# GLAST

## Science Objectives

see http://glast.gsfc.nasa.gov/

also

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

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

GBM: http://gammaray.msfc.nasa.gov/gbm/

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*GLAST Deputy Project Scientist*

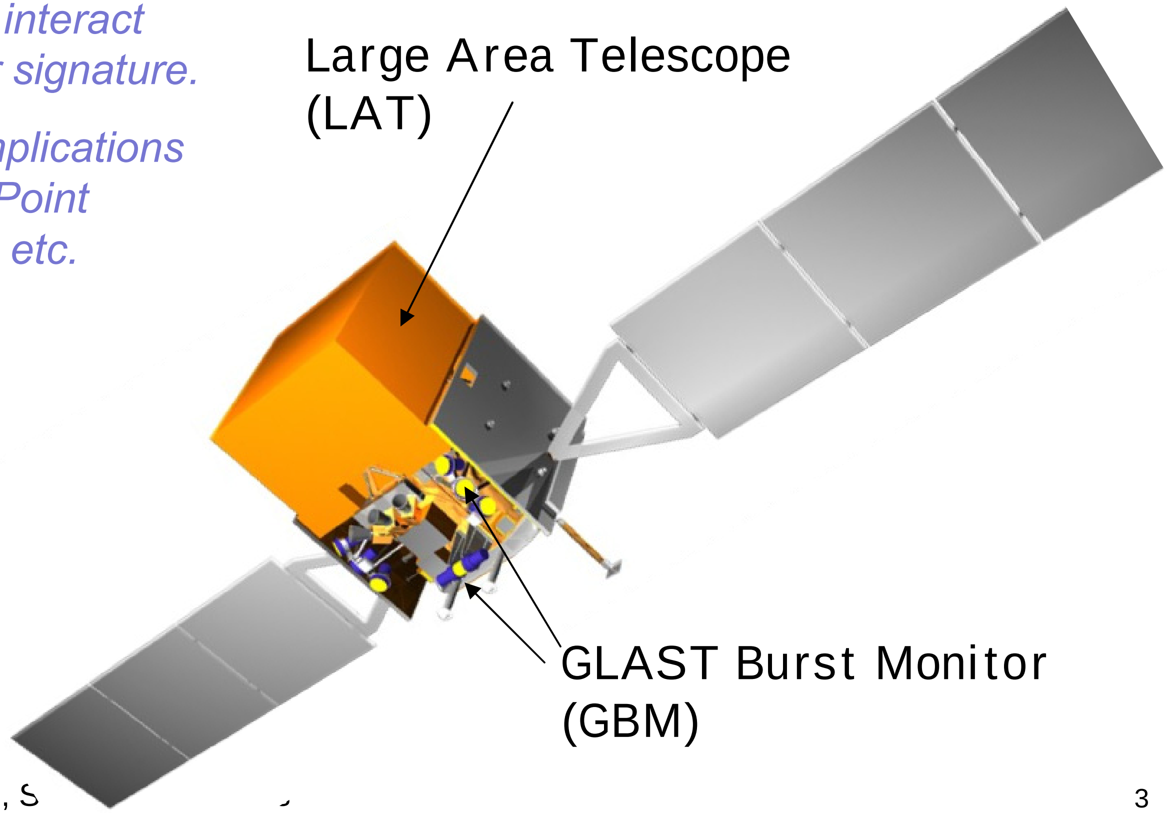
# Outline

- ***Why $\gamma$'s?  Why this energy range?  Techniques***
- ***Brief Tour of Science Topics***
- ***Science Requirements***
- ***Science Mission Elements***
- ***Summary***

# Why study γ's?

***Gamma rays carry a wealth of information:***

- *γ rays do not interact much at their source: they offer a direct view into Nature's largest accelerators.*
- *similarly, the Universe is mainly transparent to γ rays: can probe cosmological volumes. Any opacity is energy-dependent.*
- *conversely, γ rays readily interact in detectors, with a clear signature.*
- *γ rays are neutral: no complications due to magnetic fields. Point directly back to sources, etc.*



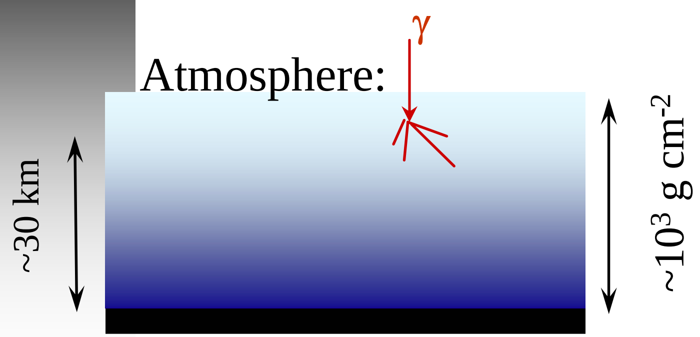

***<u>Two GLAST instruments</u>:***

***LAT: 20 MeV – >300 GeV***

***GBM: 10 keV – 25 MeV***

***Launch: 2007***

# Cosmic γ-ray Measurement Techniques




For $E_\gamma$ < ~ 50 GeV, must detect above atmosphere (balloons, satellites)

For $E_\gamma$ > ~50 GeV, information from showers penetrates to the ground (Cerenkov, air showers)

## Photon interaction mechanisms:

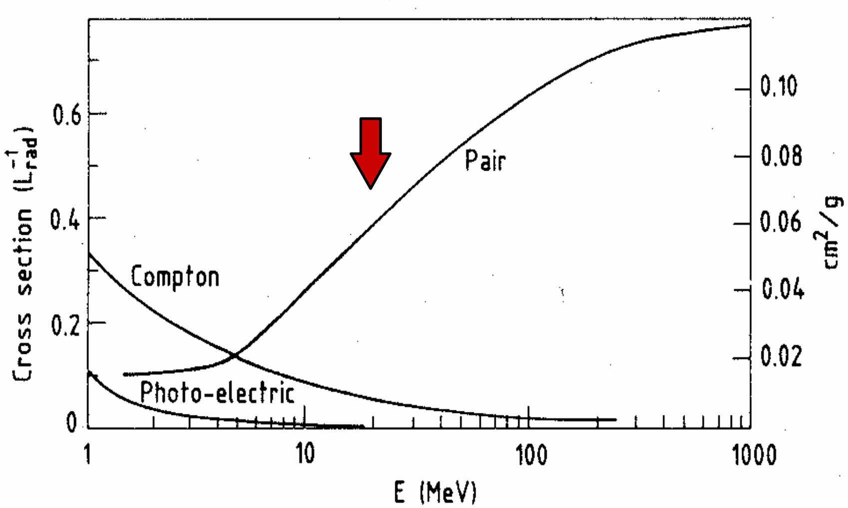
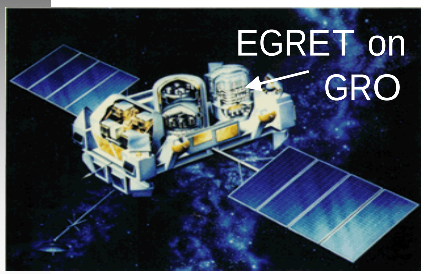
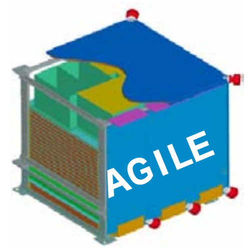


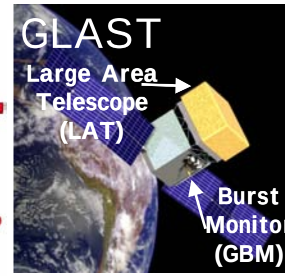

**Fig. 2:** Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

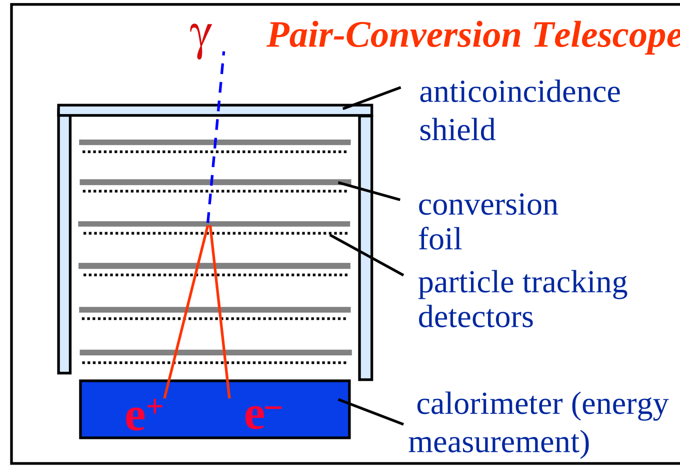
# Gamma-ray Experiment Techniques

- **_Space-based:_**
  - *use pair-conversion technique*



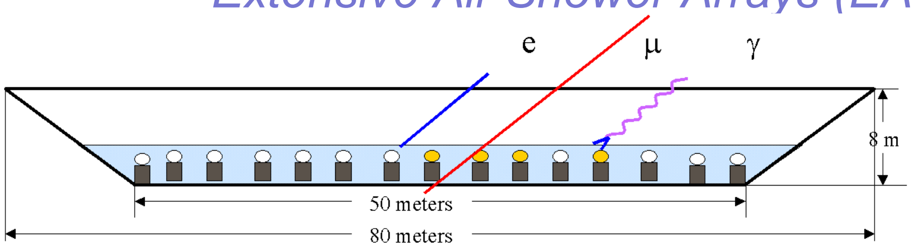




- **_Ground-Based:_**
  - *Airshower Cerenkov Telescopes (ACTs)*

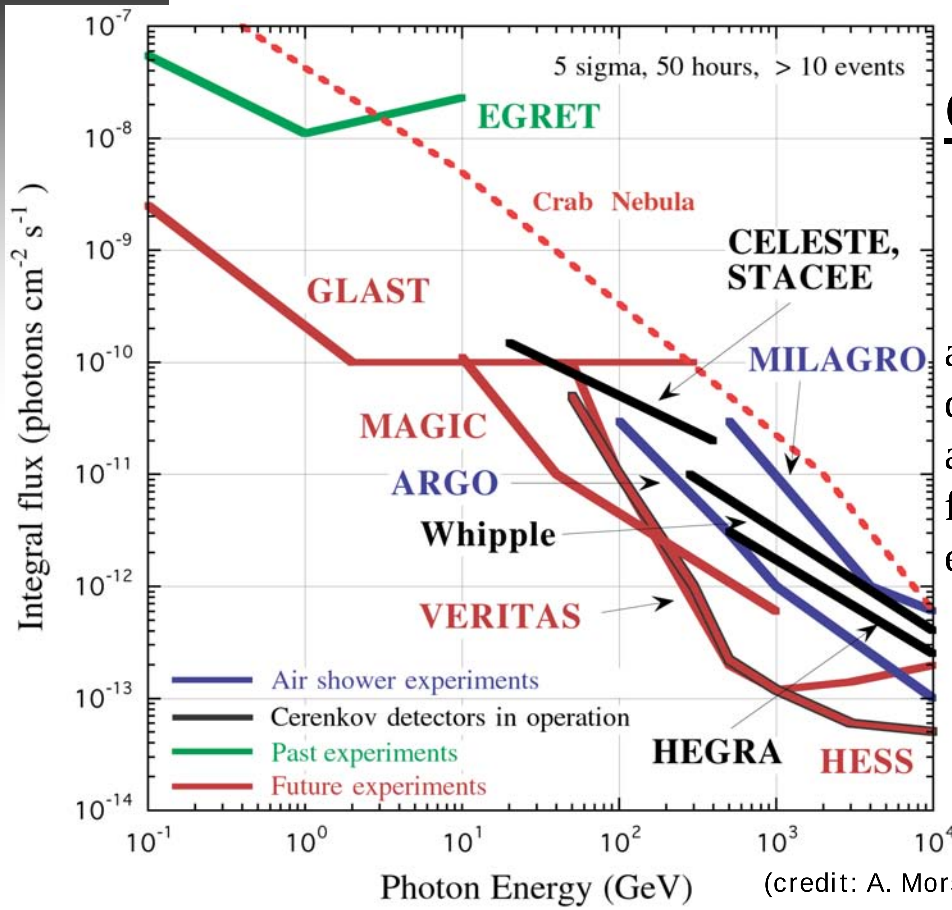
*image the Cerenkov light from showers induced in the atmosphere. Examples: Whipple, CANGAROO, HEGRA, STACEE, CELESTE, CELESTE, VERITAS, MAGIC, HESS*

  - *Extensive Air Shower Arrays (EAS)*




*Directly detect particles from the showers induced in the atmosphere. Example: MILAGRO*

# Gamma-ray Observatories



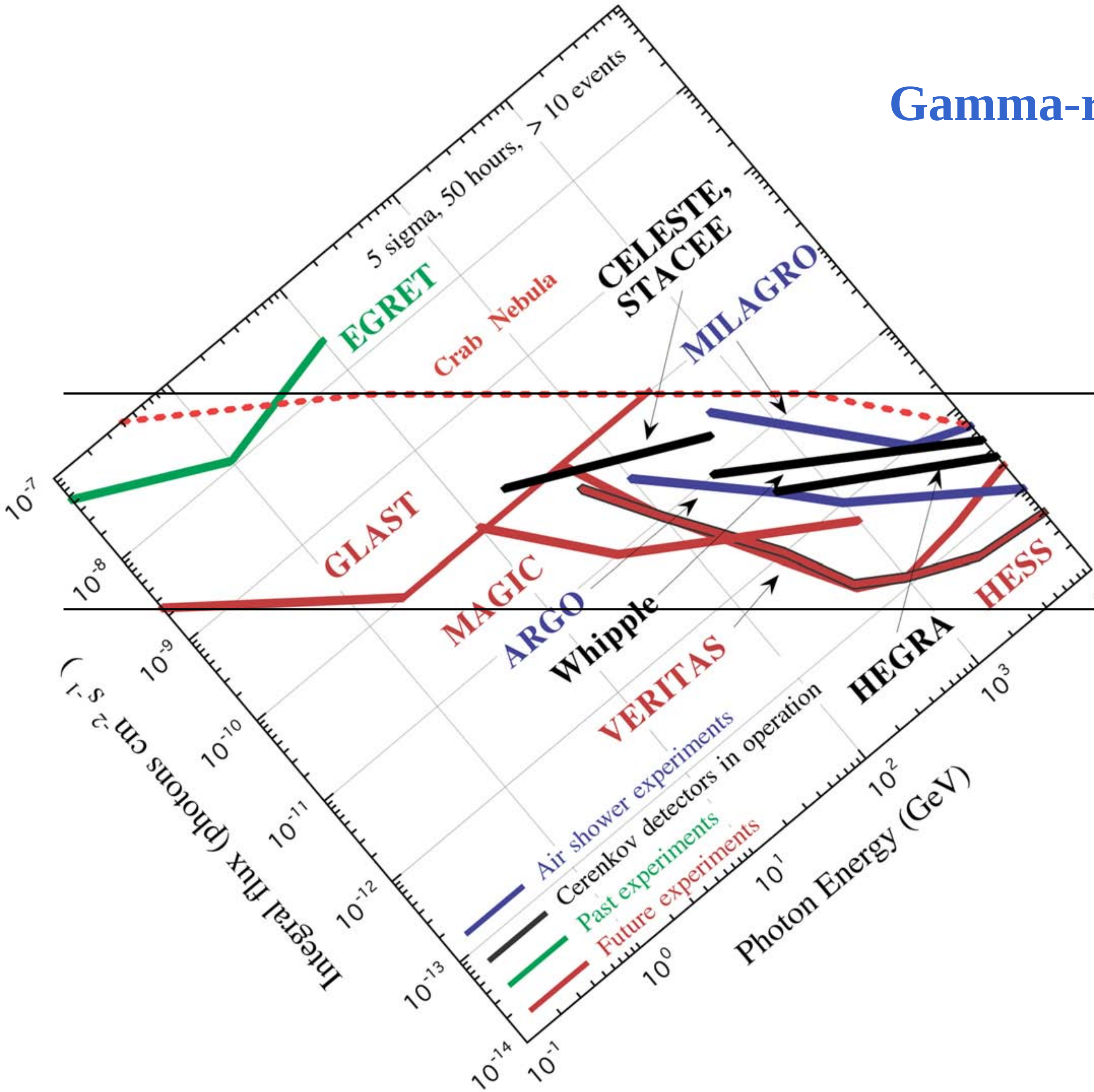

(credit: A. Morselli et al.)

## Complementary capabilities

| | ground-based | | space-based |
|---|---|---|---|
| | **ACT** | **EAS** | **Pair** |
| angular resolution | good | fair | good |
| duty cycle | low | high | high |
| area | large | large | small |
| field of view | small | large | large+can reorient |
| energy resolution | good | fair | good, w/ smaller systematic uncertainties |

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

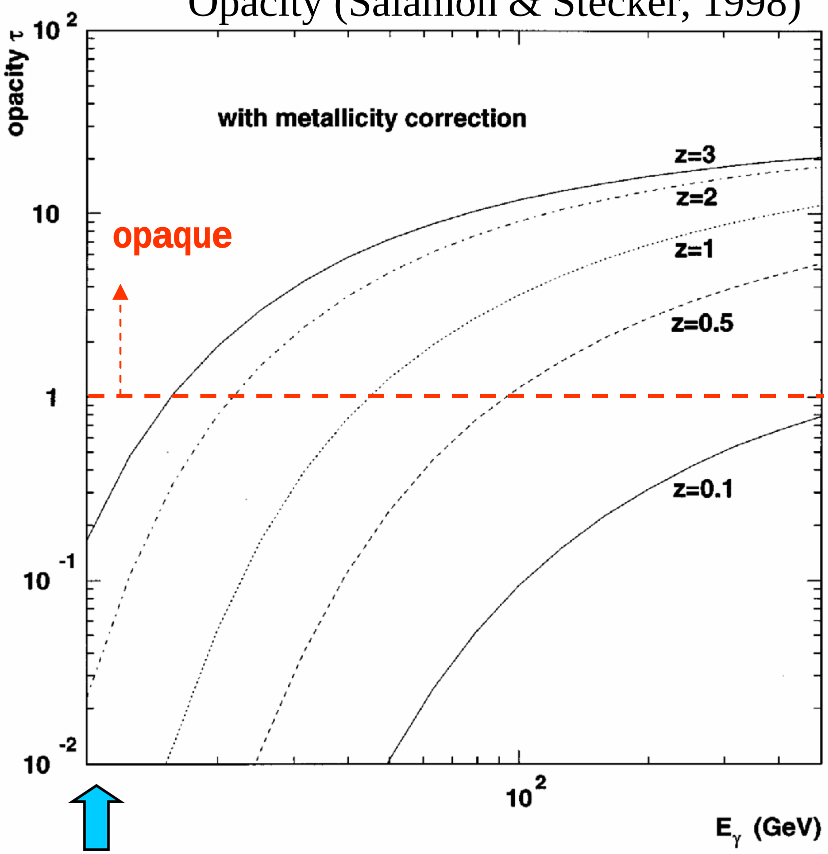
# Gamma-ray Observatories



# An Important Energy Band for Cosmology

Photons with E>10 GeV are attenuated by the diffuse field of UV-Optical-IR extragalactic background light (EBL)

Opacity (Salamon & Stecker, 1998)




No significant attenuation below ~10 GeV.

**only $e^{-\tau}$ of the original source flux reaches us**

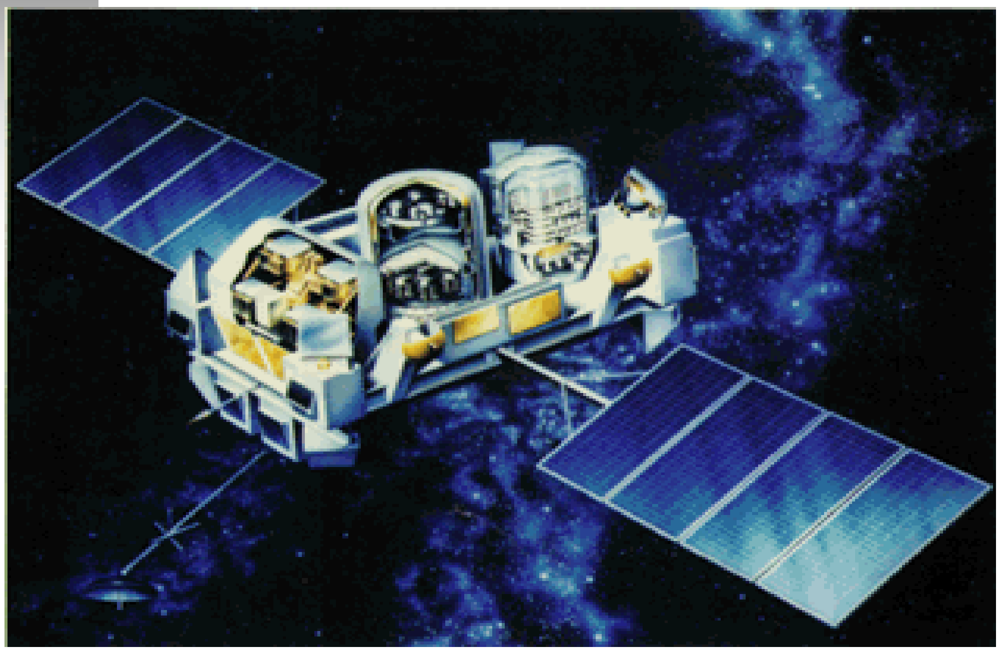
**EBL over cosmological distances is probed by gammas in the 10-100 GeV range. <u>Important science for GLAST!</u>**

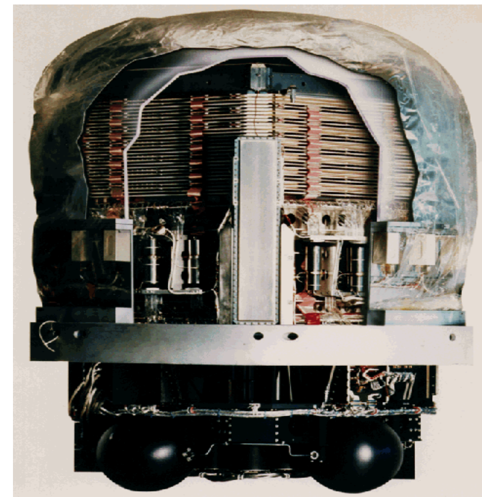
**In contrast, the TeV-IR attenuation results in a flux that may be limited to more local (or much brighter) sources.**

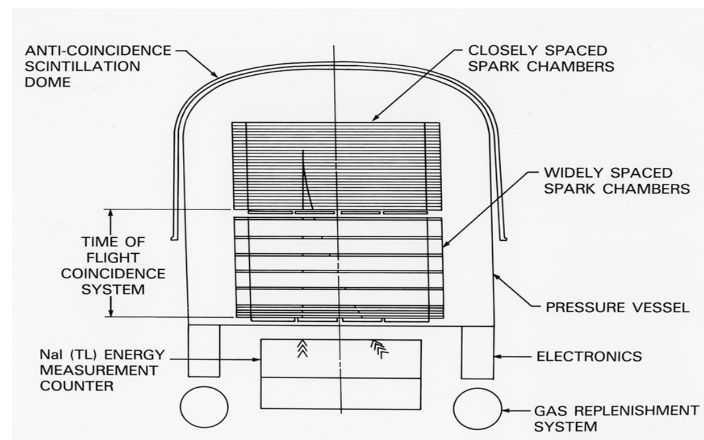
A dominant factor in EBL models is the time of galaxy formation -- <u>attenuation measurements can help distinguish models</u>.

# EGRET

**The high energy gamma ray detector on the Compton Gamma Ray Observatory (20 MeV - ~20 GeV)**







# The Success of EGRET: Probing New Territory

**History:**

SAS-2, COSB (1970's-1980's) exploration phase: established galactic diffuse flux

EGRET (1990's) established field:

- increased number of ID'd sources by large factor;
- broadband measurements covering energy range ~20 MeV - ~20 GeV;
- discovered many still-unidentified sources;
- discovered surprisingly large number of Active Galactic Nuclei (AGN);
- discovered multi-GeV emissions from gamma-ray bursts (GRBs);
- discovered GeV emissions from the sun

**GLAST LAT will explore the unexplored energy range above EGRET's reach, filling in the present gap in the energy spectrum, and will cover the very broad energy range ~ 20 MeV - >300 GeV with superior acceptance and resolution. Historically, opening new energy regimes has led to the discovery of totally unexpected new phenomena.**

# GLAST Science

***GLAST will have a very broad menu that includes:***

- *Systems with supermassive black holes*
- *Gamma-ray bursts (GRBs)*
- *Pulsars*
- *Solar physics*
- *Origin of Cosmic Rays*
- *Probing the era of galaxy formation*
- *Discovery! Particle Dark Matter? Other relics from the Big Bang? Testing Lorentz invariance. New source classes.*

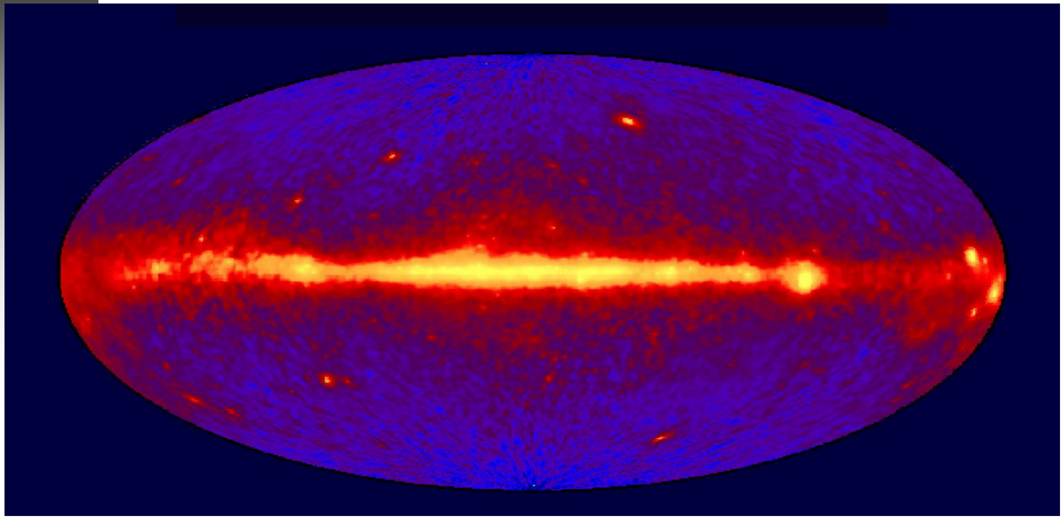
***Huge increment in capabilities.***

***GLAST draws the interest of both the the High Energy Particle Physics and High Energy Astrophysics communities.***

# GLAST LAT High Energy Capabilities

- Huge FOV (~20% of sky)
- Broadband (4 decades in energy, including unexplored region > 10 GeV)
- Unprecedented PSF for gamma rays (factor > 3 better than EGRET for E>1 GeV)
- Large effective area (factor > 4 better than EGRET)
- **Results in factor > 30-100 improvement in sensitivity**
- No expendables ⟶ long mission without degradation

# Features of the gamma-ray sky



EGRET all-sky survey (galactic coordinates) E>100 MeV

diffuse extra-galactic background (flux ~ $1.5\times10^{-5}$ $cm^{-2}s^{-1}sr^{-1}$)

galactic diffuse (flux ~O(100) times larger)

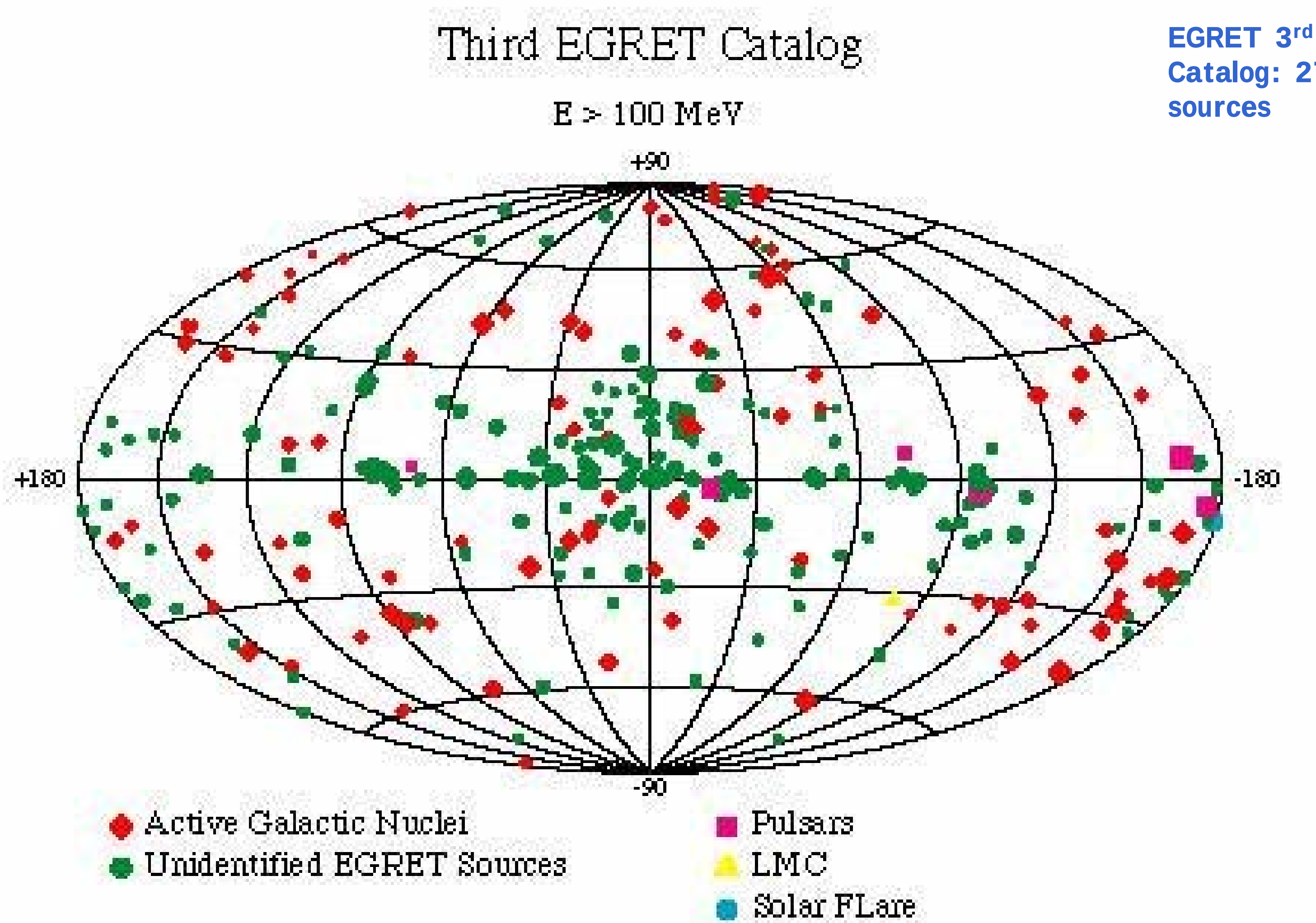
high latitude (extra-galactic) point sources (typical flux from EGRET sources O($10^{-7}$ - $10^{-6}$) $cm^{-2}s^{-1}$

galactic sources (pulsars, un-ID'd)

**An essential characteristic**: VARIABILITY in time!

⇨ Field of view, and the ability to repoint, important for study of transients.

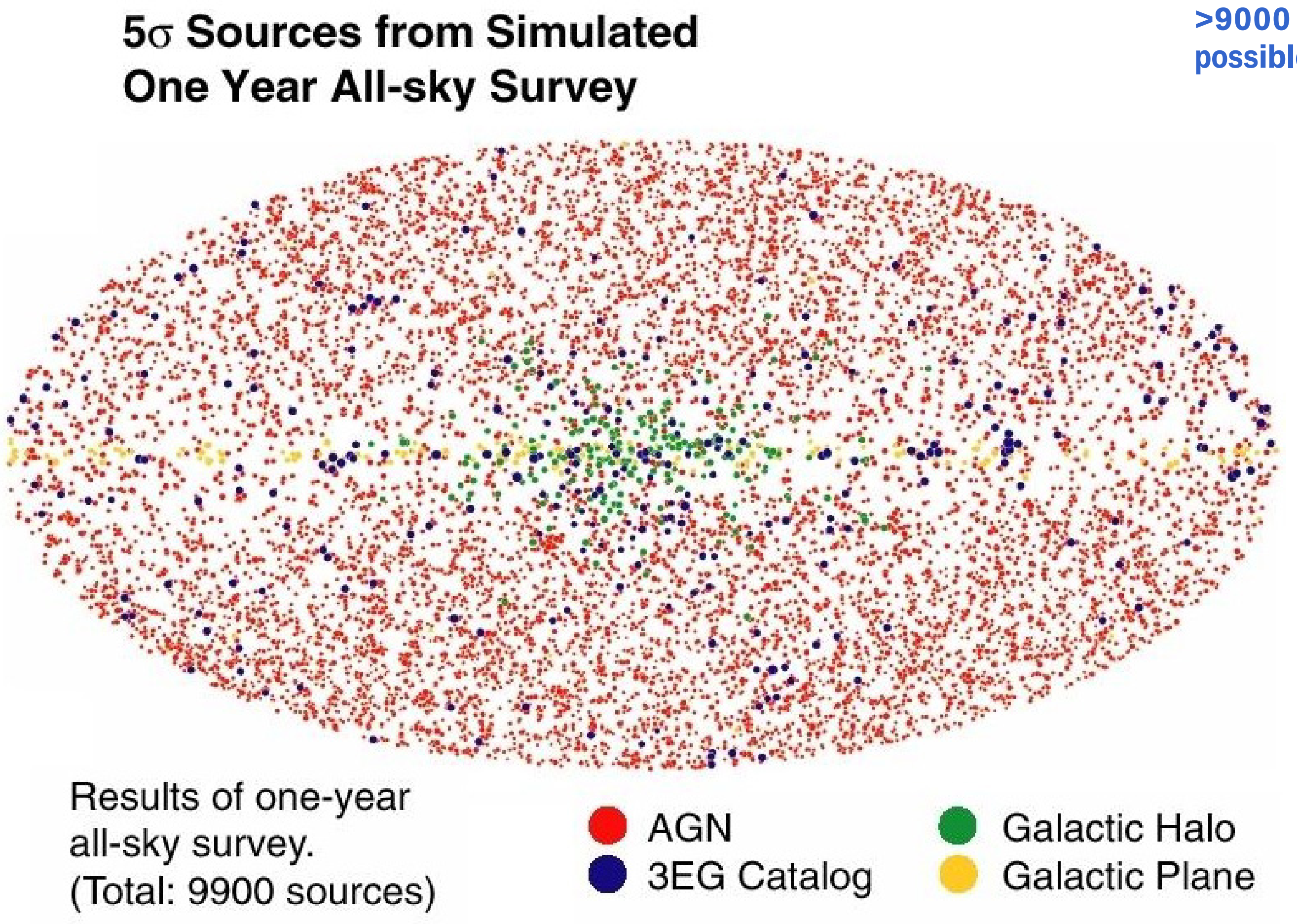
# Sources




**EGRET 3rd Catalog: 271 sources**

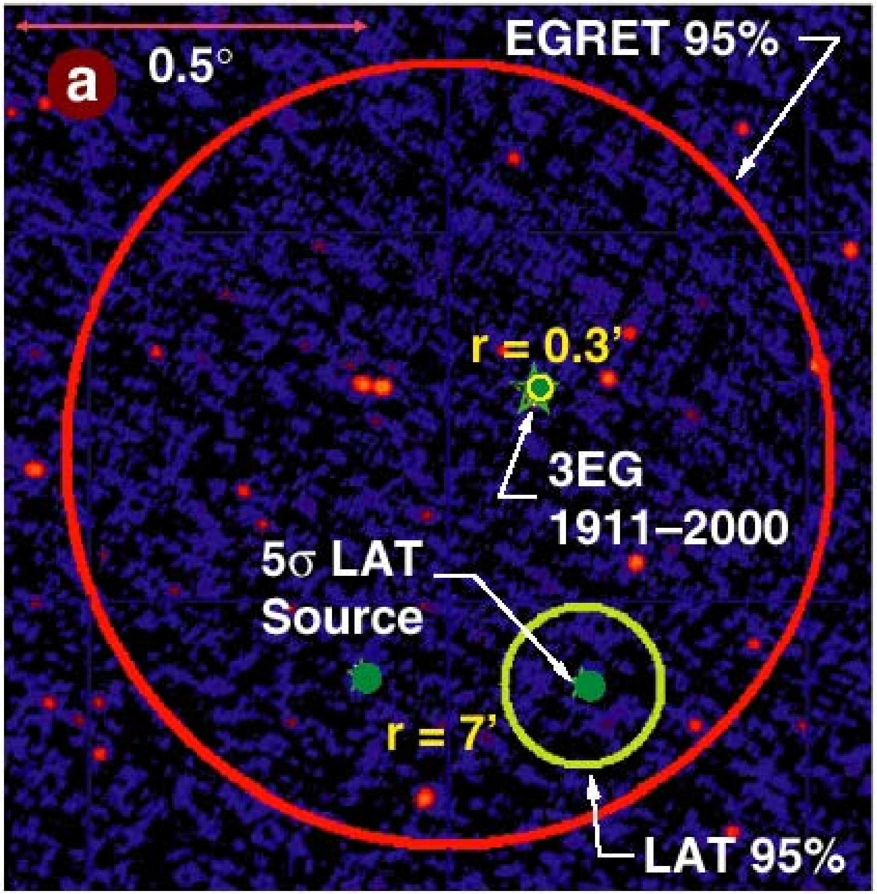
# Sources

**LAT 1st Catalog:**
**>9000 sources possible**



# Unidentified Sources

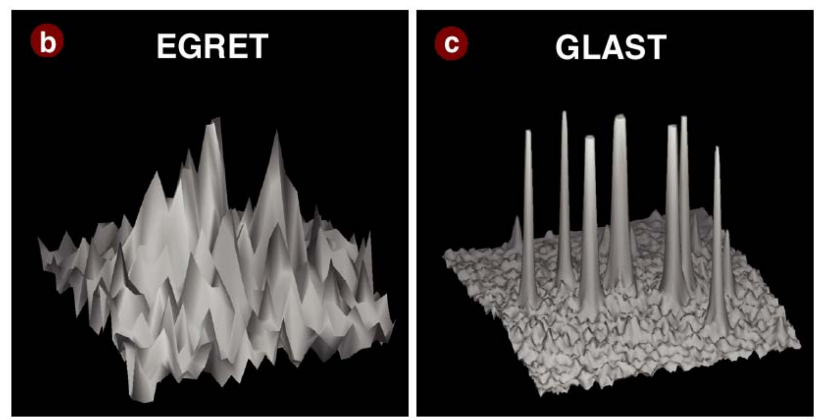
172 of the 271 sources in the EGRET 3rd catalog are “unidentified”




- Rosat or Einstein X-ray Source
- 1.4 GHz VLA Radio Source

EGRET source position error circles are ~0.5°, resulting in counterpart confusion.

GLAST will provide much more accurate positions, with ~30 arcsec - ~5 arcmin localizations, depending on brightness.

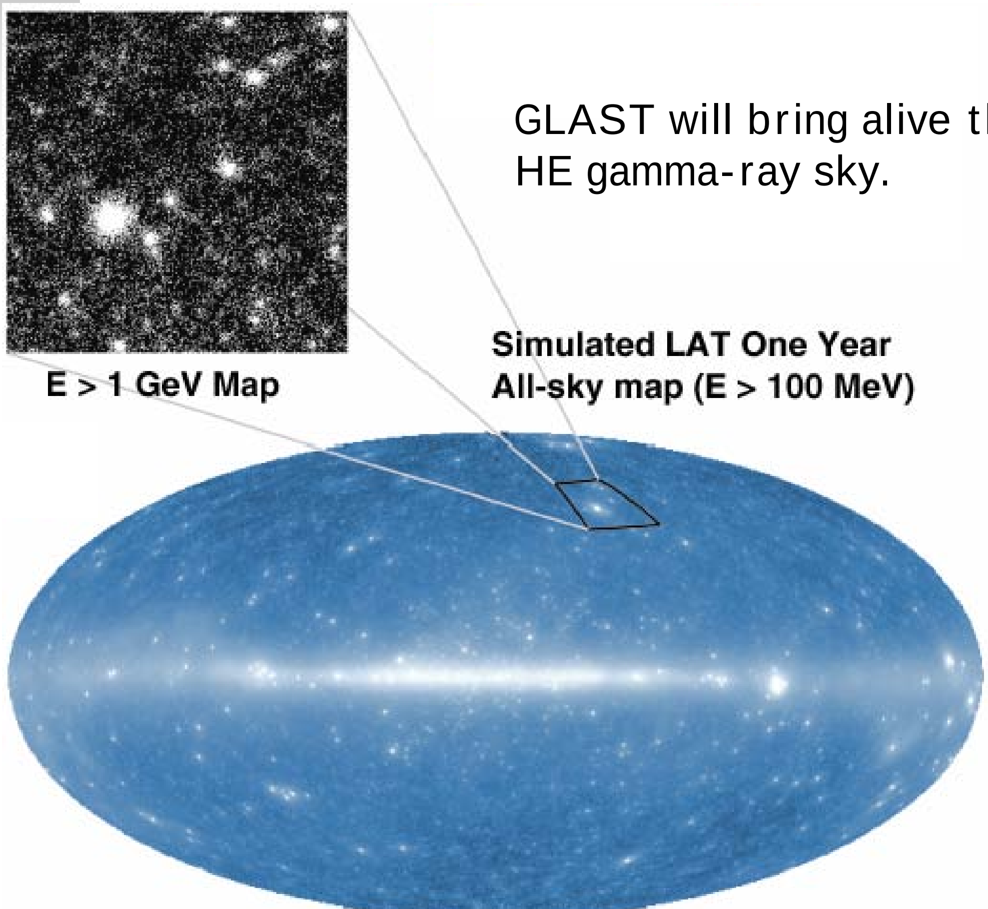



Cygnus region (15x15 deg)

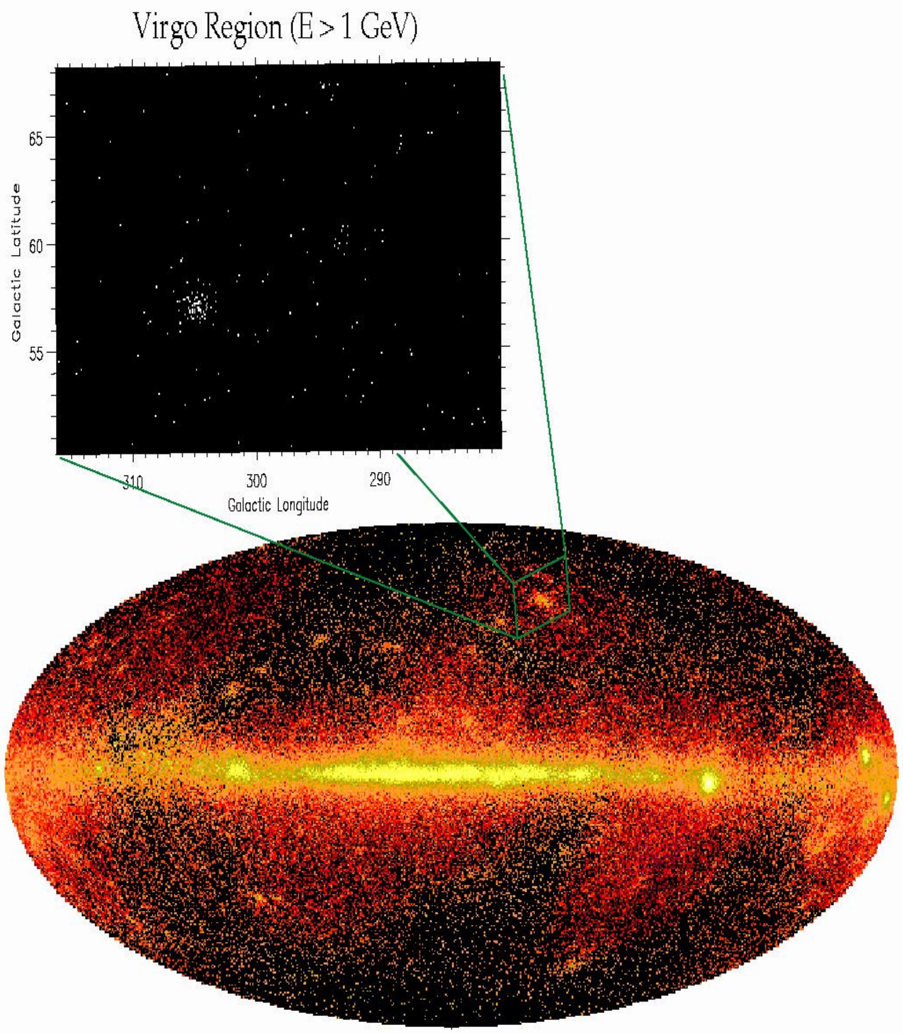
# Diffuse Extra-galactic Background Radiation

Is it really isotropic (e.g., produced at an early epoch in intergalactic space) or an integrated flux from a large number of yet unresolved sources? GLAST has much higher sensitivity to weak sources, with better angular resolution.

GLAST will bring alive the HE gamma-ray sky.




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 very early universe.



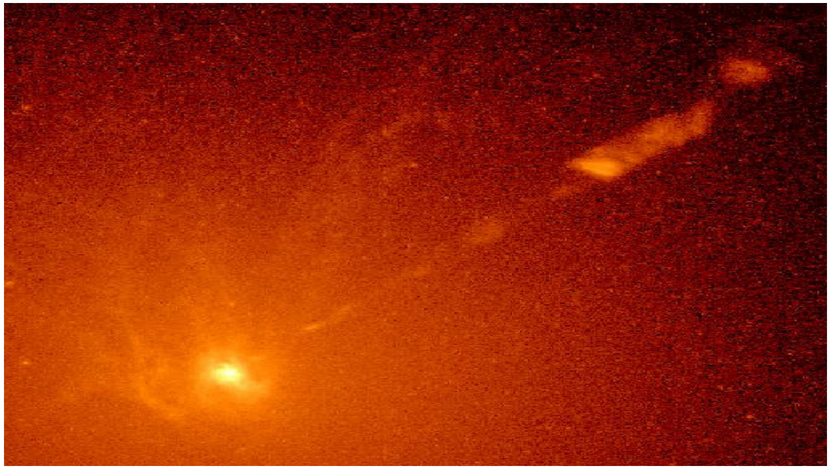
EGRET One-Year All-Sky Survey (E > 100 MeV)

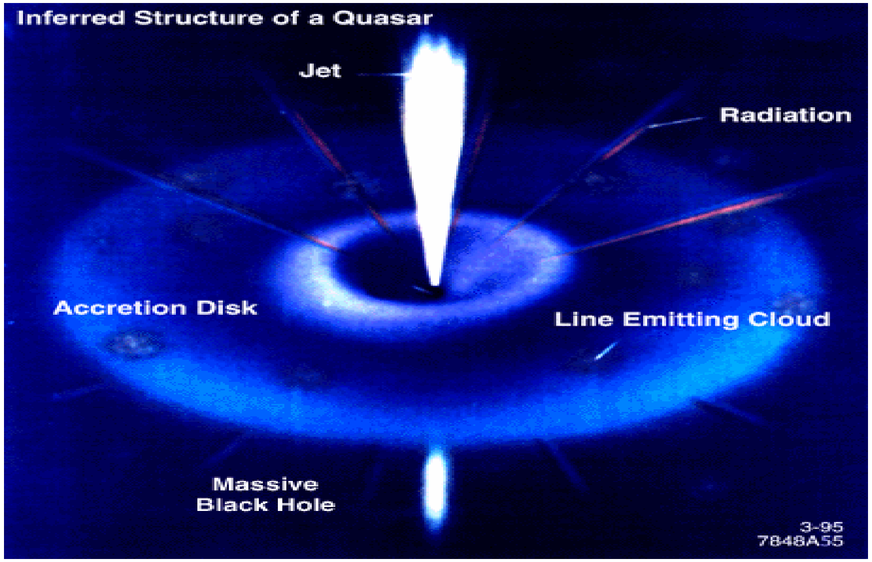
# Active Galactic Nuclei (AGN)

Active galaxies produce vast amounts of energy from a very compact central volume.

Prevailing idea: powered by accretion onto super-massive black holes ($10^6$ - $10^{10}$ solar masses). Different phenomenology primarily due to the orientation with respect to us.

HST Image of M87 (1994)



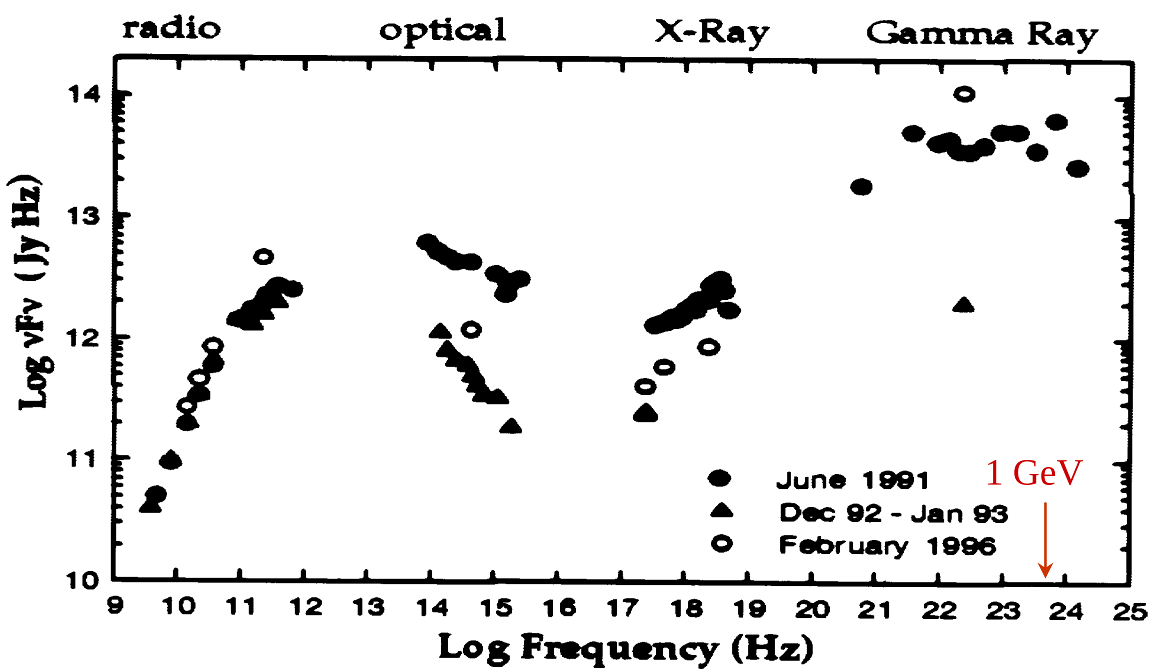



Models include energetic (multi-TeV), highly-collimated, relativistic particle jets. High energy $\gamma$-rays emitted within a few degrees of jet axis. Mechanisms are speculative; $\gamma$-rays offer a direct probe.

# AGN Shine Brightly in GLAST Energy Range

Power output of AGN is remarkable. Multi-GeV component can be dominant!

Estimated luminosity of 3C 279:
~ $10^{45}$ erg/s
corresponds to $10^{11}$ times total solar luminosity
just in γ-rays!! Large variability within days.

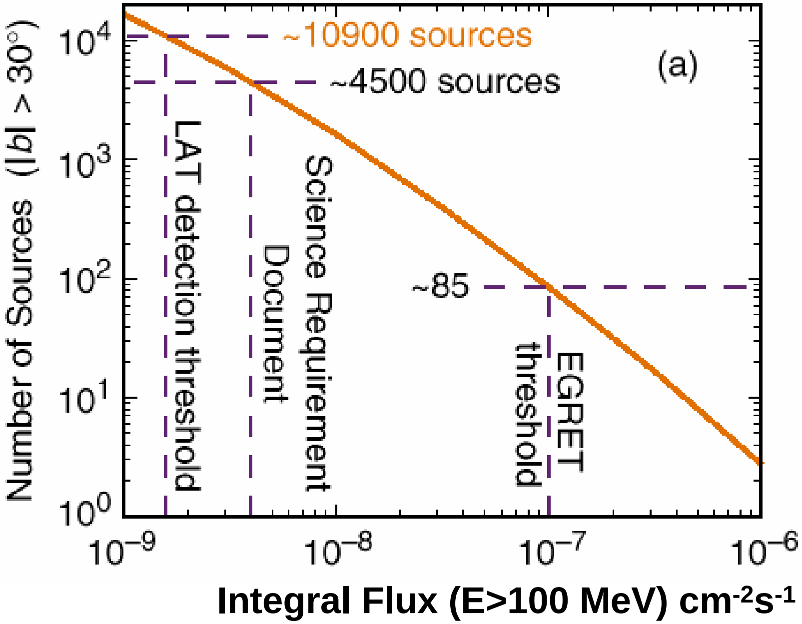



Multiwavelength Spectrum of 3C 279

Sum all the power over the whole electromagnetic spectrum from all the stars of a typical galaxy: an AGN emits this amount of power in JUST γ rays from a very small volume!

# AGN: What GLAST will do

EGRET has detected ~ 70 AGN. Extrapolating, GLAST should expect to see dramatically more – many thousands:

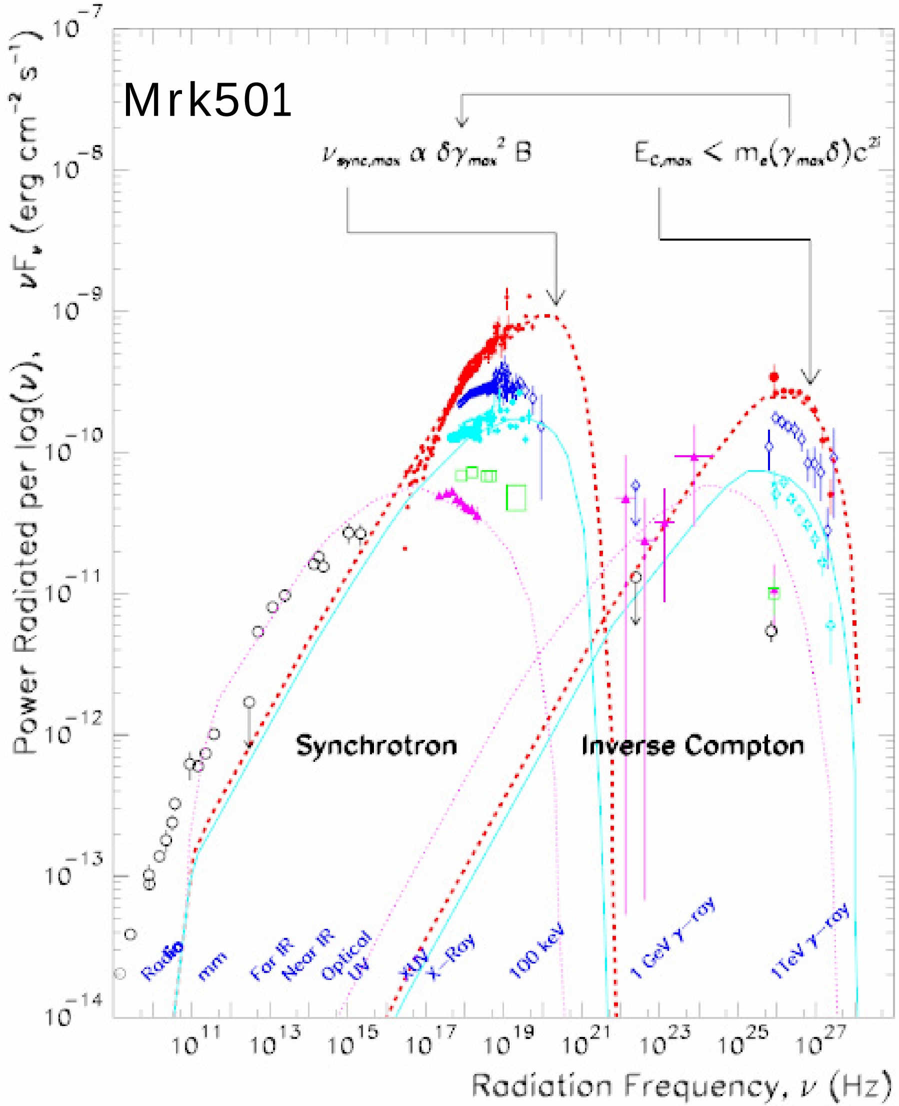



- Allows a statistically accurate calculation of AGN contribution to the high energy diffuse extra-galactic background.
- Constrain acceleration and emission models. How do AGN work?
- Large acceptance and field of view allow relatively fast monitoring for variability over time -- correlate with other detectors at other wavelengths.
- Probe energy roll-offs with distance (light-light attenuation): info on era of galaxy formation.
- Long mission life to see weak sources and transients.

**Joining the unique capabilities of GLAST with other detectors will provide a powerful tool.**

# AGN: Future Prospects

- ***Multiwavelength studies will continue to be the key to understanding how the engines work***
- ***Models: same population of HE electrons produces both components***



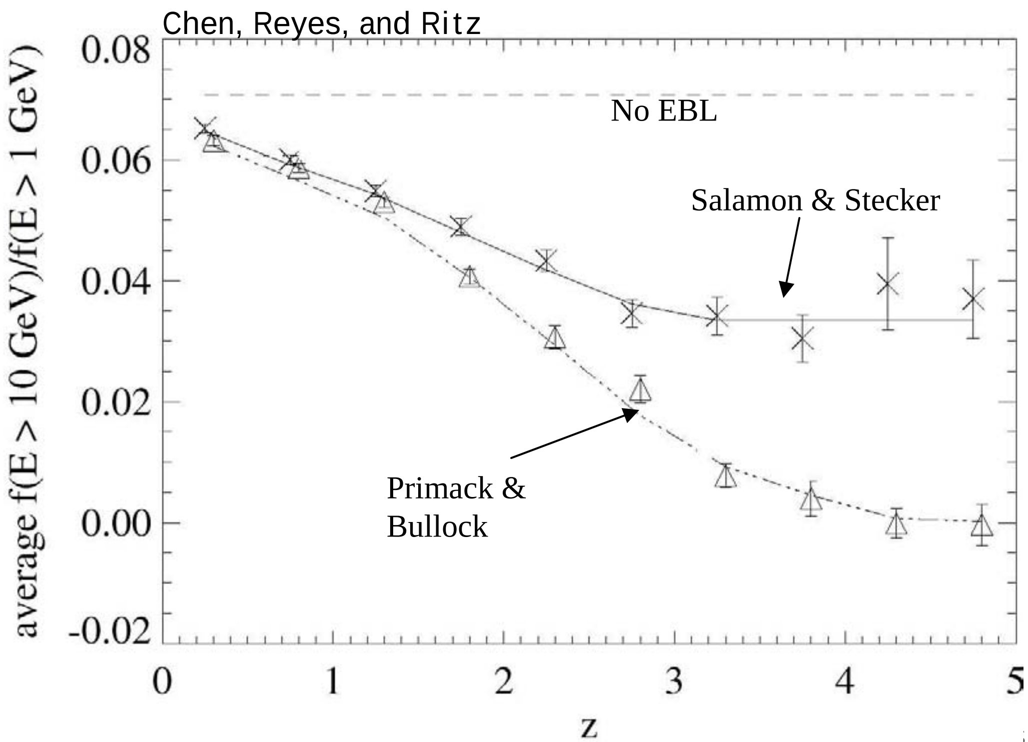
# GLAST Probes the Optical-UV EBL

- **Important advances offered by GLAST:**

  (1) thousands of blazars - instead of peculiarities of individual sources, look for systematic effects vs redshift.

  (2) key energy range for cosmological distances (TeV-IR attenuation more local due to opacity).

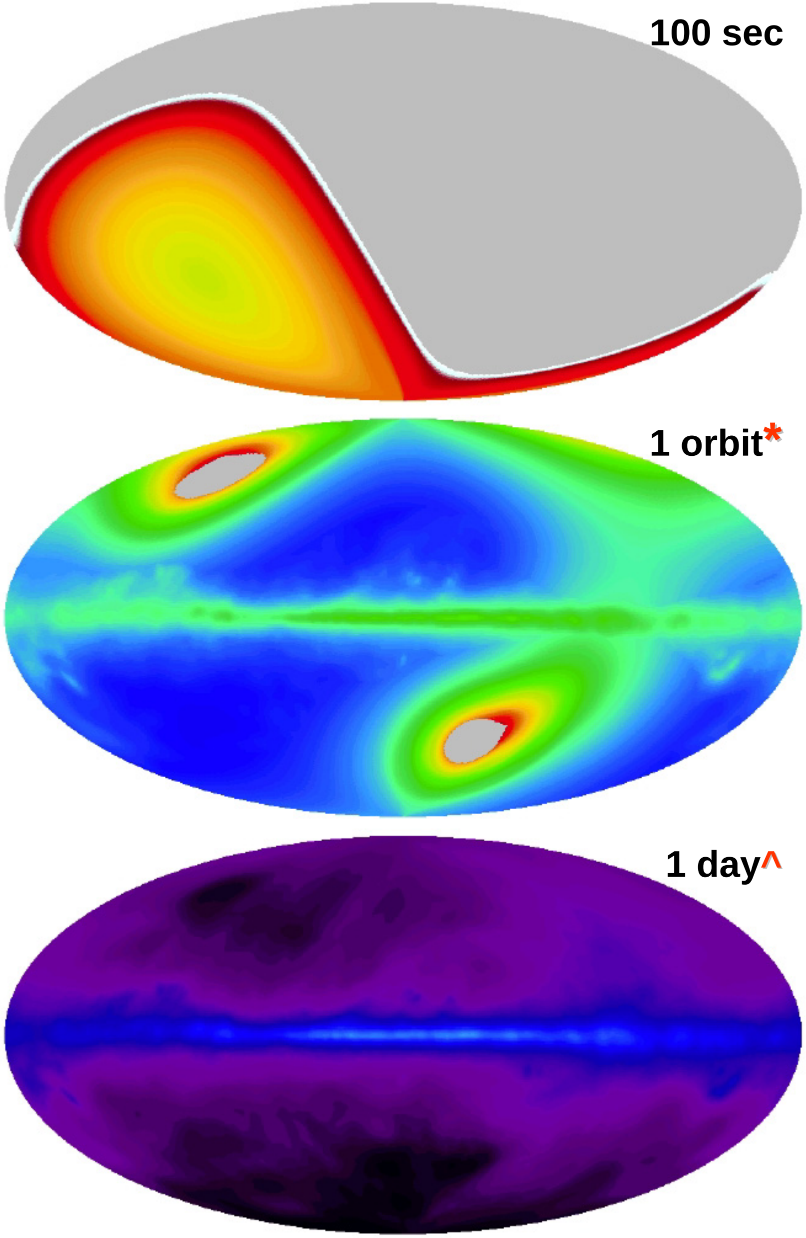
- Effect is model-dependent (this is good):

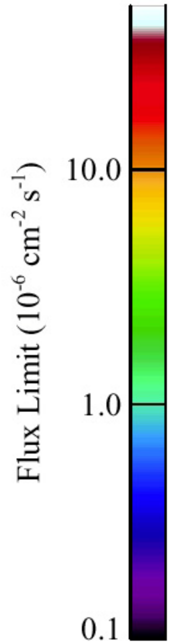



## Caveats

- How many blazars have intrinsic roll-offs in this energy range (10-100 GeV)? (An important question by itself for GLAST!) Again, power of statistics is the key.
- What if there is conspiratorial evolution in the intrinsic roll-of vs redshift? There may also be independent constraints (e.g., direct observation of integrated EBL).
- Must measure the redshifts for a large sample of these blazars!

# Transients Sensitivity During All-sky Mode




**EGRET Fluxes**

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

- Crab Pulsar
- 3EG 2020+40 (SNR $\gamma$ Cygni?)

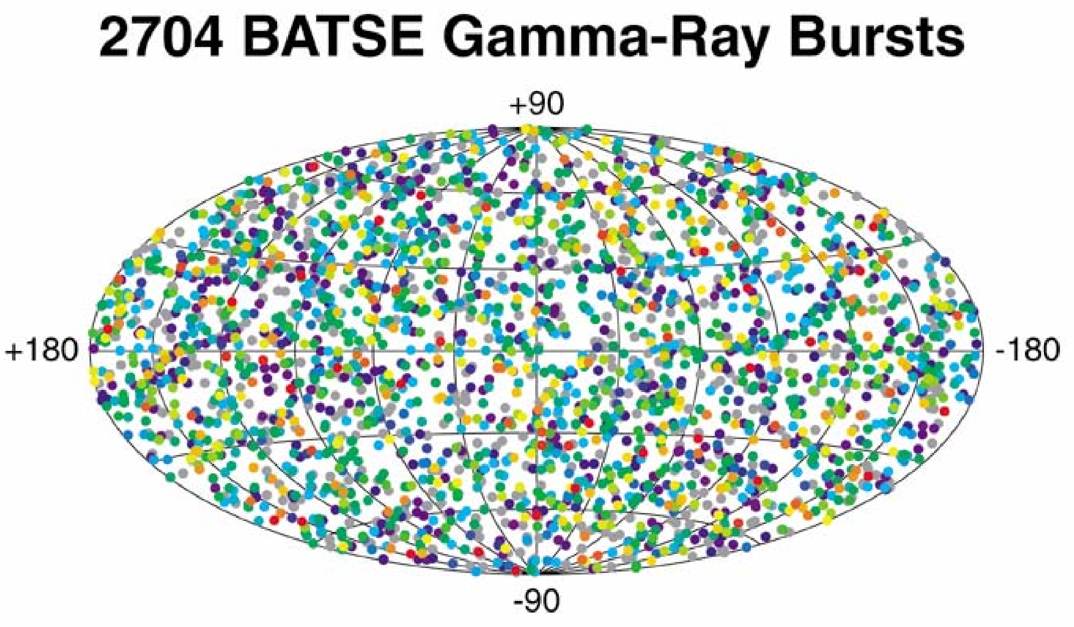
- 3EG 1835+59
- 3C279 lowest 5$\sigma$ detection
- 3EG 1911-2000 (AGN)
- Mrk 421
- Weakest 5$\sigma$ EGRET source

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

*zenith-pointed
^"rocking" all-sky scan: alternating orbits point above/below the orbit plane

# Gamma Ray Bursts

Bursts are isotropic and non-repeating (as far as we can tell):



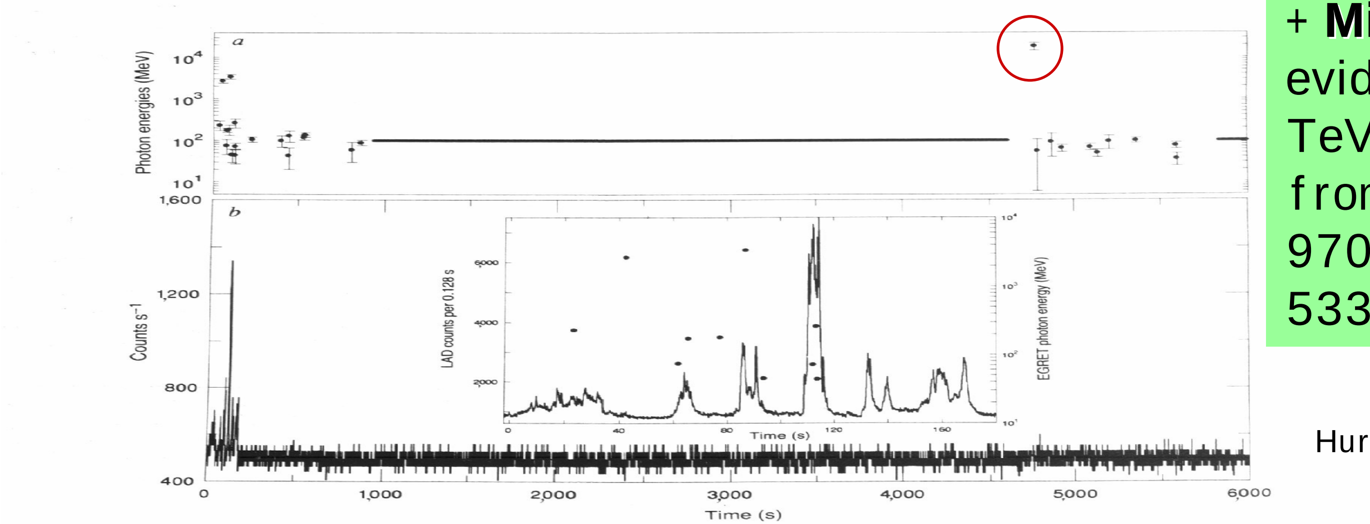

⇒important to view as much of the sky as possible

confirmed to be at cosmological distances.
some association with SNe.

# Gamma Ray Bursts

The questions persist : What are they and how do they work??
=>measure closer to the intrinsic high-energy scale.
Already good indications of interesting behavior:

EGRET has detected very high energy emission associated with bursts, including a 20 GeV photon ~75 minutes after the start of a burst:



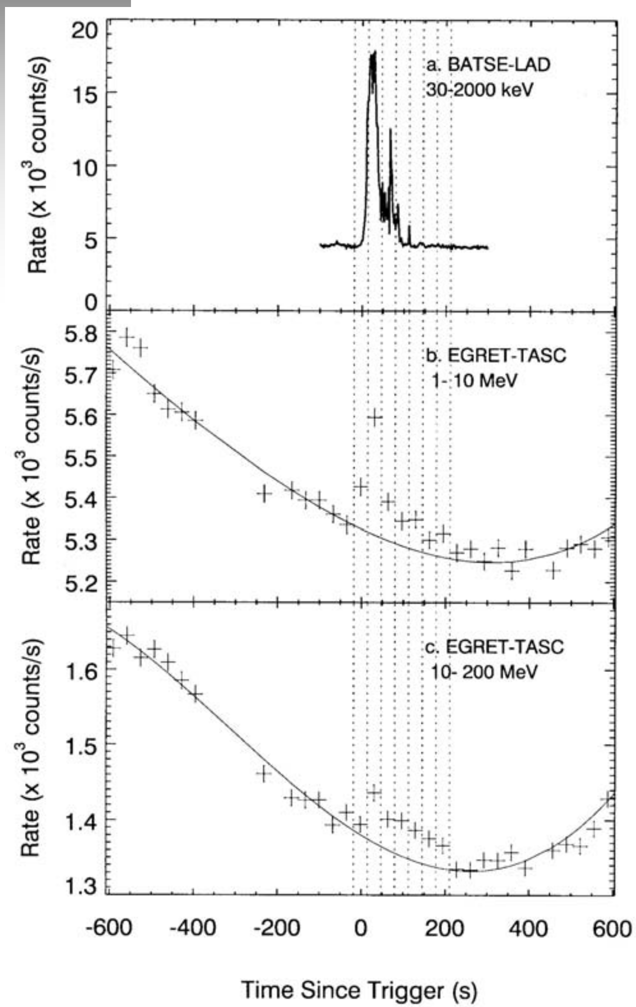

+ **Milagrito** evidence for TeV emission from GRB 970417 ApJ 533(2000)533.

Hurley et al., 1994

Future Prospects: GLAST will provide definitive information about the high energy behavior of bursts: LAT and GBM together will measure emission over >7 decades of energy.
Place your bets on additional TeV burst detections!

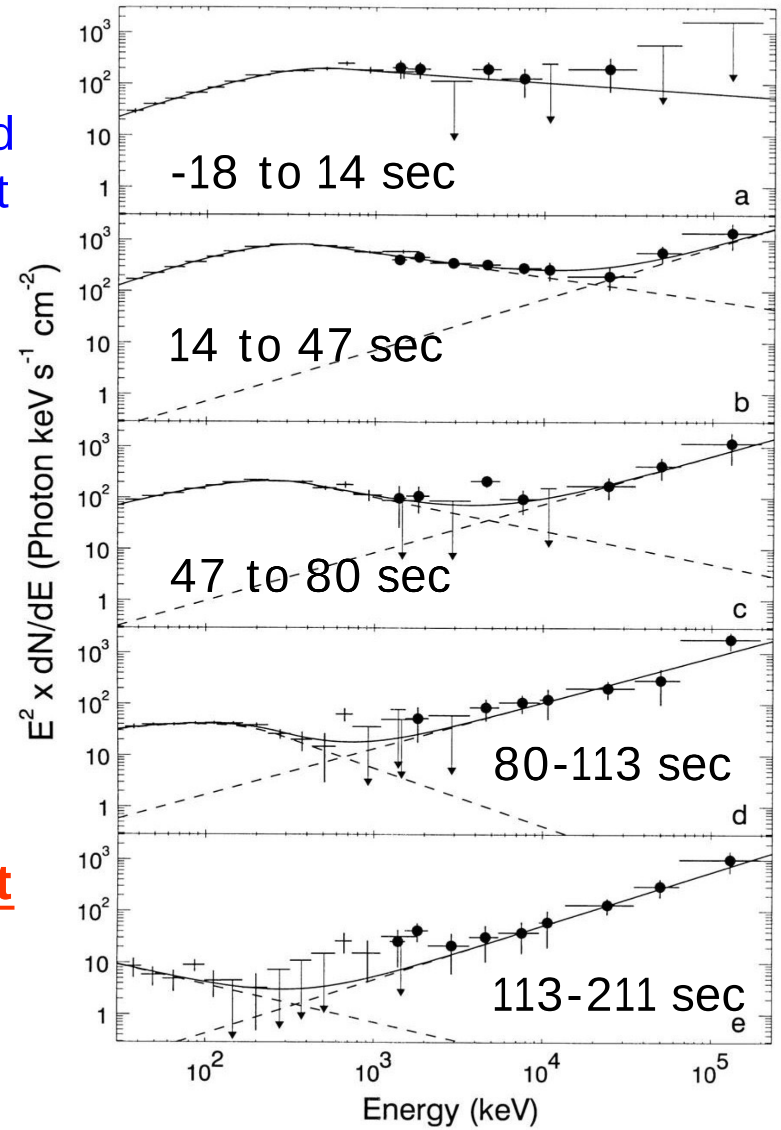
# GRB941017

***Recent analysis by Gonzalez et al., published in Nature***



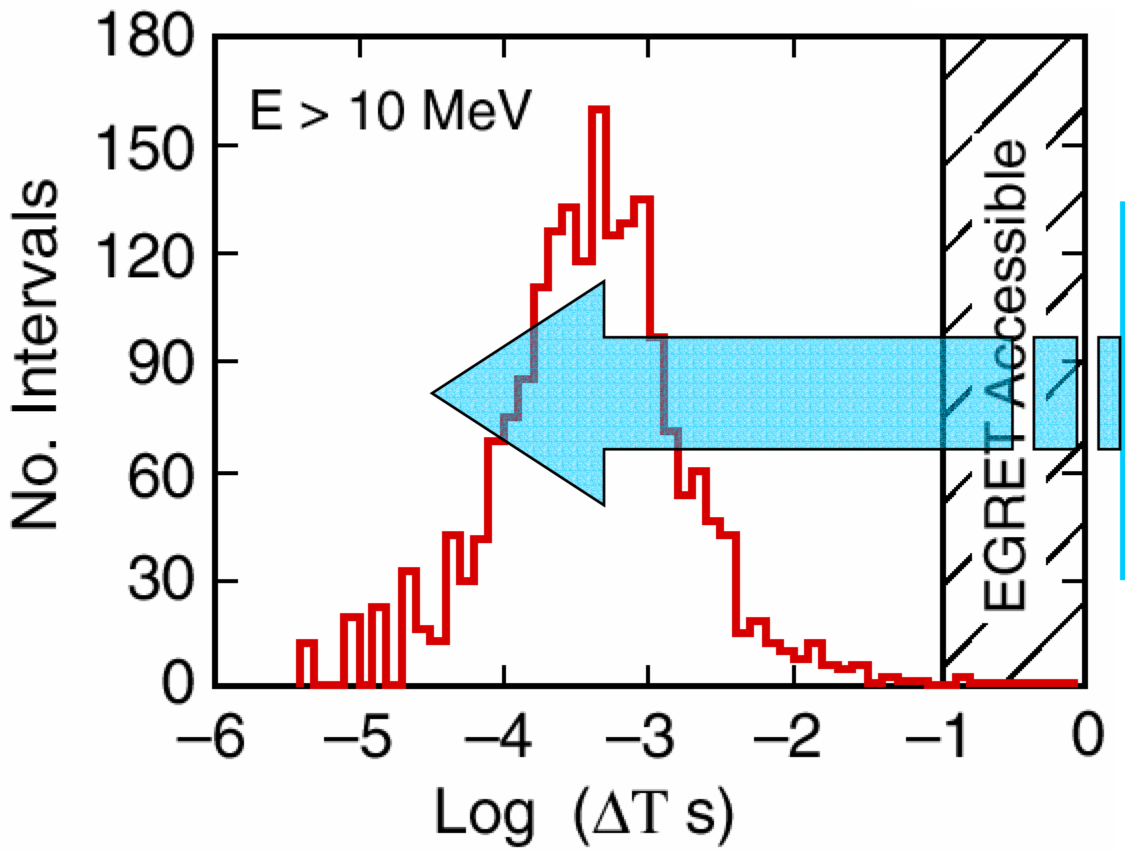

Compare data from EGRET and BATSE: Distinct high-energy component has different time behavior.
What is the high-energy break and total luminosity?
**Need GLAST data!**

**Learn important lessons from the past.**



# GRBs and Instrument Deadtime

Distribution for the 20th brightest burst in a year (Norris et al)




Time between consecutive arriving photons

LAT will open a wide window on the study of the high energy behavior of bursts.

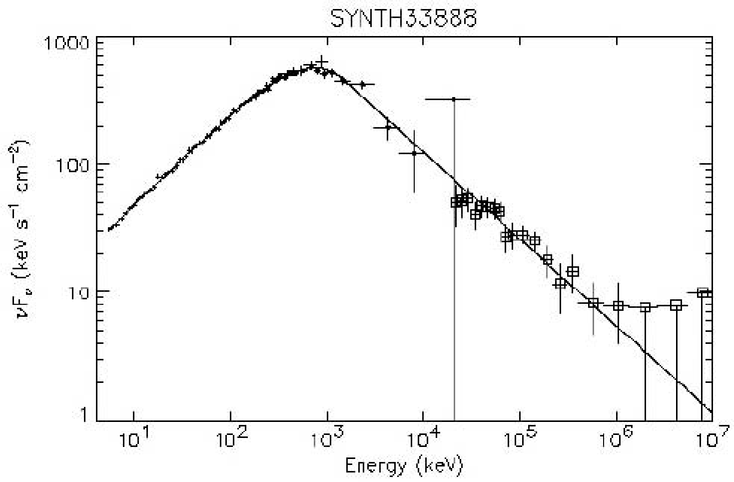
# Roles of the GBM

- ***provides spectra for bursts from 10 keV to 30 MeV, connecting frontier LAT high-energy measurements with more familiar energy domain;***

**Simulated GBM and LAT response to time-integrated flux from bright GRB 940217**

**Spectral model parameters from CGRO wide-band fit**

**1 NaI (14 º) and 1 BGO (30 º)**




- ***provides wide sky coverage (8 sr) -- enables autonomous repoint requests for exceptionally bright bursts that occur outside LAT FOV for high-energy afterglow studies (an important question from EGRET);***
- ***provides burst alerts to the ground.***

# Burst Handling

- ***Upon detection of a gamma-ray burst (GRB), GLAST can take two DIFFERENT kinds of actions:***
  - *alerts to the ground*
    - *GBM and LAT can issue alerts independently*
  - *autonomous repoint to follow burst*
    - *both GBM and LAT can generate a repoint request*
    - *GBM will probably detect more bursts than LAT. However, if LAT detects a burst, it will probably provide a better localization of the burst position.*
    - *if both GBM and LAT generate a repoint request, it is a science issue (not a spacecraft issue) to choose the target repoint location. The GBM repoint request is therefore routed through LAT; LAT either passes the GBM request through or sends LAT's position.*
    - *there is never more than one repoint request per burst. The instrument FOVs are very large.*
  - *alerts happen much more frequently than repoint requests*

# GRB Science Repoint Scenarios

**<u>Summary</u>**

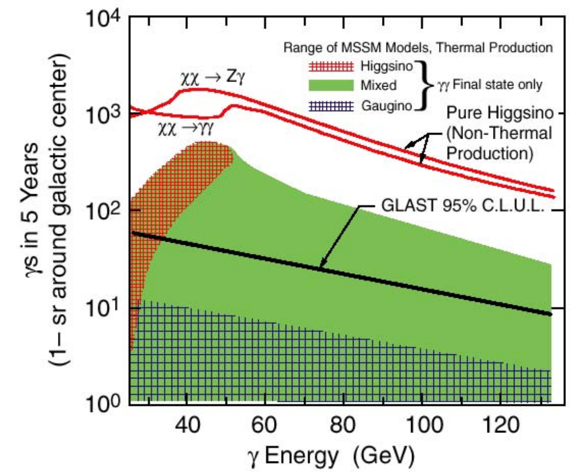
**During all-sky scanning operations, detection of a sufficiently bright burst will cause the observatory to interrupt the scanning operation autonomously and to remain pointed at the burst region during the non-occulted viewing time for a period of 5 hours (adjustable). There are two cases:**

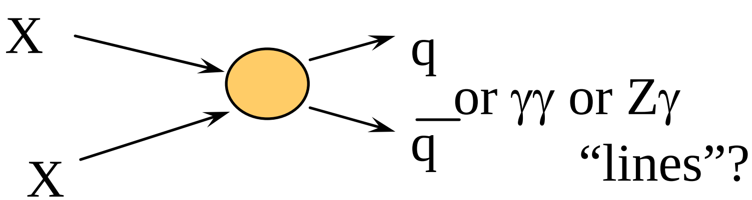
**1. <u>The burst occurs within the LAT FOV.</u> The observatory will slew to keep the burst direction within 30 degrees (adjustable) of the Z axis during the non-occulted viewing period (neglecting SAA effects). Such events are likely to occur a few times per month.**

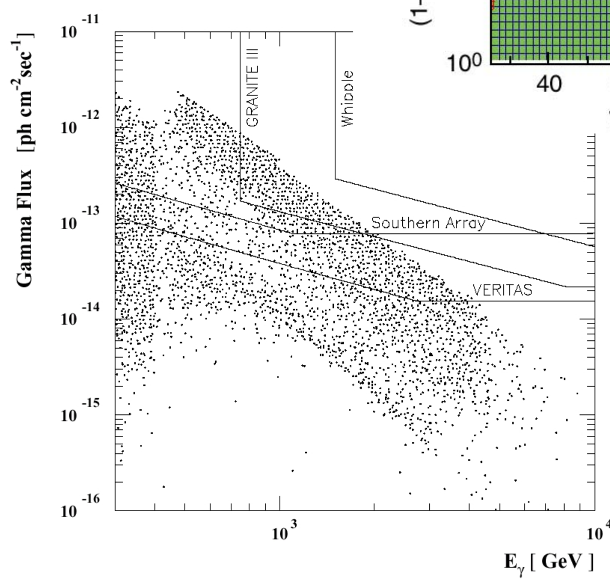
**2. <u>The burst occurs outside the LAT FOV.</u> If the burst is exceptionally bright, the observatory will slew to bring the burst direction within 30 degrees (adjustable) of the Z axis during the non-occulted viewing period (neglecting SAA effects). Such events are likely to occur a few times per year.**

# Particle 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.




**Just an example of what might be waiting for us to find!**

# Testing Lorentz Invariance

- ***Lorentz Invariance breaking models can lead to different maximum velocities by particle type (Stecker&Glashow, Coleman&Glashow):***

$$c_e \equiv c_\gamma (1+\delta), \quad 0 < |\delta| << 1$$

***Stecker:***

  - *For δ<0, photons can decay to e+e- pairs if* $E_\gamma > m_e \sqrt{2/|\delta|}$ *Observations of the Crab (E>50 TeV) implies -δ<2x10*$^{-16}$
  - *For δ>0, superluminal electrons will emit vacuum Cerenkov radiation and the threshold for pair creation will be altered. Cosmic ray data and inferred information from Mrk501 blazar observations => δ<3x10*$^{-14}$ *– 1.3x10*$^{-15}$*.*

- ***Some classes of QG models imply a linear photon velocity dispersion (Amelino-Camelia et al., Ellis, Mavromatos, Nanopoulos):***

$$V = c(1 - \xi \cdot \frac{E}{E_{QG}} + ...)$$

*Use GRBs! Effects could be O(100) ms or larger, using GLAST data alone. But ?? effects intrinsic to bursts??* ***Representative of window opened by measurements at such large distance and energy scales.***

# Requirements

- ***Mission Level II science requirements are codified in the Science Requirements Document (SRD)***
- ***See http://glast.gsfc.nasa.gov/project/cm/mcdl/***

# Observatory Science Requirements (I)

| | *Quantity* | *GLAST Requirement* [1] | *GLAST Goal* [1] | *GLAST Minimum* [1] | *Science Topic* |
|---|---|---|---|---|---|
| 28 | **Mission Lifetime** (<20% degradation) [2] | > 5 years | > 10 years | > 2 years | ALL |
| 29 | **Telemetry Downlink Orbit Average** | > 300 kbps | > 1 Mbps | > 300 kbps | ALL |
| 30 | **Telemetry Downlink Realtime** [3] | > 1 kbps | > 2 kbps | > 0.5 kbps | GRBs |
| 31 | **Telemetry Uplink Realtime** [3] | > 1 kbps | > 2 kbps | > 0.5 kbps | GRBs, AGN |
| 32 | **Time to Respond to TOO's on Ground** [4] | < 6 hours | < 4 hours | < 12 hours | GRBs, AGN |
| 33 | **Spacecraft Repointing Times for Autonomous Slews** [5] | < 10 min | < 5 min | NA | GRBs, AGN |
| 34 | **GRB Notification Time to Ground by Spacecraft** [6] | < 7 sec | < 4 sec | < 10 sec | GRBs, AGN |
| 35 | **Pointing Accuracy Absolute** [7] | < 2° | < 0.5° | < 5° | ALL |

# Observatory Science Requirements (II)

| | | | | | |
|---|---|---|---|---|---|
| 36 | **Pointing Knowledge** [7] | < 10 arcsec | < 5 arcsec | < 20 arcsec | ALL |
| 37 | **Observing Modes** | - Rocking zenith pointing [15]<br>- Pointed mode [8] | | | ALL |
| 38 | **Targeting** | No restrictions on Pointing [8] of axis normal to LAT | | | ALL |
| 39 | **Uniformity of Sky Coverage during All-sky Survey** [9] | < ± 20% | < ± 10% | < ± 30% | ALL |
| 40 | **Observatory Time Accuracy** [10] | < 10 μsec | < 3 μsec | < 30 μsec | Pulsars |
| 41 | **Observatory Absolute Position Accuracy** | < 3.3 km | < 1 km | < 10 km | Pulsars |
| 42 | **Observing Efficiency** [11] | > 90 % | > 95% | > 80% | ALL |
| 43 | **Data Loss** [12] | < 2 % | < 1% | < 5% | ALL |
| 44 | **Data Corruption** [13] | $< 10^{-10}$ | $< 3 \times 10^{-11}$ | $< 3 \times 10^{-10}$ | ALL |
| 45 | **Earth Avoidance** [14] | > 30°(adjustable) | N/A | N/A | ALL |

# Observatory Science Requirements (III)

1 Requirement = value to design to; Goal = value to strive for to enhance science; Minimum = value that if not satisfied triggers a Project review.

2 20% degradation = no more than 20% loss of LAT science return.

3 Uplink telemetry rate for at least 80% of time outside of SAA.

4 Response time for the SSC and MOC to plan and send a spacecraft repointing command after the decision is made to respond to a Target of Opportunity (TOO).

5 Time for $75^0$ slew. note: being modified for single failed wheel case

6 Time from spacecraft receipt of GRB notification from GBM or LAT to delivery to the Gamma-ray Coordinates Network (GCN) computer for 80% of all GRBs detected by the GBM or LAT.

7 1 sigma radius.

8 Pointing of axis normal to LAT to within $30^0$ of source. (No science constraint on roll axis.).

9 Sky coverage exposure uniformity integrating for 7 days, not including SAA effects.

10 Relative to Universal Time, 1 sigma r.m.s..

11 Fraction of time with data return, not including SAA effects.

12 Fraction of data taken by the instruments but not delivered to the IOC. Not including SAA data loss. Not including instrument deadtime.

13 Fraction of undetected corrupted events.

14 Axis normal to LAT shall be capable of remaining at an angle greater than this above the Earth's horizon during normal operations, with the possible exception of rapid slewing to acquire a GRB.

15 The observatory shall be capable of scanning the LAT FOV (55° half-angle) over >90% of the celestial sphere repetitively on selectable timescales as short as every 2 orbits.


# LAT Science Requirements Summary(I)

| | *Quantity* | *EGRET* | *LAT Requirement* [1] | *LAT Goal* [1] | *LAT Minimum* [1] | *Science Topic* |
|---|---|---|---|---|---|---|
| 1 | **Energy Range Low Limit** | 20 MeV | < 20 MeV | < 10 MeV | < 30 MeV | ALL |
| 2 | **Energy Range High Limit** | 30 GeV | > 300 GeV | > 500 GeV | > 100 GeV | ALL |
| 3 | **Effective Area** [2] | 1500 $cm^2$ | > 8000 $cm^2$ | > 12,000 $cm^2$ | > 8000 $cm^2$ | ALL |
| 4 | **Energy Resolution** [3] (on-axis, 100 MeV - 10 GeV) | 10% | < 10% | < 8% | < 20% | ALL |
| 5 | **Energy Resolution** [3] (on-axis, 10-300 GeV) | | <20% | <15% | <30% | ALL |
| 6 | **Energy Resolution** (>60° incidence, >10 GeV) [4] | | < 6% | < 3% | NA [5] | Dark Matter |
| 7 | **Single Photon Angular Resolution - 68%** [6] (on-axis, E>10 GeV) | 0.5° | < 0.15° | < 0.1° | < 0.3° | ALL |

# LAT Science Requirements Summary(II)

| | | | | | | |
|---|---|---|---|---|---|---|
| 8 | **Single Photon Angular Resolution - 68%** [6] (on-axis, E=100 MeV) | 5.8° | < 3.5° | < 3° | < 5° | ALL |
| 9 | **Single Photon Angular Resolution - 95%** [6] (on-axis) | | $< 3 \times \theta_{68\%}$ | $< 2 \times \theta_{68\%}$ | $< 4 \times \theta_{68\%}$ | ALL |
| 10 | **Single Photon Angular Resolution** (off axis at 55°) | | < 1.7 times on-axis | < 1.5 times on-axis | < 2 times on-axis | ALL |
| 11 | **Field of View** [7] | 0.5 sr | > 2 sr | > 3 sr | > 1.5 sr | ALL |
| 12 | **Source Location Determination** [8,9] | 5 arcmin | < 0.5 arcmin | < 0.3 arcmin | < 1 arcmin | UGOs , GRBs |
| 13 | **Point Source Sensitivity** [9,10] (> 100 MeV) | $\sim 1 \times 10^{-7}$ $cm^{-2}\ s^{-1}$ | $< 6 \times 10^{-9}\ cm^{-2}\ s^{-1}$ | $< 3 \times 10^{-9}\ cm^{-2}\ s^{-1}$ | $< 8 \times 10^{-9}\ cm^{-2}\ s^{-1}$ | AGN, UGOs, Pulsars, GRBs |
| 14 | **Instrument Time Accuracy** [11] | 0.1 ms | < 10 μsec | < 2 μsec | < 30 μsec | Pulsars, GRBs |
| 15 | **Background Rejection** [12] (Contamination of high latitude diffuse sample in any decade of energy for >100 MeV.) | <1% | <10% | <1% | <15% | Diffuse |
| 16 | **Dead Time** | 100 ms /event | < 100 μs /event | < 20 μs /event | < 200 μs /event | GRBs |

# LAT Science Requirements Summary(III)

| | | | | | | |
|---|---|---|---|---|---|---|
| 17 | **GRB Location Accuracy On-Board** [13] | | < 10 arcmin | < 3 arcmin | NA [5] | GRBs |
| 18 | **GRB Notification Time To Spacecraft** [14] | | < 5 sec | < 2 sec | NA [5] | GRBs |

1 Requirement = value to design to; Goal = value to strive for to enhance science; Minimum = value that if not satisfied triggers a Project review.

2 Maximum (as function of energy) effective area at normal incidence. Includes inefficiencies necessary to achieve required background rejection. Effective area peak is typically in the 1 to 10 GeV range.

3 Equivalent Gaussian 1 sigma, on-axis.

4 Effective area for side incidence is 0.1 to 0.2 that of normal incidence for high resolution measurements.

5 NA = Not Applicable. Minimum values are not applicable for parameters that were not Requirements in the AO 99-OSS-03 Announcement of Opportunity.

6 Space angle.

7 Integral of effective area over solid angle divided by peak effective area. Geometric factor is Field of View times Effective Area.

8 High latitude source of $10^{-7}$ $cm^{-2}$ $s^{-1}$ flux at >100 MeV with a photon spectral index of -2.0 above a flat background and assuming no spectral cut-off. 1 sigma radius. 1-year survey.

9 Derived quantities delimited by double-lined box.

10 Sensitivity at high latitudes after a 1-year survey for a 5 sigma detection.

11 Relative to spacecraft time.

12 Assuming a high-latitude diffuse flux of $1.5\times10^{-5}$ $cm^{-2}$ $s^{-1}$ $sr^{-1}$ (>100 MeV) assuming a photon spectral index of -2.1 with no spectral cut-off.

13 For burst (< 20 sec duration) with > 100 photons above 1 GeV. This corresponds to a burst of ~5 $cm^{-2}$ $s^{-1}$ peak rate in the 50 - 300 keV band assuming a spectrum of broken power law at 200 keV from photon index of -0.9 to -2.0. Such bursts are expected to occur in the LAT FOV ~10 times per year.

14 Time relative to detection of GRB.

# GBM Science Requirements Summary (I)

| | Quantity | BATSE | GBM Requirement [1] | GBM Goal [1] | GBM Minimum [1] | Science Topic |
|---|---|---|---|---|---|---|
| 19 | **Energy Range Low Limit** | 25 keV | < 10 keV | < 5 keV | < 20 keV | ALL |
| 20 | **Energy Range High Limit** | 10 MeV | > 25 MeV | > 30 MeV | > 20 MeV | ALL |
| 21 | **Field of View** [2] | $4\pi$ | > 8 sr | > 10 sr | > 6 sr | ALL |
| 22 | **Energy Resolution** [3] (0.1 - 1.0 MeV) | | < 10% | < 7% | < 12% | GRBs |
| 23 | **GRB Alert Location** [5] | | NA [4] | < 15 deg | NA [4] | GRBs |
| 24 | **GRB Notification Time To Spacecraft** [6] | | < 2 sec | < 1 sec | < 5 sec | GRBs |
| 25 | **Dead Time Average** | | < 10 $\mu$sec/event | < 3 $\mu$sec/event | < 50 $\mu$sec/event | GRBs |
| 26 | **Instrument Time Accuracy** [7] | 10 $\mu$sec | < 10 $\mu$sec | < 2 $\mu$sec | < 30 $\mu$sec | GRBs |
| 27 | **Burst Sensitivity Ground Analysis** [8] | 0.2 $cm^{-2}\ s^{-1}$ | < 0.5 $cm^{-2}\ s^{-1}$ | < 0.3 $cm^{-2}\ s^{-1}$ | < 1.0 $cm^{-2}\ s^{-1}$ | GRBs |

# GBM Science Requirements Summary (II)

| | | | | | | |
|---|---|---|---|---|---|---|
| 46 | **Burst Sensitivity On-Board Trigger** [9] | 0.3 $cm^{-2}\ s^{-1}$ | < 1.0 $cm^{-2}\ s^{-1}$ | < 0.75 $cm^{-2}\ s^{-1}$ | < 2.0 $cm^{-2}\ s^{-1}$ | GRBs |

1 Requirement = value to design to; Goal = value to strive for to enhance science; Minimum = value that if not satisfied triggers a Project review.

2 Integral of effective area over solid angle divided by peak effective area. Geometric factor is Field of View times Effective Area. Should overlap with LAT FOV.

3 Equivalent Gaussian. 1 sigma. On axis.

4 NA= Not Applicable. The addition of the GRB monitor was a "goal" in the AO 99-OSS-03. The broad-band spectroscopic capability of the GRB instrument is upgraded here to be a requirement. The location of the bursts is listed only as a goal.

5 1 sigma radius. For burst of brightness 10 $cm^{-2}\ s^{-1}$ in 50 - 300 keV band and a duration of 1 second or longer.

6 Time relative to a GBM GRB trigger. Used for both 'rapid ground notification' or 'burst alert' through TDRSS (or equivalent real-time link) and for 'LAT notification'.

7 Relative to spacecraft time.

8 GRB peak brightness sensitivity, 50 - 300 keV range, 5 sigma detection.

9 50% efficiency level for bursts occurring within the GBM FOV, excluding observational inefficiencies such as SAA passages and earth occultations, 50 - 300 keV range.

# Science Mission Elements

- **_Science Working Group (SWG)_**
  - *Membership includes the Interdisciplinary Scientists (IDS) and instrument team delegates.*
  - *Bi-monthly telecons and ~bi-annual sit-down meetings, along with science symposia to engage the community. Minutes on the web.*
- **_Users Committee_**
  - *independent of the SWG. External review/feedback on science tools planning and progress.*
  - *includes members from both the astrophysics and high-energy particle physics communities who are likely users of GLAST data.*
- **_GLAST Science Support Center (GSSC)_**
  - *Located at Goddard. Supports guest observer program, provides training workshops, provides data and software to community, archives through to HEASARC, joint software development with Instrument Teams.*

# Operations Phases, Guest Observers, Data

- ***After the initial on-orbit checkout, verification, and calibrations, the first year of science operations will be an all-sky survey.***
  - *first year data used for detailed instrument characterization, refinement of the alignment, and key projects (source catalog, diffuse background models, etc.) needed by the community*
  - *data on transients will be released, with caveats*
  - *repoints for bright bursts and burst alerts are enabled*
  - *extraordinary ToO's supported*
  - *limited guest observer program*
  - *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 science support center (GSSC).***

# Summary

- ***GLAST will address many important questions:***
  - *What is going on around black holes? How do Nature's most powerful accelerators work?*
  - *What are the unidentified sources found by EGRET?*
  - *What is the origin of the diffuse background?*
  - *What is the origin of cosmic rays?*
  - *What is the high energy behavior of gamma ray bursts?*
  - *When did galaxies form?*
  - *What else out there is shining gamma rays? Are there high-energy relics from the Big Bang? Are there further surprises in the poorly measured energy region?*
- ***Large menu of "bread and butter" science, and <u>large discovery potential.</u>***
- ***Science requirements are mature and stable.***
- ***GLAST is part of the bigger picture of experiments at the interface between particle physics and astrophysics.***

**We expect the gamma-ray community to grow in the GLAST era!!**