GLAST Large Area Telescope
- Daily Deep Survey of H.E. Universe -

Tuneyoshi Kamae
SLAC, GLAST Group
On behalf of the
GLAST-LAT Collaboration.

- Gamma-ray astronomy VS. X-ray astronomy
- What makes GLAST-LAT unique
- Where we are now
- New way to study High Energy universe
- Gamma Ray Burst study with GLAST-GBM
Gamma-ray astronomy VS. X-ray astronomy
- Transparency -

- X-ray is absorbed by ISM
- VHE $\gamma$-ray by Extragal. Bkngd Light
- GLAST will reach out to $z>>10$

Chance for serendipitous discoveries.

Total photoionization cross-section

Total photo-ionization cross-section per hydrogen atom [$x(E/1 \text{ keV})^2$] in units $10^{-22} \text{ cm}^2$ as a function of incident photon energy for a gas having a cosmic elemental abundance. The elements responsible for the discontinuities due to their $K$ edges are shown. (Adapted from Brown, R. L. & Gould, R. J., Physical Review, 81, 2252, No. 8, 1970.)

Figure 5-2 Dominant scattering mechanisms for high-energy photons injected in the post-recombination era. The region below the red line has an optical depth $\tau < 1$, thus no scattering occurs. The other regions are dominated by $e^+e^-$ pair production (PP), photon-photon scattering (GG), pair production in matter (PPM1) and pair production in ionized matter (PPM2) (Kribs & Rothstein 1997).
Gamma-ray astronomy VS. X-ray astronomy
- Cosmic sources emit gamma-rays -

![Diagram showing charged particle spectrum from ideal Fermi accelerator with various sources and their emissions in energy spectrum.](Diagram.png)
Gamma-ray astronomy VS. X-ray astronomy

- Detector Technology -

X-ray (0.5 - 10keV)
- Focusing possible
- Large effective area
- Excellent energy resolution
- Very low background
- Narrow view

Gamma-ray (0.1-500GeV)
- No focusing possible
- Wide field of view
- Limited effective area
- Moderate energy resolution
- High background
What makes GLAST unique
- Tracking of e+e- pairs -

**Pair-conversion telescope**

Measure $\theta, E, t$ of photons

**Photon cross-section in lead**

Limitations on energy coverage:
- low $E$: low cross-section $\rightarrow$ 20MeV
- high $E$: shower leakage

Limitations on angular resolution (PSF):
- low $E$: multiple scatt. $\rightarrow$ many thin layers
- high $E$: hit precision & lever arm
What makes GLAST unique
- GLAST Large Area Telescope (LAT) Design (5) -

**Instrument**
- 16 towers ⇒ modularity
- height/width = 0.4 ⇒ large field-of-view

**Tracker**
- Si-strip detectors: 236 mm pitch, total of 8.8 x 10^5 ch.

**Calorimeter**
- hodoscopic CsI crystal array
  ⇒ cosmic-ray rejection
  ⇒ shower leakage correction
- X_{Tkr} + X_{Cal} = 10 X_0 ⇒ shower max
  contained < 100 GeV

**Anticoincidence Shield**
- segmented plastic scintillator
  ⇒ minimize self-veto
  > 0.9997 efficiency & redundant readout
What makes GLAST unique
- GLAST LAT Performance -

FOV w/ energy measurement due to favorable aspect ratio

Effects of longitudinal shower profiling
What makes GLAST unique
- GLAST LAT Sensitivity -

More than 40 times the sensitivity of EGRET

Large Effective Area (20 MeV – 1 TeV)

Optimized Point Spread Function (0.35° @ 1 GeV)

Wide Field of View (2.4 sr)

Good Energy Resolution ($\Delta E/E \sim 10\%$)
What makes GLAST unique
- EGRET’s 3rd Catalog in 2 days -

All 3EG sources + ~ 80 new in 2 days

Time Variability Monitoring:
Flares (Blazars, AGNs, Coronas), Precessions and Glitches (Pulsars), Lensing (AGNs)

- 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

*zenith-pointed, ^“rocking” all-sky scan
Where we are now
- GLAST LAT Organization -
Where we are now
- Technical Direction -

DOE/NASA JOG

Level I Documents

NASA/GSFC
GLAST Project
Office

Level II Documents

SU-SLAC IPO

Level III Documents

SU-SLAC
I&T Mgr.

SU-SLAC
Engr.

SU-SLAC
Chief Elec.
Engr.

SU-HEPL
IOC Mgr.

SU-SLAC
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Engr.

SU-SLAC
Chief Elec.
Engr.

SU-HEPL
IOC Mgr.

Level III Documents

SU-SLAC
SAS Mgr.

Collaboration Institutions
Where we are now
- Funding Flow -

Funding Sources

LAT Collaboration Institutions

U.S.A.
- NASA HQ
  - NASA/GSFC GLAST Proj. Office

- DOE

France
- CNES / CEA / IN2P3

Italy
- INFN / ASI

Japan
- Ministry of Education, Culture, Sports, Science, & Technology
  - KEK (US-Japan)

Sweden
- Wallenberg Foundation

U.S.A.
- SU
  - SLAC
    - IPO
      - HEPL
      - UCSC
      - SSU

- GSFC/LHEA
- NRL

France
- CEA/DAPNIA
  - IN2P3 Labs
  - INFN Labs

Italy
- INFN Labs

Japan
- ISAS
- RIKEN Institute
- Hiroshima University

Sweden
- KTH Stockholm University
Where we are now
- Funding -

Total = $158.2M

NASA 44%
DOE 22%
UCSC 2%
France 11%
Italy 12%
Sweden 5.0%
Japan 4%
Stanford 0.3%
UW 0.3%
UCSC 2%
Where we are now
- Data Management Plan -

LAT Data Flow

GLAST LAT Collaboration

Collaboration Science Investigation

LAT Inst. Ops. Center
LAT data handling
Instrument performance
Level 0,1 data processing
LAT Data Archiving

Science Support Center
Science scheduling
Mission archiving
Guest Observer Support
Standard product processing

Guest Observers

Coordinated Multiwavelength Investigations

Mission Ops Center
LAT Data

Burst and Transient Alerts

Large loads
TOO commands

GBM data

Status, Command Loads

Schedules, Spacecraft data for archiving

GRB Coordinates Network

Alerts

Spacecraft, GBM data

Level 1 & selected Level 2,3 LAT data (e.g. source catalog; diffuse bkgrd model)
Where we are now
- Balloon Flight Engineering Model successfully flown -

Morning of August 4 (Saturday), 2001

240m
Where we are now
- Three-in-a-row trigger worked quite well -

L1T rate Vs Atmospheric depth

Atmospheric depth VS. L1T Rate of Run54

Atmospheric depth (g/cm²) is calculated as
1.02 \times \text{pressure}\text{(in mbar)}
Ev #1: 2km above ground
Ev #250000: entering level flight
Ev #285594: 15 min. in level flight

ACD: PHA 250ch (a little > pedestal)
XGT: PHA 205ch (a little > pedestal)
Geometry not right.
Cal: No calibration done yet

A beautiful electron shower
Where we are now
- Balloon event gallery No.2 -

#16044: A beautiful gamma

#19060: A beautiful gamma
Where we are now
- Balloon event gallery No.3 -

#276404: A beautiful upward V

#277127: Something entering sideway
Where we are now
- Understanding the data: Low energy e⁻/e⁺/γ spectra -

• No reliable data below extrapolate down to ~100 MeV
• We proceed being guided by Geant4 simulation
Where we are now
- BFEM data: Distr. of the top-most layer -

BFEM data in level flight vs. Geant4 simulation with soft electrons
Note: 1) The even/odd difference is due to the layer spacing
2) 25\textsuperscript{th} is fully instrumented but next several layers are not
Where we are now
- BFEM data: Distr. of the top-most layer: proton and electron -

G4 simulation, proton/electron contribution
Where we are now
- BFEM data: Distr. of the total hit layers -

BFEM data vs. G4 simulation

Proton/electron contribution

<table>
<thead>
<tr>
<th>Run55</th>
<th>Geant4 (Proton:Electron=0.27:0.73)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electron spectrum is extrapolated down to 30 MeV</td>
</tr>
</tbody>
</table>

| TOTNUMBER | Nent = 104819 | Mean = 11.36 | RMS = 5.144 |

| TOTNUMBER1 | Nent = 20736 | Mean = 16.72 | RMS = 4.653 |

Electron
Proton
New Way to Study H. E. Universe
- GLAST and study of the Early Universe -

Collisions among Proto-gal. and galaxies

Starburst activity
Super novae
Photons density
Hot gas, dust

H.E. particles
(p, e+, e-, ν)

X/γ-rays

Extra-gal. Backgnd Light

Lyman α forest

Complimentary to:
Deep surveys in IR, Optical and sub-milli.

Shocks and winds
Turbulence
Acceleration

Mass accretion to Black-Holes
AGN activities

Large-scale magnetic field
(Energy in CR and B)

Galaxy formation
(Globular clusters, dwarf gal. and gal.)

Formation of clusters of galaxies

DM

DM
New Way to Study H. E. Universe
- Merger of galaxies are very common in the Early Universe -

Figure 16: An increase in the merger fraction as a function of redshift from the HST analysis of LeFevre et al (2000). Galaxies of known redshift were examined for satellites brighter than a fixed rest-frame luminosity within a projected radius of 20h^{-1} kpc and corrections made for unrelated line-of-sight contamination. This redshift-dependent merger rate was adopted by Brinchmann & Ellis (2000) in Figure 15.
New Way to Study H. E. Universe
- Large structure formation in the Early Universe -

\( z \simeq 1000 \)

Decoupling between radiation and matter:
- Energy density of matter: \( \sim a(t)^{-3} \)
- Energy density of radiation: \( \sim a(t)^{-4} \)

Baryon Jeans mass \( \sim 10^6 \) Solar Mass ~ globular clusters?

\( z \simeq 30 \)

10kpc scale structure? ~ inner part (bulge) of galaxies?
- Search for AGNs
- Search for GRBs
- Study for bulge

\( z \simeq 4-6 \)

Proto-galaxies and star formation ~ Quasars, AGNs, and their collisions
- Search for AGNs
- Absorption by EBL
- Search for GRBs

\( z \simeq 1-2 \)

Galaxies and star formation ~ Clusters of galaxies?
- Search for AGNs and star burst galaxies
- Search for GRBs
- Gammas from clusters and large scale shock fronts
**New Way to Study H. E. Universe**

- Absorption of H.E. photons by Extragal. Background Light -

\[ \gamma \gamma \rightarrow e^+ e^- \]

**Target photon density**

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>Target photons</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>E=12eV</td>
</tr>
<tr>
<td>300</td>
<td>E=100GeV</td>
</tr>
<tr>
<td>60</td>
<td>E=50GeV</td>
</tr>
</tbody>
</table>

**Energy at detector for fixed photon energies (E) in the co-moving frame**

Not much target photons E>12eV
New Way to Study H. E. Universe
- Several classes of $\gamma$-emitting AGN/QSO -

![Diagram showing classes of $\gamma$-emitting objects (AGN, Quasar, BL Lac etc.)]

**Figure 7.** Schematic representation of the proposed unifying scheme: the sequence HBL, LBL, HPQ, LPQ corresponds to an increase in the external radiation field, the total energy density and the injected power. These in turn result in a decrease of $\gamma_{\text{peak}}$ and an increase in the Compton dominance.

**Figure 12.** Average SEDs for the ‘total blazar sample’ binned according to radio luminosity irrespective of the original classification. The overlaid curves are analytic approximations obtained according to the one-parameter-family definition described in the text.

**Discovery by Beppo-SAX**

![Graph showing the spectrum of 1510–089 with the bump around $10^{16} - 10^{17}$ Hz due to the SSC component.]

**Fig. 8.**—Overall SED of 1510–089 with the spectrum calculated using the homogeneous EC model (see text). Data are from Gear et al. (1994), Tornikoski et al. (1996), Landau et al. (1986; radio), Pian & Treves (1993; UV) and Hartman et al. (1999; EGRET). The bump around $10^{16} - 10^{17}$ Hz is due to the SSC component.

Many more $\gamma$-emitting objects (AGN, Quasar, BL Lac etc.)
New Way to Study H. E. Universe
- Multiple wavelength campaign -
VLBA 22 GHz Observations of 3C120

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Alan P. Marscher
Antonio Alberdi
Svetlana Marchenko–Jorstad
Cristina García–Miró

IAA (Spain)
BU (USA)
IAA (Spain)
BU (USA)
IAA (Spain)
New Way to Study H. E. Universe
- Super Nova Remnants: Source of high energy particles -

Super Nova Remnant 1006 seen by ASCA (X-ray band)
Image of synchrotron radiation by high energy (~200TeV) electrons in the accelerating shock front in SN1006
New Way to Study H. E. Universe
- New classes of pulsars and evolution of known pulsars -

- Synchrotron emission (X-ray) by high energy electrons (~100GeV) from the neutron star’s magnetosphere (Magnetic induction: Pulsed)
- Synchrotron emission (X-ray) by high energy electrons (~100TeV) from the nebula around the neutron star’s magnetosphere (Accelerating shock front: Unpulsed)

Figure 7-2  Three-dimensional simulation of the Vela pulsar. The spin axis is vertical. The red surface is the closed zone, the polar cap is at the base of the green (radio) beam, and the outer gap surface is in blue. The light curve, calculated for the Outer Gap model, has the same color coding.

The bell-shaped synchrotron nebula around the Crab pulsar (the small dot at the center of the opening of the bell-shaped nebula). A string-like flow of electrons along its rotation axis is also visible.
New Way to Study H. E. Universe
- New class of pulsars: Radio-quiet, gamma-ray loud pulsars -

- Until recently, all pulsars have been discovered in Radio Band, with one exception of Geminga.
- In the past 5 years several pulsars have been discovered in X-ray. They are generally very weak in Radio Band. **Many radio-quiet pulsars to be discovered**
- We now expect to find many radio-quiet pulsars. We can see through the Galaxy with gamma-rays but not with radio wave. **So we will study distribution of pulsars (ie. NS’s) in the Galaxy.**

Gemminga’s pulse profile by EGRET

**Figure 7-1** Light curve of the Geminga pulsar (period 237 ms) observed by EGRET in gamma rays above 100 MeV.
New Way to Study H. E. Universe
- Interaction of shock fronts and ISM: SN1987A -
New Way to Study H. E. Universe
- Propagation of Cosmic protons and electrons -

Gamma Cygni SNR: Pulsar, SNR, and cosmic-ray interaction with ISM

Measurement on cosmic-ray proton and electron fluxes

Radio image of Molecular H line (21cm)  EGRET image  GLAST image (simulation)

21-cm Continuum  EGRET Data  GLAST Simulation

Galactic Latitude

Figure 8-2  Radio continuum emission of the Gamma Cygni SNR at 1.4 GHz from the (Canadian Galactic Plane Survey, English et al. 1998 compared with EGRET observed and GLAST simulated images > 1 GeV. The dashed circles indicate the location of the shell of the SNR (Higgs et al. 1977). An X-ray source suspected to be a gamma-ray pulsar (Brazier et al. 1996) is shown as an asterisk. In the GLAST model of data from a 1-year sky survey, the EGRET flux has been partitioned between the pulsar and a region at the perimeter of the shell where the CRs are interacting with an ambient interstellar cloud.
New Way to Study H. E. Universe
- Propagation of cosmic ray particles -

Unidentified EGRET Sources

Source identification requires a multiwavelength approach
- localization
- variability

Evidence for at least 2 unidentified Galactic populations:
- variable Galactic halo population
- persistent Gould Belt population
New Way to Study H. E. Universe
- Anatomy of our Galaxy: Basic structure and its origin -

**Major components**

- Central bulge (nucleus, molecular ring)
- Disk (spiral arms, thin disk, thick disk)
- Halo

**Energy density**

- Starlight \( \sim 0.7 \times 10^{-12} \text{erg/cm}^2 \)
- Turbulent gas \( \sim 0.5 \times 10^{-12} \text{erg/cm}^2 \)
- Cosmic rays \( \sim 2 \times 10^{-12} \text{erg/cm}^2 \)
- Magnetic field \( \sim 2 \times 10^{-12} \text{erg/cm}^2 \)
- CMB \( \sim 0.4 \times 10^{-12} \text{erg/cm}^2 \)

**Luminosity**

- Radio \( \sim 3 \times 10^{38} \text{erg/s} \)
- Infrared \( \sim 3 \times 10^{41} \text{erg/s} \)
- Optical \( \sim 3 \times 10^{43} \text{erg/s} \)
- X-ray \( \sim 10^{39-40} \text{erg/s} \)
- \( \gamma \)-ray (>100MeV) \( \sim 5 \times 10^{38} \text{erg/s} \)

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Fig. 1.— Pattern of spiral arms and the molecular ring in the star count model. Each little square is 1 kpc wide.
New Way to Study H. E. Universe  
- Multi-Wave Analysis of Galactic Diffuse Emissions –

- **Galaxy Simulator Project**
  - Separate pi-zero and electron brems contributions
  - Determine total mass of nearby GMCs C/H ratio
  - Galactic electron distribution SNR association?
  - Galactic arm structure.... What are between arms?
  - Correlation with radio, X & hard-X observations
  - Galactic magnetic field: strength and large scale structure
  - Determine total amount of cold dark baryonic matter

Giant Molecular Clouds in Cygnus region  
(galactic arm structure?)

Pi-zero flux measurement by GLAST will determine the total mass in the GMCs and their C/H.
New Way to Study H. E. Universe
- Cosmic Ray Contents in Nearby Galaxies -

GLAST will measure cosmic electron and proton fluxes for LMC, SMC and M31

Past SN rate, past history of galaxies, stability of galaxies

LMC by EGRET

LMC by GLAST (simulation)

LMC in IR (IRAS)
New Way to Study H. E. Universe
- Thorough end-to-end simulations needed –

GLAST-LAT Gamma-ray Sky Model
- Galactic diffuse emission model
- Galactic point sources
- High latitude emission model
- Extragalactic point sources
- Extragalactic diffuse sources

GLAST-LAT Background Simulator
- Primary and secondary protons
- Primary alpha
- Primary and secondary e-/e+
- Atmospheric gammas and X-rays

Simulated observation data (1s step)
Real observation data (1s step)

Detector simulator (Geant4)
Data reduction
Comparison (fitting)

Satellite orbit and Orientation (~1sec step)
Science
Gamma Ray Burst study with GLAST-GBM
- GLAST Gamma-ray Burst Monitor -

**LAT:**
- Capture > 25% of GRBs in LAT FOV (2 sr or more)
- Deadtime of < 100 msec per event
- Spectral resolution < 20%, especially at energies above 1 GeV

**GBM:**
- Monitor energy range: 10 keV - 20 MeV
- Monitor FOV of 8 sr (shall overlap that of the LAT)
- Notify observers world-wide:
  - Recognize bursts in realtime
  - Determine burst positions to few degree accuracy
  - Transmit (within seconds) GRB coordinates to the ground
  - Re-point the main instrument to GRB positions within 10 minutes
Gamma Ray Burst study with GLAST-GBM
- Monitor GRB with wide energy coverage -

• Cover the classical gamma-ray band where most of the burst photons are emitted by GLAST Gamma-ray Burst Monitor (GBM)
• Monitor all of the sky visible from Low-Earth Orbit (10keV-30MeV)
• Monitor 40% of the sky visible from LEO (20MeV-500GeV)
• Identify when and where to re-point the spacecraft to optimize observations and notify other observers

Simulation:
Spectrum of an intense GRB by GLAST
Gamma Ray Burst study with GLAST-GBM
- GRB afterglow in > 20 MeV ? -

• EGRET discovered high energy GRB afterglow
  – only one burst
  – dead time limited observations
• GLAST will observe many more high energy afterglows
  – strong constraint to GRB models
Gamma Ray Burst study with GLAST-GBM

- GRB flux for > 20 MeV ? -

EGRET suffered severely from its dead time. GLAST can record far more photons.

EGRET missed ~95% of photons for bright GRBs. GLAST will collect

x5(area)x10-100(deadtime)=x50-500 more photons
Gamma Ray Burst study with GLAST-GBM
- Temporal correlation btwn X-ray and γ-ray -

Standard wisdom about GRB is: the more energetic, the closer to the central energy source. GLAST measures both in X-ray/soft γ-ray (GBM) and high energy γ-ray (LAT), arrowing to study temporal correlation between them.

Figure 6-2 Simulated time profile of a GRB detected by the LAT and the GBM. The pulses are narrower at LAT energies.
Gamma Ray Burst study with GLAST-GBM

- Two models of GRB: Hypernovae and mergers of compact objects -
Biggest Bonus
- Discovery of Dark Matter Particle -

- Identify relatively narrow spectral lines coming from two photon decay.
- For overall WIMP decays, the spectral feature will not be easy to detect.

Figure 5-1 Simulated diffuse extragalactic gamma-ray flux measurements for GLAST (upper points) and EGRET (lower points). The dashed lines show the flux from unresolved AGNs, the dotted lines the contributions from WIMP decays in the early universe, and the solid line shows the total (Willis 1996).
Schedule
- Overall Schedule as of March 2001 -

Calendar Years


Formulation

SRR

PDR

NAR

I-CDR (Joint DOE/NASA Review)

M-CDR

Build & Test Engineering Models

Build & Test Flight Units

Inst. I&T

Inst.-S/C I&T

Schedule Reserve

Inst. Delivery

Launch

Ops.

NASA-PDR and DOE-Baseline Review Rescheduled for Jan. 8, 2001

NASA announced a new launch date of March 2006