GLAST:
Exploring the High Energy Universe where Particle Physics and Astrophysics Collide

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GLAST Education and Public Outreach
Mission

- First space-based collaboration between astrophysics and particle physics communities
- Launch expected in 2006
- First year All-sky Survey followed by…
- Competitive Guest Observer Program
- Expected duration 5-10 years
GLAST Burst Monitor (GBM)

• PI Charles Meegan (NASA/MSFC)
• US-German secondary instrument
• 12 Sodium Iodide scintillators
  – Few keV to 1 MeV
  – Burst triggers and locations
• 2 bismuth germanate detectors
  – 150 keV to 30 MeV
  – Overlap with LAT
• http://gammaray.msfc.nasa.gov/gbm
Large Area Telescope (LAT)

- PI Peter Michelson (Stanford)
- International Collaboration: USA NASA and DoE, France, Italy, Japan, Sweden

- LAT is a 4 x 4 array of towers
- Each tower is a pair conversion telescope with calorimeter

http://www-glast.stanford.edu
Pair Conversion Telescope

- Photons materialize into matter-antimatter pairs:
  \[ E_\gamma \rightarrow m_{e^+}c^2 + m_{e^-}c^2 \]

- Electron and positron carry information about the direction, energy and polarization of the \( \gamma \)-ray
LAT Schematic

- Tiled Anticoincidence Shield
- Silicon strip detectors interleaved with Lead converter
- Cesium Iodide hodoscopic calorimeter
New Technologies

CHALLENGES:
- Largest silicon strip detector array ever assembled (1.5 million channels from total of 90 m² of silicon detectors)
- On-board data system sophistication: distributed, adaptable, programmable trigger
<table>
<thead>
<tr>
<th></th>
<th>EGRET</th>
<th>GLAST LAT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Range</td>
<td>20 MeV - 30 GeV</td>
<td>20 MeV - 300 GeV</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Effective Area</td>
<td>1500 cm$^2$</td>
<td>8000 cm$^2$</td>
</tr>
<tr>
<td>Field of View</td>
<td>0.5 sr</td>
<td>&gt; 2 sr</td>
</tr>
<tr>
<td>Angular Resolution</td>
<td>5.8° @ 100 MeV</td>
<td>~ 3° @ 100 MeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>~ 0.15° &gt; 10 GeV</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>~ 10$^{-7}$ cm$^{-2}$ s$^{-1}$</td>
<td>&lt;6 x 10$^{-9}$ cm$^{-2}$ s$^{-1}$</td>
</tr>
<tr>
<td>Source Location</td>
<td>5 - 30 arcmin</td>
<td>0.5 - 5 arcmin</td>
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</tbody>
</table>
EGRET’s Legacy

- Established blazars as largest class of extra-galactic $\gamma$-ray emitters
- Observed many blazar flares, some $<1$ day
- $>60\%$ of $\sim 270$ sources are unidentified
- Measured extra-galactic $\gamma$-ray background
- Discovered gamma-rays from 4 pulsars
- Showed $E<10^{15}$ eV cosmic rays are galactic
- Detected solar flares and some $\gamma$-ray bursts at $E>1$ GeV
3rd EGRET Catalog

Third EGRET Catalog
E > 100 MeV

- LMC
- Pulsars
- Solar Flare
- Active Galactic Nuclei
- Unidentified EGRET Sources
Simulated LAT all-sky map

An all-sky intensity map above 100 MeV obtained from a Monte Carlo simulation of a one-year survey with GLAST.
Identify and understand nature's highest-energy particle accelerators:

- active galactic nuclei
- pulsars
- black holes
- supernova remnants
- γ-ray bursts
LAT Log N vs. Log S

LAT should detect thousands of gamma-ray sources

![Graph showing the relationship between Number of Sources (|b| > 30°) and Integral Flux (> 100 MeV, cm⁻² s⁻¹). The graph indicates that LAT should detect approximately 4500 sources.](image)
Unidentified Sources

- 170 of the 270 sources in the 3rd EGRET catalog have no counterparts at longer wavelengths
- Variable sources appear at both low and high galactic latitudes
- High-latitude sources appear to be both extra-galactic and galactic
- Steady medium latitude sources may be associated with Gould’s belt (star forming region)
Possible Unidentified Sources

- **Radio-quiet pulsars:** Geminga-like objects can be found with direct pulsation searches.
- **Previously unknown blazars:** flaring objects will have good positions, helping IDs.
- **Binary systems:** shocked winds between companions will show time variability.
- **Microquasars:** time variability, $X/\gamma$ correlation.
- **Clusters of galaxies:** steady, high-latitude sources should show shock spectra.
• 3C279 is brightest AGN at high energies
• Multi-wavelength coverage essential to understand flare mechanism
• Where are the acceleration and emission sites in blazar jets? Multi-wavelength campaigns from radio to TeV

• How do galaxies “cool their jets”? Study $X/\gamma$

• Are jets leptonic or hadronic? Study $H-\alpha/\gamma$ to distinguish between leptonic models. Study $X/\gamma$ to distinguish leptonic/hadronic models

→ All require energy and time-resolved spectra of blazars during flares and quiescence
• Are radio galaxies also HE \( \gamma \)-ray sources? Seyferts? Increased sensitivity by \( 10^2 \)
• How do blazars evolve? Detect \( 10^3 \) sources
• Is extra-galactic \( \gamma \)-ray background truly diffuse? Or is part due to annihilation or decay of exotic particles? Detect \( >10^3 \) sources
• Is AGN cutoff intrinsic or due to EBL? Study AGN spectra above 10 GeV
LAT studies 3C79

1996 flare

Spectral cutoff
LAT studies EBL cutoff

Probe history of star formation to $z \sim 4$ by determining spectral cutoff in AGN due to EBL
AGN Log N vs. Log S

- LAT should detect $3 \times 10^3$ blazars
- Set limits on diffuse extra-galactic background $\rightarrow$ limits on decay or annihilation of exotic particles
LAT vs. Ground-based HE Arrays

Sensitivity of Present and Future Detectors

Typical differential source flux $\propto E^{-2}$

Integral Flux (photons cm$^{-2}$ s$^{-1}$)

Photon Energy (GeV)

GLAST

EGRET

$E^{-1}$

CELESTE, STACEE

VERITAS

VERITAS (large zenith angle)

Whipple

MILAGRO
Ground-based HET Arrays

• HETs have detected 7+ sources at E > 250 GeV
  – 3 pulsar nebulae, 4 AGN, 1 possible SNR
• New HETs will reach down to ~50 GeV
• HETs have good sensitivity to flares of 15 min, & source localization to 10-30 arcmin
• Major limitations are <5° FOV, low-duty cycles and calibration uncertainties
• GLAST LAT can alert HETs to flaring objects & provide cross-correlation to calibrate spectra in overlap region
Multi-wavelength Mkn 501

Energy [eV]

log luminosity $\nu L_\nu$ (erg/s)

Frequency [Hz]

○ - Estimate of GLAST Response for 2-year All-Sky Scan
Most scientists believe that Galactic CR are accelerated in SNR shocks.

EGRET detected $\pi^0$ bump at 68 MeV → direct evidence of nucleon-nucleon interactions.

EGRET detected $\gamma$-rays from LMC but not SMC → CR production varies.

Some EGRET sources could be SNRs, but poor resolution prevented confirmation.

X-ray and TeV observations of SN1006 show shocked electrons accelerated to CR-energies.
LAT studies Supernova Remnants

EGRET observations could not distinguish between pulsar (X-ray source) and shocked regions.
LAT studies SNR and CRs

- Spatial separation of shocked acceleration regions from pulsar component
- Detect $\pi^0$ bump in SNR spectra from accelerated nuclei (on top of electron acceleration signatures – inverse Compton and bremsstrahlung)
- Determine relative number densities of electrons and nucleons in CRs
- Study CR production in other galaxies
- Improve H$_2$ measurements by mapping $\gamma$-rays
EGRET pulsars
Outer gap vs. polar cap models

• Where are particles accelerated?
• How is particle beam energy converted into photons?
• What is shape of pulsar beam?
• How many pulsars are there? Birth rate?
• Where is most of the energy?
Vela pulsar outer gap model

- Green is radio
- Blue is gamma-ray
- Red is closed magneto-spheric surface

Yadigaroglu and Romani 1995
Up to 250 pulsars will be detectable, with half previously unknown in radio (McLaughlin and Cordes 2000)
LAT studies pulsars

High quality phase-resolved spectra for $10^2$ pulsars

High energy photons essential!
Dark Matter – a short review

• Evidence:
  – Rapidly moving galaxies in clusters
  – Rotation curves of galaxies
  – Hot gas in galaxy clusters
  – Gravitational lensing
  – Stability of rotating spiral galaxies

• Types:
  – Baryonic vs. non-baryonic
  – Cold vs. Hot

Hot gas in Galaxy Cluster
Searching for dark matter

- The lightest supersymmetric particle $\chi$ is a leading candidate for non-baryonic CDM.
- It is neutral (hence neutralino) and stable if R-parity is not violated.
- It self-annihilates in two ways:
  - $\chi \chi \rightarrow \gamma \gamma$ where $E_\gamma = M_\chi c^2$
  - $\chi \chi \rightarrow Z\gamma$ where $E_\gamma = M_\chi c^2(1 - M_Z^2/4M_\chi^2)$
- Gamma-ray lines possible: 30 GeV - 10 TeV
First Light from Dark Matter?

EGRET evidence for > 1 GeV excess

Courtesy of D. Dixon, University of California, Riverside
Diffuse emission from Relic decay

- Set limits on relic mass, density and lifetime
WIMP line detectability

∀ γ–γ line

∀ Z–γ line

Supersymmetry model calculations by Bergstrom, Ullio and Buckley 1998 – assume enhanced density near Galactic Center (Navarro, Frenk and White 1996)
Conclusions

- GLAST will open new areas of investigation at the boundary of astrophysics and particle physics

- GLAST is the first of many missions that will combine resources from astrophysics and particle physics

- GLAST will show us the connection between the smallest sub-atomic particles and the largest structures in the Universe

- Connections….from Quarks to the Cosmos!
The GLAST Science Document (GSD) GLAST: Exploring Nature’s Highest Energy Processes with the Gamma-ray Large Area Space Telescope (Seth Digel, editor) may be downloaded from

ftp://lheaftp.gsfc.nasa.gov/pub/myersjd

The GLAST outreach web site:

http://www-glast.sonoma.edu

The GLAST LAT web site:

http://www-glast.stanford.edu
For more information:

Figures are from the Gamma-ray Image Gallery:

For more information on the Connections program:
http://www.quarkstothescosmos.org

For more information on NASA’s Cosmic Journeys:
http://journeys.gsfc.nasa.gov

For a copy of this talk:
http://perry.sonoma.edu/materials
LAT Studies Blazars

• Constrain jet acceleration and emission models
  • hadronic vs. leptonic
• Measure spectral cut off with distance to redshift $z > 4 \rightarrow$ star formation history of universe
• Statistically accurate calculation of blazar contribution to the high energy diffuse extragalactic background $\rightarrow$ diffuse limits
• Blazar evolution
• New types of gamma-ray emitting AGNs