The GLAST Large Area Telescope (LAT)

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On behalf of the LAT collaboration

http://www-glast.stanford.edu/

Outline

• Introduction
  – Mission
  – Collaboration
  – Instrument

• Overview of the LAT Science capabilities

• Schedule
GLAST Mission

GLAST measures the direction, energy and arrival time of celestial gamma rays

- LAT measures gamma-rays in the energy range ~20 MeV - >300 GeV
- GBM provides correlative observations of transient events in the energy range ~20 keV – 20 MeV

Launch: September 2006
Orbit: 550 km, 28.5° inclination
Lifetime: 5 years (minimum)

Gamma-ray Large Area Space Telescope

GLAST Mission
- high-energy gamma-ray observatory; 2 instruments
  - Large Area Telescope (LAT)
  - Gamma-ray Burst Monitor (GBM)
- launch (March 2006): Delta 2 class
- orbit: 550 km, 28.5° inclination
- mission operations
- science
  - LAT Collaboration
  - GBM Collaboration
  - Guest Observers
- lifetime: 5 years (minimum)

GLAST Observatory
- spacecraft
- LAT
- GBM

LAT Inst. Ops. Center
LAT data handling
Instrument performance
Level 1 data-processing
Support LAT Collaboration Science Investigation

Science Support Center
Science scheduling
Archiving
Guest Observer Support
Standard product processing

GBM Inst. Ops. Center
Instrument performance
Standard product processing

Mission Ops Center
Observatory safety
Spacecraft health
Commanding
Mission scheduling
Level 0 processing
GBM data handling

GRB Coordinates Network

GBM Data

Schedules

GBM Data

Status
Command Loads

LAT Data

Alerts
Large Loads
CRIEAL loads

Spacecraft
 status

GBM Data

Status
Command Loads

GBM Data

Schedules
GLAST Large Area Telescope (LAT)

**GLAST LAT and Collaboration Overview**

- **Si Tracker Tower**
  - pitch = 228 µm
  - 5.52 x 10⁴ channels
  - 12 layers x 3% X₀
  - 4 layers x 18% X₀
  - 2 layers

- **CsI Calorimeter**
  - Hodoscopic array
  - 8.4 X₀ x 8 x 12 bars
  - 2.0 x 2.7 x 33.6 cm
  - cosmic-ray rejection
  - shower leakage correction

- **ACD**
  - Segmented scintillator tiles
  - 0.9997 efficiency
  - minimize self-veto

- **Grid (Thermal Radiators)**

- **Data acquisition**

- **3000 kg, 650 W (allocation)**
  - 1.8 m x 1.8 m x 1.0 m
  - 20 MeV – 300 GeV

- **The Instrument will be integrated at SLAC. It will be tested at SLAC and NRL ("environmental tests")**

**GLAST LAT Overview: Performance**

- **Single Photon Angular Resolution**
  - 3.5° @ 100 MeV
  - 0.15° @ 10 GeV

- **Point Source Sensitivity**
  - < 6 x 10⁻⁹ ph cm²/s
  - (est. performance: < 3 x 10⁻⁹ ph cm²/s)

- **40 times EGRET’s sensitivity**

- **Source Localization**
  - 0.3' – 1' (unid EGRET)

- **Large Effective Area**
  - \( A_{\text{eff, peak}} > 8,000 \text{ cm}^² \)

- **Wide Energy Range:** 20 MeV – >300 GeV

- **Wide Field of View**
  - (> 2 sr)

- **Low dead time:** < 100 µs/event

- **Good Energy Resolution**
  - \( E/E \sim 10\% \); 100 MeV – 10 GeV
  - < 20\% ; 10 GeV – 300 GeV

Instrument performance meets (or exceeds) all requirements in 433-SRD-0001
Why do we need a satellite?

Atmosphere:

- For $E_{\gamma} < \sim O(100)\ GeV$, must detect above atmosphere (balloons, satellites, rockets).

- For $E_{\gamma} > \sim O(100)\ GeV$, information from showers penetrates to the ground (Cerenkov).

GLAST complements the capabilities of ground-based observatories.
Why \gamma rays?

**Photons**
- Universe is essentially transparent to gamma rays (except for attenuation at high energies, \(\sim 20 \text{ GeV}\))
- not affected by magnetic fields (point directly back to sources)
- probe cosmological volumes

H.E. Gamma rays are essentially non thermal, hence they can probe the Universe in regions that are far from equilibrium. These are responsible for the most violent energy processes in Nature.

What is the source of energy for Nature’s largest accelerators, limits on large extra dimensions, searches for Dark Matter?

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**Overview of GLAST capabilities**

EGRET shows many possible counterparts. Will GLAST be able to identify these sources?

3\textsuperscript{rd} EGRET Source Catalog

3C279 AGN

Crab pulsar

Solar Flare

GRB

Cygni-SNR

Cosmic ray acceleration
The GLAST Large Area Telescope (LAT)

**Gamma Ray Sky**

From space...
- Third EGRET Catalog
  - E > 100 MeV

From the ground...
- Why so few sources at TeV?
- TeV Gamma-Ray Source Catalog

<table>
<thead>
<tr>
<th>Energy</th>
<th>EGRET</th>
<th>GLAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 MeV - 30 GeV</td>
<td>1500 cm²</td>
<td>&gt; 10000 cm²</td>
</tr>
<tr>
<td>Effective area</td>
<td>0.5 sr</td>
<td>&gt; 2.0 sr</td>
</tr>
<tr>
<td>Field of view</td>
<td>~ $10^{-7}$ γ cm² s⁻¹</td>
<td>&lt; $6 \times 10^{-9}$ γ cm² s⁻¹</td>
</tr>
<tr>
<td>Sensitivity (1yr)</td>
<td>15 '</td>
<td>&lt; 0.5 '</td>
</tr>
<tr>
<td>Localization</td>
<td>100 ms</td>
<td>&lt; 100 µs</td>
</tr>
</tbody>
</table>

Large area
Low instrumental background

EGRET
- 1991-2001

GLAST
- 2006 - ?
  - 5 yr operation requirement
  - 10 yr operation goal
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Science capabilities - resolution

Source identification requires a multiwavelength approach
- localization
- variability

Source localization (68% radius)
- bursts 1 to tens of arcmin
- Unidentified EGRET sources 0.3' to 1'

Unidentified EGRET Sources

Evidence for at least 2 unidentified Galactic populations:
- time-variable Galactic population
- persistent Gould Belt population

Science capabilities – transient sensitivity

EGRET Fluxes
- GRB940217 (100sec)
- PKS 1622-267 flare
- 3C279 flare
- Vela Pulsar
- Crab Pulsar
- 3EG 2020+40 (SNR Cygni?)
- 3EG 1835+59
- 3C279 lowest 5σ detection
- 3EG 1911-2000 (AGN)
- Mrk 421
- Weakest 5σ EGRET source

*zenith-pointed, ^"rocking" all-sky scan

wide field-of-view

EGRET Fluxes
- low deadtime
  (for light curve)

all 3EG sources + 80 new detected in 2 days
~200 bursts per year
AGN flares > few min

100 sec
1 orbit
1 day

Elliott Bloom, SLAC (KITP New Cosmology Conference 8/21/02)
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Science capabilities - Gamma-Ray Bursts

The Gamma-Ray Burst mystery...
- Isotropic on sky (BATSE/CGRO)
- Last from milliseconds to ~100 seconds
- Brightest transient phenomenon in the Universe
- ~1 per day - no repetitions
- Progenitors still not known

GLAST will....
- place strong constraints on physical conditions within the source region (because GeV photons are strongly susceptible to absorption via gamma-gamma pair conversion..)
- detect a GRB about once every 2 days, quite possibly including bursts from the first generation of stars

AGN - Supermassive Black Holes ?

Up to 10000 times the luminosity of typical galaxy in a volume of one cubic parsec! (1 pc = 3.1 x 10^{16} cm ~ 3 light years) (assuming isotropic emission)

Accretion processes can explain huge output power since they are very efficient

Changes in Luminosity in a fraction of a day!
Variability constrains the size of the emitting source
**Diffuse Background Emission**

- **Galactic** (falls rapidly at higher latitudes, away from the plane we have less gas, backgrounds are instrumental, extragalactic diffuse and point sources such as pulsars)
- **Extragalactic** [b] > 10 deg (backgrounds are instrumental, galactic diffuse and point sources such as AGN)

Diffuse Model includes:
- *Cosmic ray nucleon interactions* with nucleons in the interstellar gas, which dominates for E > 70 MeV (via pizero decays)
- *Bremstrahlung* of cosmic ray electrons which dominates below ~ 20 MeV
- *Inverse Compton interactions* between relativistic cosmic ray electrons and soft photons in the interstellar gas (100 MeV photons appear from interactions between 1 – 100 GeV e- with MW to UV photons). More significant at high latitudes.

Hunter et al (1997), showed that there is generally a good agreement between EGRET observations of the gamma ray diffuse radiation in the Galactic Plane and model calculations.

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**Extragalactic Diffuse Background**

Could the EGRET diffuse background have a larger contribution of extragalactic point sources, such as AGN (blazars), which were not completely resolved?

EGRET estimated

\[ \frac{d^2N}{dE d^2l} \propto \frac{1}{e^{120 \gamma}} \]

after subtraction of point sources and emission from the galactic disk and the galactic center (model dependent)

(Sreekumar et al, 1998)
EGRET Limits on Large Extra Dimensions

New Supernova Limit on Large Extra Dimensions: Bounds on Kaluza-Klein Graviton Production

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(Received 22 March 2001; published 11 July 2001)

If large extra dimensions exist in nature, supernova (SN) cores will emit large fluxes of Kaluza-Klein gravitons, producing a cosmic background of these particles with energies and masses up to about 100 MeV. Radiative decays then give rise to a diffuse cosmic ray background with $E_{\gamma} < 100$ MeV which is well in excess of the observations if more than $0.5\% - 1\%$ of the SN energy is emitted into the new channel. For two extra dimensions we derive a conservative bound on their radius of $R < 0.9 \times 10^{-4}$ mm; for three extra dimensions it is $R < 1.9 \times 10^{-7}$ mm.

DOI: 10.1103/PhysRevLett.87.051301
PACS numbers: 97.60.Bw, 04.50.+h, 11.10.Kk, 11.25.Mj

Dark Matter

- Energy matter density/critical density
- Contributions from matter, cosmological constant, baryonic matter, non-baryonic matter

$\Omega = \Omega_M + \Omega_B + \Omega_{NB}$

$0.3 + 0.05 = 0.7 + 0.25$

$\approx 90\%$ of matter in the universe is non-luminous

DARK MATTER

- Baryonic: White Dwarfs, Brown Dwarfs, Black Holes, Neutron Stars, Jupiters, neutrinos
- Non Baryonic: MACHOS, Molecular clouds, HOT, COLD, WIMPS, axions, neutralinos, axinos, gravitinos

- Hot: relativistic speeds at the time galaxies were forming
- Cold: non-relativistic speeds at the time galaxies were forming
- LSP: Lightest Supersymmetric Particle

Elliott Bloom, SLAC (KITP New Cosmology Conference 8/21/02)
The Nature of the Dark Mass in the Center of the Milky Way
REINHARD GENZEL, ANDREAS ECKART, THOMAS OTT, FRANK EISENAUER

Derivation of stellar proper motions within 3" of the compact radio source Sgr A* obtained from 0.15 astrometric K-band maps in five epochs between 1992 and 1996. Allow whose infrared counterpart may have been detected, for the first time, in a deep image in June 1996. All available checks including a first comparison with high resolution maps now becoming available from other groups support our conclusion that there are several fast moving stars ($\geq 10^3$ km/s) in the immediate vicinity (0.01 pc) of Sgr A*.

From the stellar radial and proper motion data, we infer that a dark mass of $2.61 (\pm 0.15_{stat}) (\pm 0.35_{sys}) \times 10^6 M_\odot$ must reside within about a light week of the compact radio source. Its density must be $2.2\times10^{10} M_\odot$pc$^{-3}$ or greater. There is no stable configuration of normal stars, stellar remnants or sub-stellar entities at that density. From an equipartition argument we infer that at least 5% of the dark mass ($\geq 10^5 M_\odot$) is associated with the compact radio source Sgr A* itself and is concentrated on a scale of less that 15 times the Schwarzschild radius of a $2.6\times10^6 M_\odot$ black hole. The corresponding density is $3\times10^{23} M_\odot$pc$^{-3}$ or greater. If one accepts these arguments it is hard to escape the conclusion that there must be a massive black hole at the core of the Milky Way.

Gamma Ray Excess from the Galactic Center

EGRET analysis revealed an excess of $\gamma$ rays from a position consistent with the galactic center

The EGRET team (Mayer-Hasselwander et al., 1998) have seen a convincing signal for a strong excess of emission from the galactic center, with $I(E) \times E^2$ peaking at $\sim 2$ GeV, and in an error circle of 0.2 degree radius including the position $l = 0^\circ$ and $b = 0^\circ$. In their paper it was speculated that among other possible causes, this excess could be due to the continuum $\gamma$-ray spectrum from WIMP annihilation. With the dramatically improved angular resolution and effective area of GLAST, this effect should become both more localized and pronounced if it is a Galactic Center phenomenon.
Is There a Galactic Halo that Glows in High Energy Photons Photons?

Contours of photon intensity in units of $10^{-5}$ ph cm$^{-2}$ sec$^{-1}$ sr$^{-1}$ for $E_{\gamma} > 1$ GeV, after subtraction of "best estimate" of Galactic diffuse model. Data indicates presence of a galactic halo (Dixon et al. 1998).

Neutralino Annihilations

Good particle physics candidate for galactic halo dark matter is the LSP in R-parity conserving SUSY

$$\chi^0_1 = a_1 \tilde{B} + a_2 \tilde{W}^3 + a_3 \tilde{H}_1^0 + a_4 \tilde{H}_2^0$$

If true, there may well be observable halo annihilations

Example: $\chi^0$ from Standard SUSY, annihilations to jets, producing an extra component of multi-GeV $\gamma$ flux that follows halo density (not isotropic) peaking at ~ 0.1 $M\chi^0$ or lines at $M\chi^0$. Background is galactic $\gamma$ ray diffuse.

Although calculation for $\gamma$-rays is less uncertain than for other signals (multi-GeV antiprotons, positrons) a null result will not likely constrain SUSY parameter space.

If SUSY uncovered at accelerators, GLAST may be able to determine its cosmological significance quickly.
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**SUSY LSP Halo Annihilation**

\[ \chi \chi \rightarrow \gamma \gamma \]

Bergström & Ullio 1997; Bern, Gondolo, Perelstein 1997

GLAST \( \sigma_{E/E} \sim 3\% \)

\( \theta \geq 50^\circ \)

Navarro, Frenk & White Halo (No Clumps)

Central Core

\[ \rho(r) = \frac{\rho_0}{(r/\xi)(1+r/\xi)^2} \]

\( \xi = 3.4\text{ kpc}, \rho_0 = 0.4\text{ GeV/cm}^3, R_c = 8.5\text{ kpc} \)

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**GLAST MC Limits on MSSM from \( \gamma \) lines**

GLAST monenergetic \( \gamma \) "line" sensitivity (95 % CLUL) vs \( E_\gamma \). Colored areas are a range of MSSMs within a restricted parameter space from standard assumptions and thermal relic abundance calculations. Red lines are rates assuming a non-thermal origin with Higgsino accounting for the bulk of the Galactic halo.
EGRET Data & DarkSUSY models
(Moore DM Halo Profile - \( \gamma = 1.5 \))

We are not claiming DM discovery...

\(~ 2^\circ\) around the galactic center

A. Morselli, A. Lionetto, A. Cesarini, F. Facietto, P. Ullio, 2002

Estimated reaches before LHC

MSSM
\( A_0 = 0 \)
\( \mu > 0 \)
\( m_t = 174 \text{ GeV} \)
\( \tan \beta = 10 \)

2 years exposure.
Fixed Halo profile, indirect limits better if halo is clumpy

0.025 < \( \Omega_{\text{CDM}} h^2 \) < 1
0.1 < \( \Omega_{\text{CDM}} h^2 \) < 0.3

GLAST Preliminary
A. Morselli et al.

Excluded by chargino mass limit > 95 GeV
\( \tan \beta = 10 \)

See astro-ph 0008115
Particle dark matter constraints from the Draco dwarf galaxy

C. Tyler, PHYS. REV D 66, 023509 (2002)

Draco dwarf spheroidal galaxy, 79 kpc from Earth,
M/L = 440 ± 240 M_{solar}/L_{solar}, M ~ 8.6 × 10^7 M_{solar}.

Draco has the mass of a dwarf galaxy and the starlight of a globular cluster.

Schedule

GLAST scheduled for launch in September 2006