; changing environment around Pulsars; GRB Afterglows; variability in Galactic Winds; and evolution of Cosmic Ray interaction at around nearby SNRs.

The sensitivity integrated over one year will go typically 40 times deeper than the EGRET 3rd Cataolog. For point sources on or near the Milkyway galactic disk, however, the improvement will be less because of the strong diffuse disk emission coming into the PSF. Biggest improvement in sensitivity relative to EGRET comes for point sources which lie at high galactic lattitude and emit gamma-rays above a few GeV. For such objects the PSF will be > 5 times finer and identification with objects observed in the radio, optical and X-ray bands will be much easier than was with EGRET (see Fig.7). We expect many hundresd of BL Lac objects, Blazars, and Gamma-ray Bursts to be identified with their radio, optical, and X-ray counterparts.

Diffuse gamma-ray emission will also be very interesting both from astronomical and particle physics points of view. In the Galactic Center and Halo, gamma-rays from decay and interaction of dark matter particles are expected; in nearby galaxies (eg. LMC, SMC, and M31) and clusters of galaxies, gamma-rays due to cosmic-ray interaction with their interstellar gas will be detected.

We will discuss a little more on selected topics that may be of interest to the cosmic-ray physics community.

2.1. Interaction of cosmic-ray with interstellar matter and photon field

Cosmic-rays trapped in our Galaxy are believed to be produced mostly by supernovae and their interaction with Inter-Stellar Matter (ISM): particle acceleration in pulsars and pulsar winds are

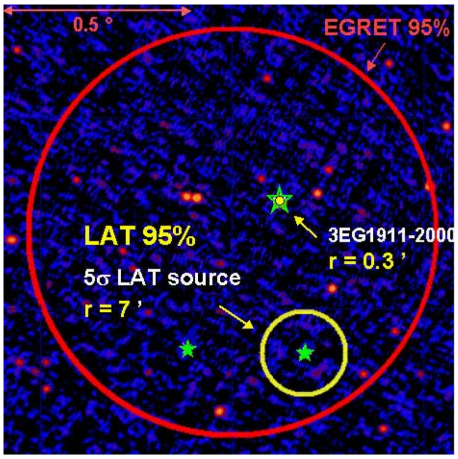

Figure 7. Expected improvement in PSF for sources with a power-law spectrum (index∼ 2) in the high galactic latitude.

also parts of this scenraio. Charged particles can be accelerated further by shock fronts, magnetic reconnection, or collision with higher energy particles. Most abundant high energy charged particles are protons, electrons and positrons.

High energy protons can interact with ISM and produce neutral pions, which decay into two gamma-rays. High energy e^+ and e^- can emit gamma-rays by bremsstrahlung off ISM nuclei, synchrotron radiation off magnetic field, and inverse Compton scattering off photon field. The flux of gamma-rays emitted by interaction with ISM will be proportional to the cosmic-ray intensity and the ISM density. Others will depends on the strength of magnetic field and density of photon field.

Gamma-rays will also be attenuated by interaction with ISM, magnetic field and photon field. These production and attenuation mechanisms can bring new information otherwise unattainable: e.g., density of IR to UV photons at cosmological distance and magnetic field on the neutron stars.

If the cosmic-ray composition is known at a region of the Galaxy, for example, gamma-ray flux measurements by GLAST-LAT can measure the total ISM mass or photon field of the location. If the ISM mass or photon field is known at a location (e.g. for a Giant Molecular Cloud), GLAST-LAT can measure cosmic-ray composition and flux at the location.

2.2. Extended emission in the Galaxy and beyond

In presentations the GLAST-LAT collaboration has made deal mostly with the point source sensitivity and strategy to improve it. Recent developments in astrophysics bring forward dynamic nature of galaxies, the Galactic Center region, association of supernova remnants with molecular clouds, and others. They are likely be observed as extended sources.

The broadest extended source may be the Galactic diffuse gamma-ray emission, which contains thousands of gamma-ray point sources and tens of diffuse components. Resolution of these sources and components may be beyond the capability of the LAT. Some selected regions of the Galaxy may be, however, much simpler and contain interesting astrophysics issues. They include high Galactic latitude region, the anti-Galactic Center region, and the Galactic halo.

In the high latitude region, determination of the inverse Compton component [8] will measure the electron flux in the region. The Galactic halo may show contribution of particle dark matter annihilation. The anti-Galactic Center region will allow us to study the local structure near the Sun.

Study of extended emission with GLAST-LAT requires a reliable Galactic diffuse emission model. It will be a long iterative process between better observational data and model refinement. The outcome of such tedious study will bring wealth of reward, which makes it worthwhile.

3. Conclusion

GLAST-LAT has been approved as the follow-up project of EGRET and expected to enhance and extend science EGRET has pioneered in 1990's. This presentation emphasizes that the LAT will bring an entirely new feature EGRET did not have: the deep daily survey of the entire

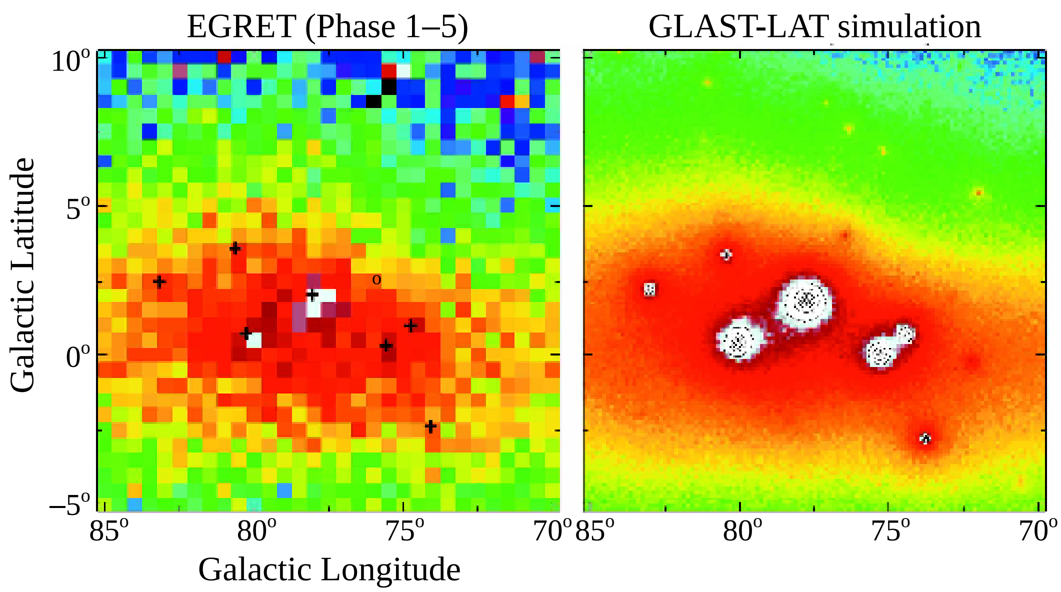

Figure 8. Left panel: Evidence for cosmic-ray proton interacting with Giant Molecular Clouds in Cygnus region obtained by EGRET. Right panel: Expected image of the same region by GLAST-LAT (simulation).

sky.

In the history of instrument-based astronomical observation, such feature is unprecedented. GLAST-LAT will detect many transient phenomena and long term variabilities, which will uncover dynamic characters of many astronomical objects.

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