Outline

• Overview of the GLAST Observatory
  – Current status of two instruments (GBM and LAT)

• GLAST Science
  – Highlights of Instrument Capabilities
  – Selected Physics Topics
    – Particle Acceleration
      » Active Galactic Nuclei
      » Supernova Remnants
    – Diffuse $\gamma$ Ray Emission
    – Dark Matter Searches and New Physics

• Timeline
GLAST will measure the direction, energy and arrival time of celestial $\gamma$ rays
Will follow on the measurements by its predecessor (EGRET) with unprecedented capabilities

**GLAST Observatory : Overview**

Orbit
565 km, circular

Inclination
28.5°

Lifetime
5 years (min)

Launch Date
Aug 2007

Launch Vehicle
Delta 2920H-10

Launch Site
Kennedy Space Center

LAT
will record gamma-rays in the energy range
~ 20 MeV to >300 GeV

Observing modes
All sky survey
Pointed observations

Re-pointing Capabilities
Autonomous
Rapid slew speed
(75° in < 10 minutes)

GBM
will provide correlative observations of transient events in the energy range
~10 keV – 25 MeV
**GLAST Burst Monitor: Overview**

**NaI and BGO counters exposed to the entire sky**

- **NaI crystals (12)**
  - low-energy spectral coverage
  - ~10 keV to ~1 MeV
  - rough burst locations

- **BGO crystals (2)**
  - high-energy spectral coverage
  - ~150 keV to ~30 MeV

**GBM**
- 10 keV to ~25 MeV

**Correlative observations of transient phenomena**

- **Spectral Measurements**
  - measures spectra for bursts
  - connects with LAT measurements

- **Afterglows in Gamma Ray Bursts**
  - Wide Sky Coverage (8 sr)
  - autonomous repoint for exceptionally bright bursts that occur outside LAT field of view

- **Connections to the Ground Network of Telescopes**
  - burst alerts to the LAT and ground telescopes within seconds

**Principal Investigator:** Charles Meegan

E. do Couto e Silva
Current Status of GBM Assembly

12 NaI modules

2 BGO modules

Environmental Tests at Max Planck Institute
Large Area Telescope: Overview

The LAT is a pair-conversion telescope of 16 towers surrounded by plastic scintillators.

**Silicon Microstrip Tracker**
- ~ 80 m² of silicon
- 8.8 x 10^5 readout channels
- Strip pitch = 228 µm
- xy layers interleaved with W converters
- Total Rad length ~1.5 X₀

**Calorimeter**
- Hodoscopic array
- Array of 1536 CsI(Tl) crystals in 8 layers
- Total Rad length ~8.5 X₀

**Anti-Coincidence Detector**
- 89 scintillator tiles
- Segmented design

**Silicon Microstrip Tracker**
- Measures γ direction
- γ identification

**Calorimeter**
- Measures γ energy
- Shower imaging

**Anti-Coincidence Detector**
- Rejects background of charged cosmic rays
- Segmentation removes self-veto effects at high energy

**Currently there is no other telescope covering this energy range**

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Current Status of LAT Assembly

- 18 CAL modules completed
- 16 CAL modules @ SLAC
- ~80m² of silicon in hand
- 8 TKR modules @ SLAC
- Six Towers in the flight grid
- ACD completed and being tested at GSFC. Delivery to SLAC scheduled for mid August
Photon Candidates
10-20% of cosmic ray showers are not muons

Muon candidates
Most of the 200Hz of triggers recorded with 6 towers are muons

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Science with GLAST

- High Energy Sky Survey:
  - Unidentified EGRET sources and GLAST Source Catalog
    - unresolved point sources
  - Population Studies
    - To avoid peculiarities of individual sources (AGN, Pulsars, SNR...)
  - Diffuse Gamma ray emission
    - Galactic and Extragalactic
  - Physics of particle acceleration
    - AGN jets
    - energy conversion
    - shocks in SNRs
    - role of hadrons in radiation processes

- High-energy behavior of transients:
  - Gamma Ray Bursts
  - Solar Flares

- Discovery Potential:
  - New classes of astrophysical objects
  - Origin of Extragalactic Background
  - Searches for Dark Matter and Extra Dimensions
  - Tests of Lorentz Invariance

LAT strengths:
All-sky monitoring
Broad range of time scales
Energy range
LAT will Rediscover the $\gamma$ Ray Sky

### Source class

<table>
<thead>
<tr>
<th>Source class</th>
<th>Seen by EGRET</th>
<th>Predicted with GLAST</th>
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</thead>
<tbody>
<tr>
<td>Unidentified sources</td>
<td>170</td>
<td>?</td>
</tr>
<tr>
<td>Rotation powered pulsars</td>
<td>3-6</td>
<td>100-500</td>
</tr>
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<td>Blazars</td>
<td>50-80</td>
<td>&gt;2000</td>
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<tr>
<td>Normal galaxies</td>
<td>2</td>
<td>4-5</td>
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<tr>
<td>Gamma ray bursts</td>
<td>5</td>
<td>&gt;500</td>
</tr>
<tr>
<td>Supernova Remnants/plerions</td>
<td>1-5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Radio galaxies</td>
<td>1-1</td>
<td>?</td>
</tr>
<tr>
<td>X ray binaries/microquasars</td>
<td>1-1</td>
<td>?</td>
</tr>
<tr>
<td>Starburst galaxies</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>Cluster of galaxies</td>
<td>0</td>
<td>?</td>
</tr>
</tbody>
</table>

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All Sky Monitoring with Improved Sensitivity

During the all-sky survey, GLAST will have sufficient sensitivity after $O(1)$ day to detect (5σ) the weakest EGRET sources!!!

EGRET Fluxes
- GRB940217 (100sec)
- PKS 1622-287 flare
- 3C279 flare
- Vela Pulsar

*zenith-pointed"
Gamma Ray Bursts: GBM and LAT

- **GBM**
  - Huge field of view (8sr)
  - Measure spectra for bursts from 10 keV to 30 MeV

- **LAT**
  - Wide field of view (>2sr)
  - Extends spectral coverage to higher energies

**GLAST**
Can be re-pointed to catch exceptionally bright bursts that occur outside the LAT field of view

GLAST all-sky monitoring will be follow transient phenomena to a wide range of time scales from ~ 30 µs (GRB, solar flares) to hours or longer (AGN)

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Most of the EGRET AGNs were blazars
- Variability: relativistic jets
- Jets point towards us!

Radiation is produced by one or more of the following processes
- Synchrotron Self Compton
- External Compton
- Proton Induced Cascades
- Proton Synchrotron

Key issues to be addressed
- Energetics of the source
- jet formation
- jet collimation
- nature of the plasma
- particle acceleration
Multiwavelength Observations

- Contemporaneous observations with other wavelengths
  - disentangle effects from state changes within individual sources
- GLAST will provide “continuous” baseline in GeV
  - helpful to ground based TeV γ–ray telescopes

\(3^{rd}\) EGRET catalog

High γ-ray state (Verstrand et al. 1995)

Blazar PKS 2155-304

Atmosphere:

For \(E_g > \sim O(100)\) GeV, must measure light emitted at the atmosphere (Cerenkov)

GeV-TeV campaigns will complement GLAST science!

Multiwavelength planning in progress:

http://glast.gsfc.nasa.gov/science/multi/
Time lags: hadronic or leptonic model in AGNs?

- Leptonic processes are “preferred” by theorists
  - Hadronic models have not yet been excluded!
- Time lags between AGN flares may suggest dominance of hadronic processes

Changes in Luminosity in a fraction of a day!
Variability constrains the size of the emitting source
SNR: Sites of Hadronic Acceleration?

- Supernova Remnants: sites of galactic cosmic ray acceleration
  - Non-thermal emission (X-rays)
  - Signs of $\gamma$-ray activity
    - EGRET: GeV activity near SNR (3EG J1714-3837)
    - HESS: Recent detection of TeV $\gamma$-rays

- Question:
  - Do $\gamma$ rays originate from hadronic or leptonic processes?

- Measurements in the range of 100MeV-100GeV
  - essential ingredient to resolve the origin ($p$ vs $e^{+/-}$)

Adapted from Aharonian’s talk at the Texas Symposium 2004
AGN: Extragalactic Background Light

- High Energy photons (e.g. from AGN) can be absorbed via pair production
  - GeV (TeV) photons interact with intergalactic photons UV(IR)
  - strong dependence on the distance from the source (inferred from redshift)
- GLAST will see thousands of AGN
  - look for systematic effects vs redshift
  - key energy range for cosmological distances

Effect is model-dependent (this is good):

A dominant factor in EBL models is the era of galaxy formation

AGN roll-offs may help distinguish models of galaxy formation
EGRET Gamma Ray Emissions $> 100$ MeV

- **Extragalactic Emission**
  - Higher latitudes
    - $|b| > 10°$

- **Galactic Emission**
  - Falls rapidly at higher latitudes
  - Gas density concentrated in the p

- **Galactic plane**
  - Contains about 90% of the $\gamma$ ray emission
    - Mostly high energy cosmic ray interactions with the interstellar medium (ISM)
• GLAST can shed light in one of the long-standing problems in high energy astrophysics
  – The origin of the extragalactic background

Galactic Diffuse $\gamma$ ray is subtracted
Reanalysis using slightly modified e- spectrum with respect to the local injected spectrum

What is it made of?

Blazars
  – we know…

New physics
  – we can probe…

Primordial diffuse
  – If else fails…
Galactic Diffuse Gamma Ray Emission

The $\gamma$ ray sky is dominated by diffuse emission
Accurate modelling is essential

Many more point sources
Background determination for energy above 10 GeV
Sharper definition of the diffuse background
(smaller bins in the sky)
Complex Modeling of Particle Transport

Sources of CR: SNRs, Shocks, Superbubbles

Particle acceleration
Photon emission

Need to model:
- Number density of primary nuclei
- Production cross section
- Gas distribution and composition

Charged particle measurements will provide consistency checks for γ ray models
After diffuse background subtraction there was an excess of $\gamma$ in the EGRET Data:

- Revisited pp cross section: accounts for a fraction of the GeV excess

**Old pp interaction models**
- Constant inelastic cross-section
- Feynman scaling
- No diffraction dissociation

**New pp interaction model**
- Rising cross-sections
- Scaling violation
- Diffraction dissociation

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Can WIMPs be the source of Dark Matter?

- **Direct searches:**
  - scattering of WIMPS with nucleons in the detector
    - DAMA, CDMS, EDELWEISS, etc.

- **Indirect Searches:**
  - WIMP annihilations into other particles
    - GLAST, ICECUBE, ANTARES, GENIUS, HEAT, AMS, etc.

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**Weakly Interacting Massive Particles (WIMP)**

- **Galactic**
  - Earth
    - neutrinos
  - Sun
    - neutrinos
  - Galactic Halo
    - antideuterons
    - antiprotons
    - positrons
    - photons
  - Galactic Center
    - positrons
    - photons

- **Extragalactic**
  - photons
Dark Matter Candidate: Neutralino

If true, there may well be observable halo annihilations

- Good particle physics candidate for galactic halo dark matter
  - Lightest Supersymmetric Particle in R-parity conserving SUSY

\[ \chi_1^0 = a_{11} \tilde{B} + a_{12} \tilde{W}^3 + a_{13} \tilde{H}_1^0 + a_{14} \tilde{H}_2^0 \]

continuum energy spectrum
Higher statistics...
but higher background

Distinct signature
a “peak” in the energy spectrum !
Lower background...
but lower statistics
Dark Matter from SUSY: \( \gamma \) line and continuum

Large uncertainties in the Particle spectrum Halo model Background estimation

Detection rates can increase if halo is \textit{clumpy}

\[ E_\gamma = 78 \pm 7.8 \text{ GeV} \]

Maximal \( S_{\gamma \text{ line}} \)

\[ \text{Flux, } \phi \left[ \text{photons cm}^{-2} \text{s}^{-1}\right] \]

\[ \text{Galactic latitude, } b \left[ \text{degrees}\right] \]

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Halo Dark Matter Searches with GLAST

- **WIMP Annihilations in halo Clumps (b > |10| 0):**
  - continuum $\gamma$ from $\pi^0 @ \sim 100$ MeV
  - lines ($2 \gamma, \gamma\Z$) (Bergstrom et al)
    - Depends on models of clumps
    » see previous slide

- **IC from secondary electrons** (Baltz & Wai 04)
  - $>\text{GeV}$ IC from e + starlight
    - near galactic plane $< 30^0$ (trapping by B field)

- **KK DM Scenario** – electron “line” (20% Br) smeared into a sharp edge via mainly IC
  - $>500 \text{ GeV}: \sim 100 \text{ e}\pm$/year edge height
    - all-sky signature!
    » see next slide
Dark Matter: SUSY or Extra Dimensions?

- SUSY
  - Lightest Supersymmetric Particle
    - Neutralino
  - Accelerator bounds
    - \( M_{\chi^0} > \text{tens of GeV} \)
  - Search for photons

- Extra Dimensions
  - Lightest Kaluza-Klein Particle
    - \( B^1 \)
  - Accelerator bounds
    - \( M_{B^1} > 300 \text{ GeV} \)
  - Search for photons and leptons
    - Charged leptons are not helicity suppressed
    - 59% charged leptons
    - 35% quarks

Limited statistics with GLAST hard to measure but very interesting…!
### Extra Dimensions: Possible GLAST Signatures?

#### Large Extra Dimensions

- Thermal graviton emission (how much energy went into the bulk without affecting cosmological evolution?) (Perez-Lorenzana 2005)
  - BBN (Hannestad 2004)
  - For \( n=2 \) there would be many KK Modes which would release too much energy into gravitons

- Gravitons emitted by stellar objects take away energy
  - SN (Hannestad 2003)
    - NS shines because gravitons are gravitationally trapped

- Massive Graviton decays into \( \gamma \gamma \) continuously emitted by the Universe (less robust)
  - Excess in diffuse gamma ray emission around 30 MeV
  - Gamma ray emission from NS in the galactic bulge
    - Problem: heavy KK can decay into more lighter KK modes
      - not on SM particles only

#### Universal Extra Dimensions

- \( B^1B^1 \) annihilation in Galactic Center
  - Two photons via loop diagrams (Servant and Tait)

- \( B^1B^1 \) annihilation in Galactic Center
  - Charged lepton production is not helicity suppressed
    - 59% charged leptons
    - 35% quarks
    - 4% neutrinos
    - 1% charged gauge bosons
    - 0.5 % neutral gauge bosons
    - 0.5 % Higgs bosons
  - Primary gamma rays
    - Bremsstrahlung of charged leptons
  - Secondary gamma rays
    - Photons from qq and synchrotron

- High Energy Signal (hundreds of GeV)
  - Limited statistics and maybe \( \Delta E/E \)

- Low Energy Signal (\(< 100\) MeV)
  - Uncertainties in the background

- Can theorists give us a signal between 10 and 100 GeV?
  - LZP (Agashe and Servant hep-ph 0403143)
GLAST MISSION ELEMENTS

- Large Area Telescope & GBM
- TLM: S-band @ 1,2,4,8 kbps
- TLM: Ku-band @ 40 Mbps (13 GB/day average)
- CMD: S-band @ .25, 4 kbps

GLAST Spacecraft

Mission Operations Center (MOC)

GLAST Science Support Center

GBM Instrument Operations Center

HEASARC GSFC

Internet 2

GRB Coordinates Network

TDRSS SN S & Ku

White Sands

DELTA 7920H

GPS
Operation Phases

• First year of science operations
  – initial on-orbit checkout, verification, and calibrations, followed by an all-sky survey
    – detailed instrument characterization
    – refinement of the alignment
  – key projects needed by the community
    – source catalog, diffuse background models, etc.
  – Transients
    – data on transients will be released, with caveats.
    – repoints for bright bursts and burst alerts enabled.

• First Year Guest Observer Program
  – limited first-year guest observer program
  – extraordinary Targets of Opportunities supported.
  – workshops for guest observers on science tools and mission characteristics for proposal preparation

• Observing plan in subsequent years
  – driven by guest observer proposal selections by peer review.

• All data released through the GLAST Science Support Center (GSSC).
The GLAST mission is
  – completing the fabrication phase and
  – is well into integration.

LAT, GBM, and spacecraft assembly
  – complete by early 2006.

Delivery of the LAT and GBM instruments
  – for observatory integration in spring 2006.

Observatory integration and test
  – spring 2006 through summer CY07.

Major scientific conference,
  – the First GLAST Symposium, being planned for early 2007.