Gamma-ray Large Area Space Telescope

GLAST Mission, LAT Project, Science Opportunities

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Stanford University

DOE Program Review
SLAC, Stanford University
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Outline

• GLAST Mission overview

• Large Area Telescope (LAT) Project overview and status

• Science overview
Through most of history, the cosmos has been viewed as eternally tranquil.
During the 20th century the quest to broaden our view of the universe has shown us the vastness of the Universe and revealed violent cosmic phenomena and mysteries.
GLAST is an important part of the continuing quest to broaden our view of the universe.

- observe, with unprecedented detail, cosmic arenas of extreme violence
- explore Nature’s highest energy processes (10 keV – 300 GeV)

LAUNCH: September 2006
GLAST Mission

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

- **LAT** measures gamma-rays in the energy range \( \sim 20 \text{ MeV} \)
  - \( >300 \text{ GeV} \)

- **GBM** provides correlative observations of transient events in the energy range
  \( \sim 20 \text{ keV} – 20 \text{ MeV} \)
Summary of GLAST Project History

• from its conception, GLAST developed by a collaboration of astrophysicists and particle physicists
• major leap in capability brought by modern detector technology

• LAT concept & technology in development by collaboration since 1992
  – extensive beam tests of LAT elements, including high-altitude balloon flight of prototype LAT tower; validation of Monte Carlo model

• GLAST endorsed by NASA Space Science Advisory Committee, Nov 1997

• Presented to DOE HEPAP, Jan 1997; submitted proposal for LAT to DOE, Feb 1998; reviewed by SAGENAP, April 1998

• Collaboration Proposal for LAT Flight Instrument accepted by NASA, Feb 2000
  - proposal endorsed by CNES, CEA, IN2P3, ASI, INFN, JGC, SGC
  - subsequently, LoAs, MoAs signed or in final-draft form to formalize agreements

• NRC Decadal Astronomy & Astrophysics Review ranks GLAST highest priority “moderate-size” space mission for next decade, Sept 2000
Complementary capabilities of GLAST and ground-based \(\gamma\)-ray observatories

The next-generation ground-based and space-based experiments are well matched.
GLAST Mission overview

GLAST Science
- Study Cosmos in Energy Range from 10 keV-300 GeV
- Factor of 40 More Sensitivity
- Full Sky Coverage in 3 Hours
- Gamma-Ray Burst Alerts

GPS Signals Provide
- Time 10 μsec
- Position <3.3 km

Commands 2 kbps
Telemetry 32 kbps 2.5 Mbps

Commands 4 kbps
SW Uploads 4 kbps
TOO 250 bps

Telemetry 1 kbps
Alert Messages 1 kbps

X-Band
- Science Data
- 10 Mbps

S-Band
- Science Data
- 10 Mbps

Data, Command Loads
Schedules

LAT Instrument Operations Center
Science Support Center
GBM Instrument Operations Center

Alerts

Mission Operations Center

GRB Coordinates Network
TDRSS (SN)
White Sands (SN)

HEASARC

Malindi (GN)
DELTA 2920H-10
Hawaii-USN(GN)
Si Tracker
pitch = 228 µm
8.8 \times 10^5 channels
18 planes (16 with converters)

CsI Calorimeter
hodoscopic array (8 layers)
6.1 \times 10^4 channels

ACD
segmented scintillator tiles

Grid
mechanical backbone

LAT: 4 \times 4 modular array
3000 kg, 650 W
20 MeV – 300 GeV

Data Acquisition
Single Photon Angular Resolution
3.5° @ 100 MeV
0.15° @ 10 GeV

Point Source Sensitivity:
< 6 x 10^{-9} ph cm^{-2}s^{-1}
(est. performance:
< 3 x 10^{-9} ph cm^{-2}s^{-1})

Source Localization:
0.3’ – 1’

Wide Energy Range: 20 MeV - >300 GeV

40 times EGRET’s sensitivity and extends energy range to 300 GeV

Wide Field of View (> 2 sr)

Low dead time: < 100 µs/event

Large Effective Area (A_{eff})_{peak} > 8,000 cm^2

Good Energy Resolution
\Delta E/E \sim 10\%; 100 MeV – 10 GeV
\sim < 20\%; 10 GeV – 300 GeV
GLAST LAT Collaboration

United States
- California State University at Sonoma
- University of California at Santa Cruz - Santa Cruz Institute of Particle Physics
- Goddard Space Flight Center – Laboratory for High Energy Astrophysics
- Naval Research Laboratory
- Stanford University – Hanson Experimental Physics Laboratory
- Stanford University - Stanford Linear Accelerator Center
- Texas A&M University – Kingsville
- University of Washington
- Washington University, St. Louis

France
- Centre National de la Recherche Scientifique / Institut National de Physique Nucléaire et de Physique des Particules
- Commissariat à l'Energie Atomique / Direction des Sciences de la Matière/ Département d'Astrophysique, de physique des Particules, de physique Nucléaire et de l'Instrumentation Associée

Italy
- Agenzia Spaziale Italiana (ASI), Science Data Center
- Istituto di Astrofisica Spaziale, (IASF, CNR)
- Istituto Nazionale di Fisica Nucleare (INFN)

Japan GLAST Collaboration
- Hiroshima University
- Institute for Space and Astronautical Science
- RIKEN

Swedish GLAST Consortium
- Royal Institute of Technology (KTH)
- Stockholm University

126 Members (including 62 Affiliated Scientists)
18 Postdoctoral Students
22 Graduate Students
International contributions to the LAT

Si Tracker

ACD

Grid (& Thermal Radiators)

CsI Calorimeter

Electronics, Data Acquisition & Flight Software

e^+ e^-
Collaboration Organization

Senior Scientist Advisory Committee
– membership

- N. Gehrels, Chair
- P. Michelson, PI/Spokesperson
- G. Barbiellini, Italy
- R. Bellazzini, Italy
- E. Bloom, U.S.
- T. Burnett, U.S.
- P. Carlson, Sweden
- R. Dubois, U.S.
- I. Grenier, France
- N. Johnson, U.S.
- R. Johnson, U.S.
- T. Kamae, Japan
- J. Ormes, U.S.
- S. Ritz, U.S.
- H. Sadrozinski, U.S.
- D. Smith, France
- D. Thompson, U.S.
- K. Wood, U.S.

SSAC Charter

- Advise PI/Spokesperson on the conduct of the LAT Science Investigation
- Implement collaboration membership policy and publication policy
- Advise PI and LAT Management on LAT design issues that critically impact science performance
- Meet monthly
GLAST scheduled for launch in September 2006
Fabrication Phase funding contributions

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<th>Country/Group</th>
<th>Contribution</th>
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<tr>
<td>NASA</td>
<td>52.1%</td>
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<tr>
<td>DOE</td>
<td>23.2%</td>
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<tr>
<td>France</td>
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<tr>
<td>Japan</td>
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<tr>
<td>UCSC</td>
<td>1.8%</td>
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<tr>
<td>SLAC Science Staff</td>
<td>6.3%</td>
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TOTAL = $159.7M
DOE = $37.0M
NASA = $83.3M
US/Japan = $1.0M
Subtotal = $121.3M
International Memoranda of Agreement

MoAs between Stanford Univ-SLAC and:

- INFN, ASI, Italy
  - Status: pending signature
- IN2P3, France; NRL
  - Status: √ signed
- CEA/DSM/DAPNIA, France; NRL
  - Status: √ signed
- Royal Inst. of Technology & Stockholm Univ., Sweden; NRL
  - Status: √ signed
- Hiroshima Univ., ISAS & RIKEN, Japan; UCSC/SCIPP
  - Status: √ signed

Purposes of Agreements

- establish areas of responsibility and commitments to LAT Project (e.g. deliverables, science participation, )
- establish International Finance Committee to review status of commitments

Agreements available on Web:
www-glast.slac.stanford.edu/LAT-Details/MOAs/MOAList.htm
<table>
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<tr>
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<td>signed</td>
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<tr>
<td>NASA – CNES Agreement</td>
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<td>NASA – ASI Agreement</td>
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<tr>
<td>NASA – Japan</td>
<td>draft in process</td>
</tr>
<tr>
<td>NASA – Sweden</td>
<td>draft in process</td>
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LAT Project status summary and highlights for the next year

• DOE Baseline Review / NASA PDR Review, January 2002
  Delta Baseline–PDR Review, July 2002
  - LAT Project baselined; CD-2 approval (Nov 2002)

• the transition from design to flight fabrication is currently underway
  – engineering models being completed and evaluated
    • completed subsystem peer reviews

• International Finance Committee formed to regularly review funding agency commitments – 1st meeting, February 18-19, 2003; next meeting scheduled for September 2003
  – international partners have been delivering on commitments
  – 03’ funding commitments are particularly critical to maintaining schedule

• first flight hardware deliveries to SLAC scheduled for February-March, 2004
  – first 4 calorimeter and tracker modules will be integrated into Calibration Unit (CU)
  – LAT Grid delivered June 2004 – LAT integration begins

• collaboration meeting planned for Sept 15-19, 2003 in Rome, Italy
  – meeting will concentrate on collaboration plan for operations phase: instrument operations, science data analysis, etc.
Questions addressed by high-energy gamma-ray observations

• What are the mechanisms and sites of cosmic-ray generation (acceleration)?

• What are the unidentified sources of high-energy radiation revealed by the Compton Observatory?

• What are Gamma-Ray Bursts?

• What is the origin of the apparently isotropic, diffuse extragalactic gamma-ray background?
Collaboration Science Working Groups

I. Working Group I: Extended Sources and Diffuse Radiation
Galactic Diffuse Radiation and Emission from Normal Galaxies
Gamma-ray Emission from Molecular Clouds
Cosmic Ray Acceleration and Gamma-ray Emission from SNR shells and Plerions
High-Energy Emission from Galaxy Clusters

II. Working Group II: Galactic Sources and Unidentified Sources
Particle Acceleration and Gamma-ray Emission in Pulsars and Binary Systems
Unidentified Sources: Population Studies
Unidentified Sources: Radio/optical/X-ray identifications
High-Energy Emission from Stellar-Mass Galactic Black Hole Candidates
The Galactic Center

III. Working Group III: Extragalactic Sources
Extragalactic Diffuse Radiation and LogN-LogS of Extragalactic Sources
Gamma-ray Emission Mechanisms in Blazar AGNS
Cosmic Evolution of AGN Blazars and Spectral Cutoffs: Population and EBL Studies
High-Energy Emission from Seyfert galaxies and Radio galaxies

IV. Working Group IV: Searches for New Physics
Searches for Dark Matter
Search for Signatures of Quantum Gravity
Search for Primordial Black Hole Evaporation

V. Working Group V: GRBs and Solar Flares
Gamma-Ray Bursts: Testing emission models; afterglows and multiwavelength observations
Solar Flares
2704 gamma-ray bursts: isotropic distribution

average spectrum of Seyfert galaxies

map of the Galactic center at 511 keV
CGRO – Science Legacy

COMPTEL

1-30 MeV map of Galaxy

EGRET

$^{26}\text{Al}$ map of Galaxy  - 1.809 MeV relic of Galactic nucleosynthesis over past few million years

All-sky survey (70 MeV – 10 GeV)
EGRET all-sky survey
(70 MeV – 10 GeV)
AGN-Blazar geometry

VLBA Observations of 3C120 (Gomez, et al)
Markarian 421 – broad-band spectrum
source identification requires a multiwavelength approach
  - localization
  - variability

source localization (68% radius)
  - γ-ray bursts: 1 to tens arcminutes
  - unid EGRET sources: 0.3’ – 1’

Unidentified EGRET sources

evidence for at least 2 unidentified Galactic populations
  time variable Galactic population
  persistent Gould belt population
LAT science capabilities – transient sensitivity

enabling LAT capabilities
- wide field-of-view
- low deadtime (for light curve)

- GRB940217 (100sec)
- PKS 1622-287 flare
- 3C279 flare
- Vela Pulsar
- Crab Pulsar
- 3EG 2020+40 (SNR γ Cygni?)
- 3EG 1835+59
- 3C279 lowest 5σ detection
- 3EG 1911-2000 (AGN)
- Mrk 421
- Weakest 5σ EGRET source

detect all EGRET sources after ~day
~200 γ-bursts/year
AGN flares >few minutes
GLAST Survey: ~10,000 sources (2 years)
Constraints on extragalactic background light (EBL) from high-redshift $\gamma$-ray blazars

EBL: - indicator of integrated luminosity of the universe
- can provide unique information on origin of structure at early epochs

Photons with $E > 10$ GeV are attenuated by the diffuse field of UV-Optical-IR extragalactic background light (EBL) $\gamma + \gamma \rightarrow e^+ + e^-$


No significant attenuation below 10 GeV
high-energy isotropic diffuse radiation from x-rays to gamma-rays

The origin of the diffuse extragalactic gamma-ray flux is a mystery. Either sources are there for GLAST to resolve (and study!) OR there is a truly diffuse flux from the early universe.

Estimated contributions:
- Steep-spectrum quasars
- Seyfert I
- Seyfert II galaxies
- Type 1a Supernovae
discovery potential: dark matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of gamma rays.

- Identify relatively narrow spectral lines
  - Requires energy range with response to at least 300 GeV
  - Requires spectral resolution:
    5% at energies above 10 GeV (goal of 3%)

\[ \gamma \gamma \text{ or } Z_{\gamma} \text{ lines} \]

\( e.g. \) halo WIMP annihilation
discovery potential: large extra dimensions

“GLAST is a new dimension search engine”
- Savas Dimopoulos, March 1, 2003

- theories with large (submillimeter) extra dimensions: alternative way to solve the hierarchy problem of particle physics
  - move the Planck scale to near the weak scale
  - observed weakness of gravity due to presence of \( n \) new spatial dimensions large compared to electroweak scale
    (Arkani-Hamed, Dimopoulos & Dvali 1998)

- Recently, Hannestad & Raffelt (2002) pointed out that SNe would produce Kaluza-Klein gravitons that are generic for these theories
  - produced non-relativistically, so many are gravitationally bound to SN core (i.e, neutron star) → KK particle halo
  - KK gravitons decay (\( \tau \sim 10^9 \) years) to \( \nu\nu, e^+e^- \), and \( \gamma\gamma \)
discovery potential: large extra dimensions

- Constraints from EGRET observations (Hannestad & Raffelt 2002):

  \( \gamma \)-ray flux limits for nearby NS limit compactification scale
  \[ \geq 500 \text{ TeV (n=2)} \]
  \[ \geq 30 \text{ TeV (n=3)} \]

- GLAST will have point source sensitivity of ~ \(1.5 \times 10^{-9} \text{ ph cm}^{-2} \text{ s}^{-1}\)

\[ f_{KK} = 10^{-7} \]
where \( f_{KK} \) is the fraction of SN energy emitted as KK gravitons.
GLAST: Exploring Nature’s Highest Energy Processes

September 2006 launch