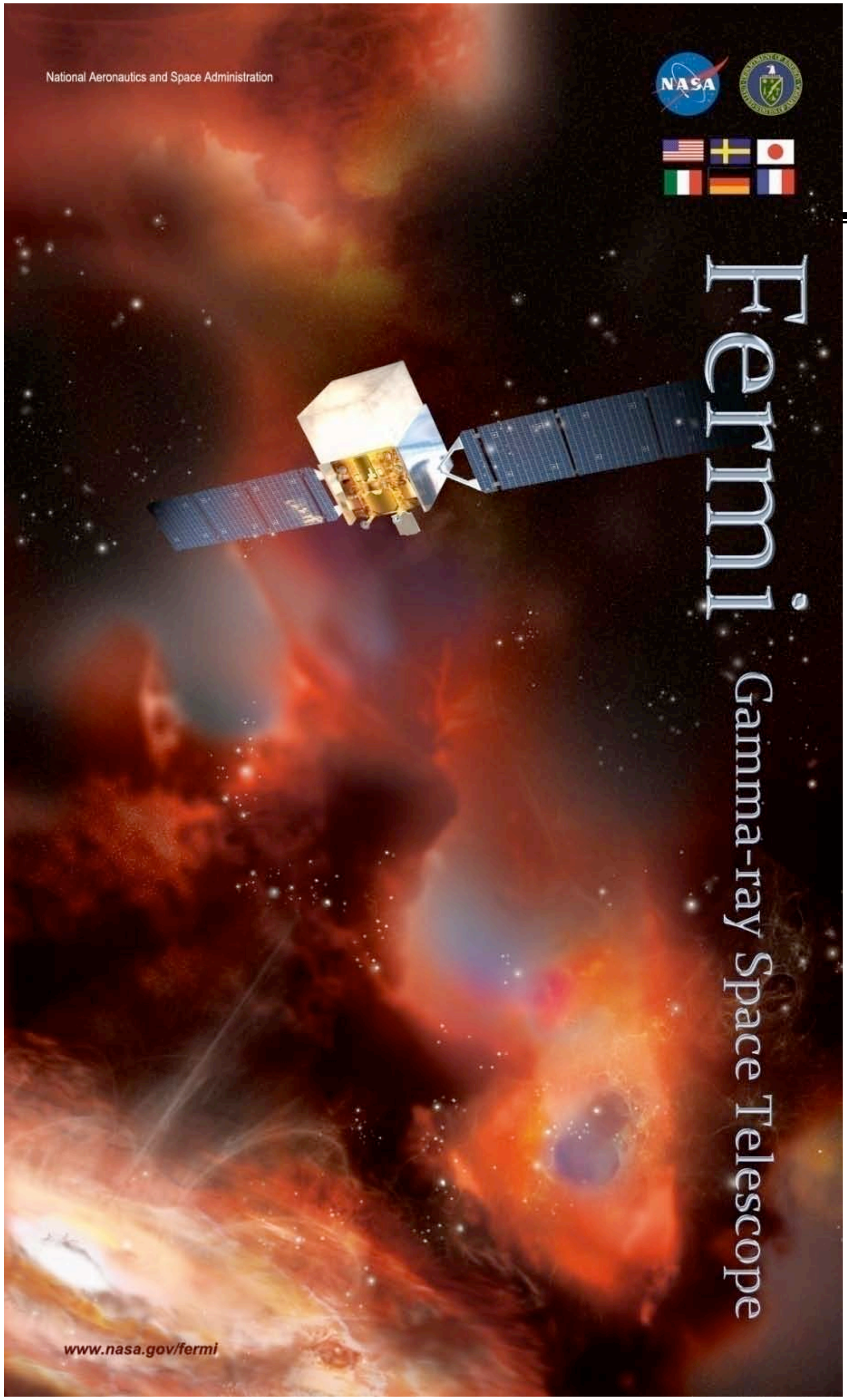


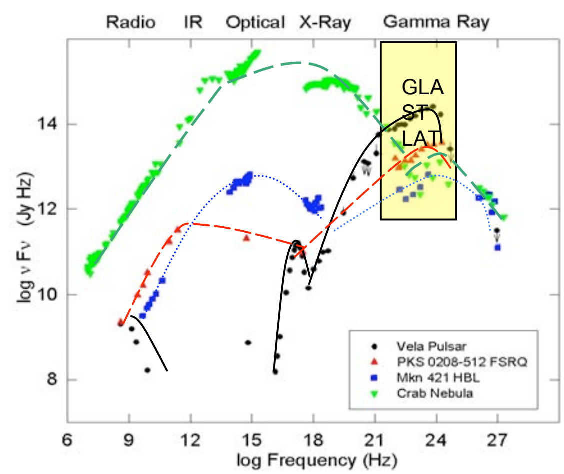
Early Results from the Fermi Gamma-ray Space Telescope

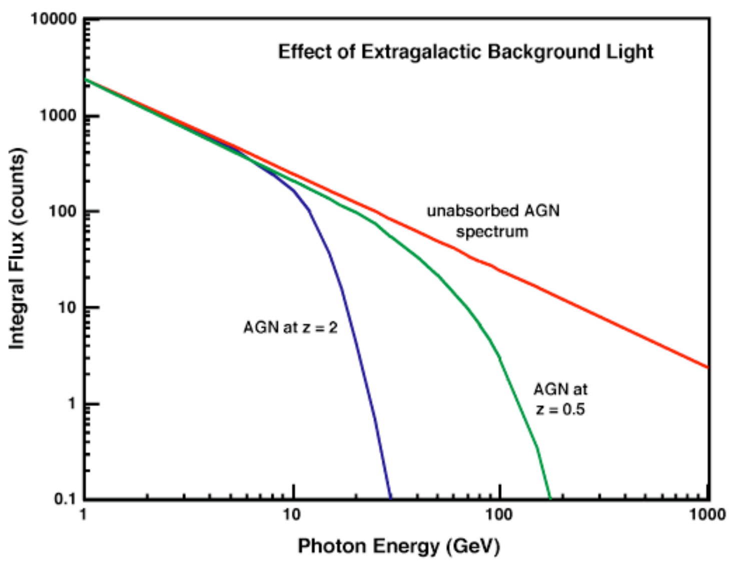
Julie McEnery
NASA/GSFC

Why High Energy Gamma-Rays?

- **High energy gamma-rays explore nature's accelerators - "Where the energetic things are"**
  - **natural connections to UHE cosmic-ray and neutrino astrophysics**

High energy photons often produced in a different physical process to the lower energy emission -> Independent handle on the physical conditions.





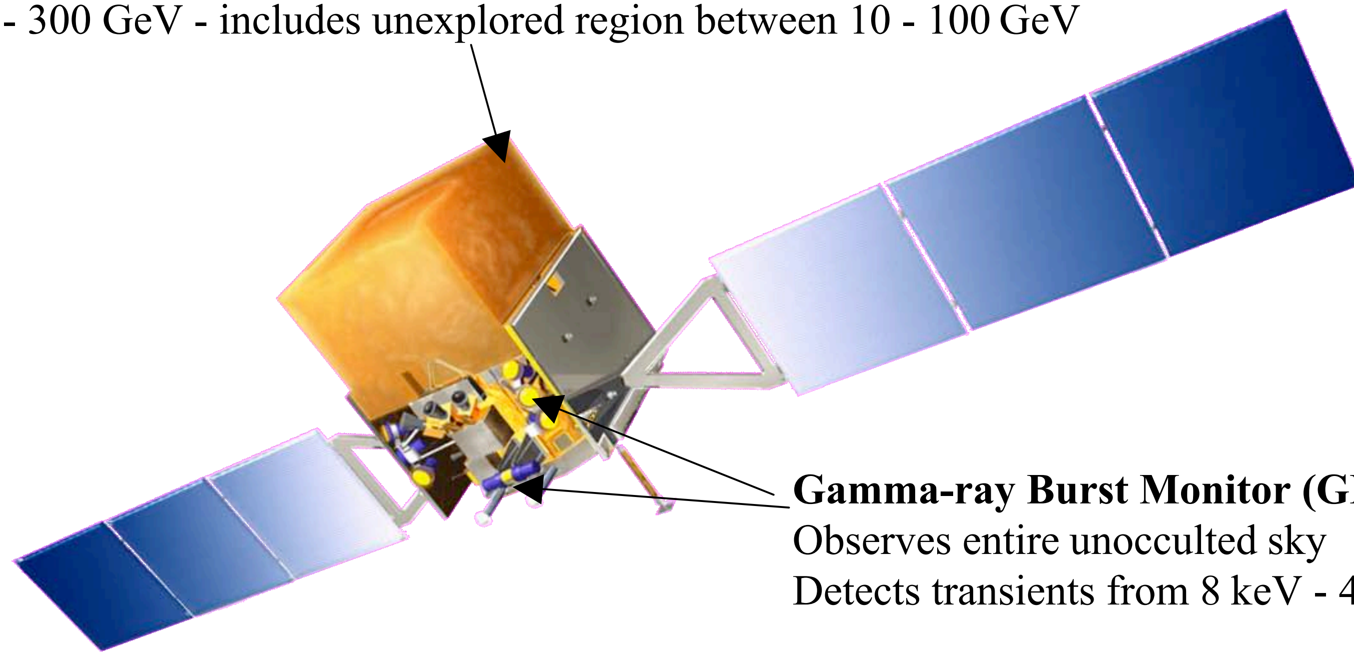
High energy gamma-rays can be attenuated by pair-production with lower energy photons

•Probe conditions in emission regions (gammas need to get out)

•Explore the optical/UV diffuse background

The Fermi Observatory

Large Area Telescope (LAT)
Observes 20% of the sky at any instant, views entire sky every 3 hrs
20 MeV - 300 GeV - includes unexplored region between 10 - 100 GeV



Gamma-ray Burst Monitor (GBM)
Observes entire unocculted sky
Detects transients from 8 keV - 40 MeV

- **Huge improvement over previous missions in this waveband**
  - **EGRET made many ground breaking discoveries, but left many tantalising questions for GLAST to address.**
    - **Highest energy photons from GRB/Energetics**
    - **AGN populations**
  - **New source classes likely to emerge:**

Early Morning, 11 June 2008

Launch!

- **Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT**
- **Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.**

A moment later…

And then…

Fermi LAT Collaboration

- France
  - IN2P3, CEA/Saclay
- Italy
  - INFN, ASI, INAF
- Japan
  - Hiroshima University
  - ISAS/JAXA
  - RIKEN
  - Tokyo Institute of Technology
- Sweden
  - Royal Institute of Technology (KTH)
  - Stockholm University
- United States
  - Stanford University (SLAC and HEPL/Physics)
  - University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
  - Goddard Space Flight Center
  - Naval Research Laboratory
  - Sonoma State University
  - Ohio State University
  - University of Washington

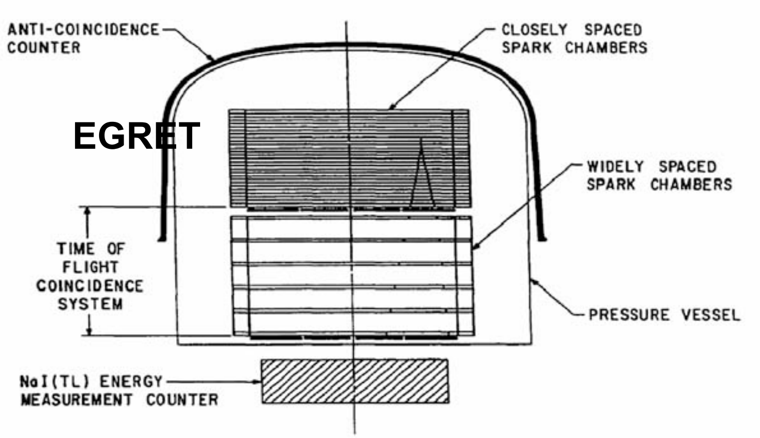
Principal Investigator:
Peter Michelson (Stanford University)

construction managed by
Stanford Linear Accelerator Center (SLAC), Stanford University

LAT as a Telescope

	Years	Ang. Res. (100 MeV)	Ang. Res. (10 GeV)	Eng. Rng. (GeV)	$A_{eff}\ \Omega$ (cm^2 sr)	# γ-rays
EGRET	1991–00	5.8°	0.5°	0.03–10	750	1.4×10^6/yr
AGILE	2007–	4.7°	0.2°	0.03–50	1,500	4×10^6/yr
Fermi LAT	2008–	3.5°	0.1°	0.02–300	25,000	1×10^8/yr

- LAT has already surpassed EGRET and AGILE celestial gamma-ray totals
- Unlike EGRET and AGILE, LAT is an effective All-Sky Monitor
  whole sky every ~3 hours



CGRO EGRET

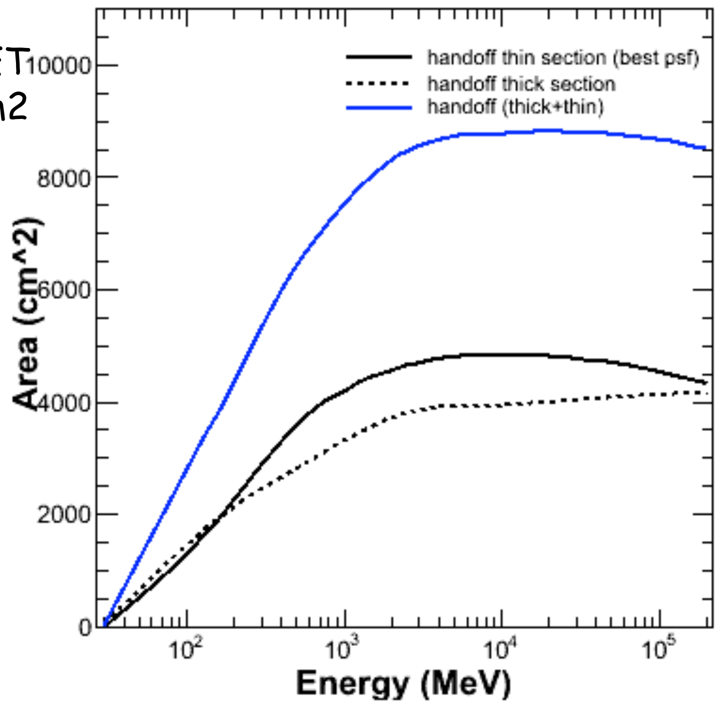
AGILE (ASI)

Fermi / LAT

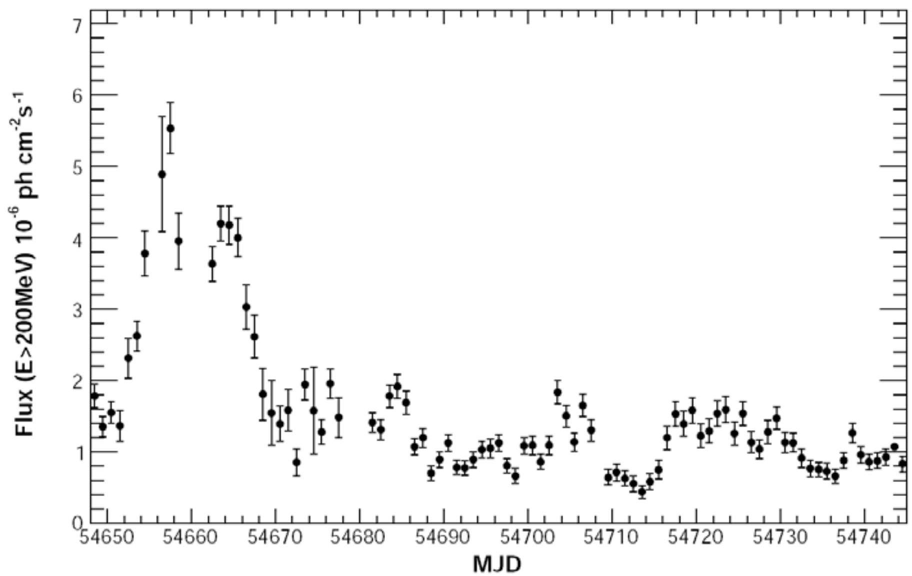
LAT performance - effective area

http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm

c.f. EGRET
~1500 cm2



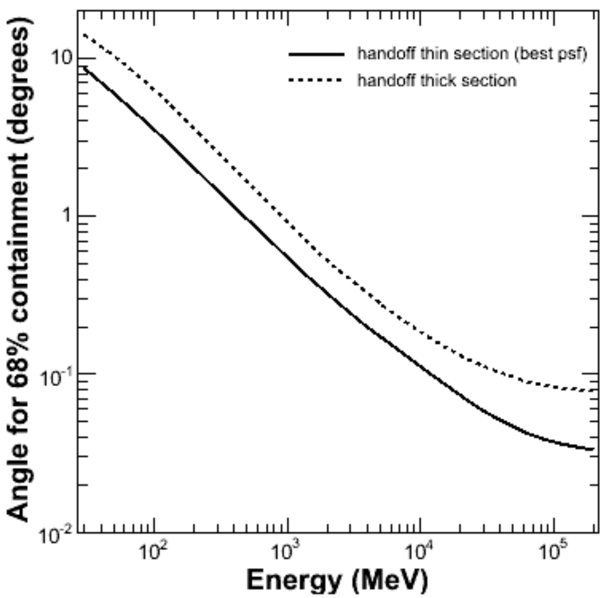
3C 454.3

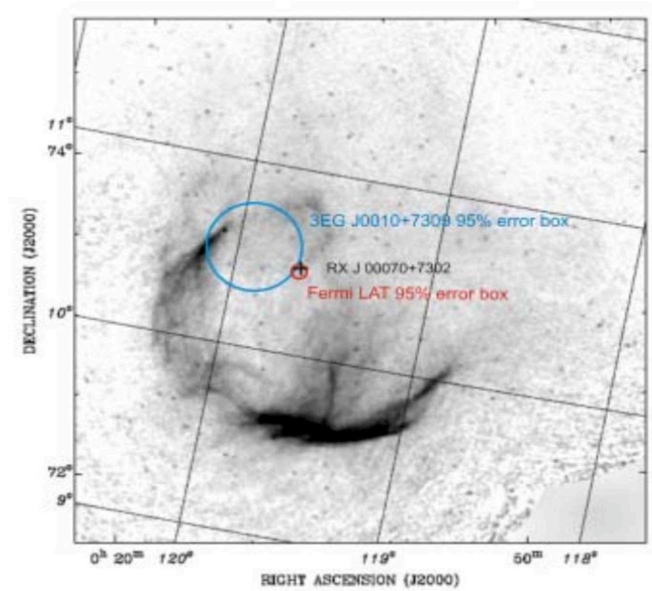


- **Large effective area means that more gamma-rays are detected in GLAST for a given source brightness.**
- **Effective area remains flat out to a few hundred GeV -> broad spectral coverage**
- **Improves sensitivity; observations of rapid variability/transients (typical minimum integration for bright sources is 1 day, but can go smaller for brightest sources)**

LAT Performance - Angular resolution

http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm



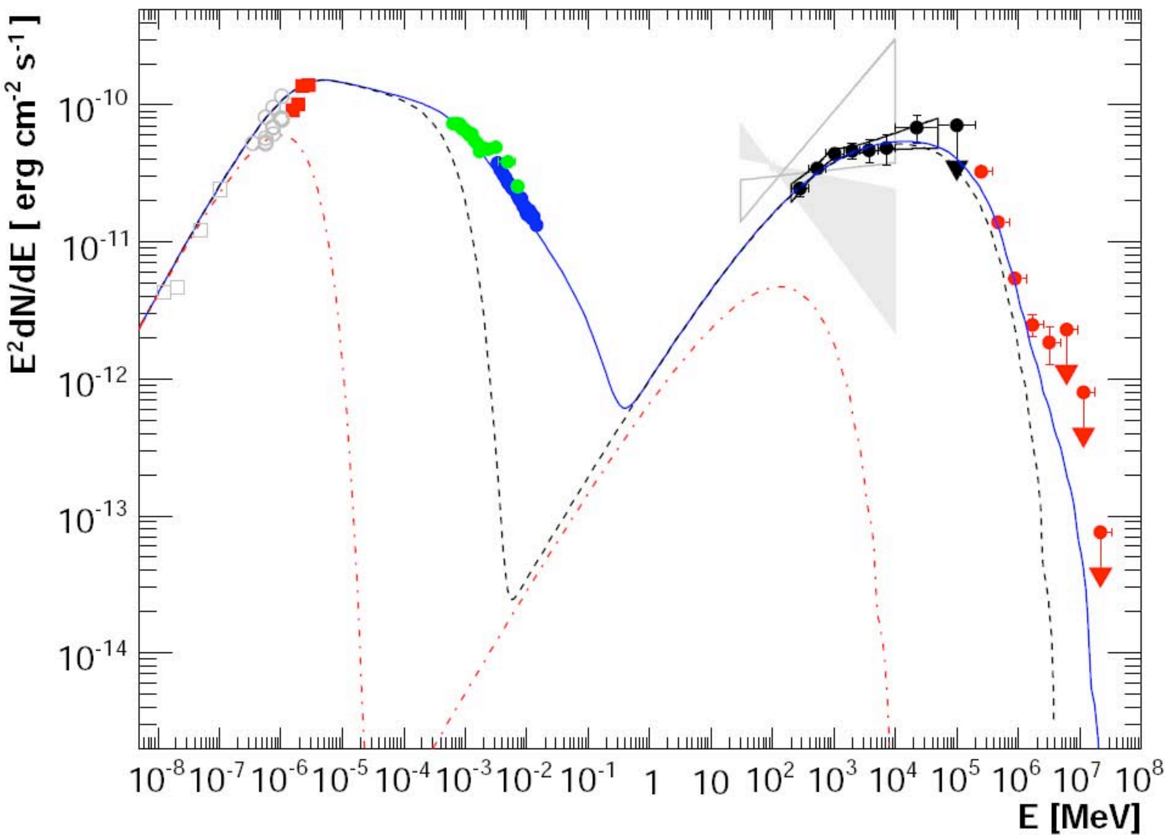


- **Angular resolution rapidly improves with increasing energy.**
- **Improved sensitivity (less background); greatly improved source locations, reduced source confusion - particularly for hard spectrum sources.**
- **Source localizations 5-10's arcmin typically - can follow up with MW observations.**
  - **Everything is better when we know where to look!**

LAT Performance - Energy range

LAT energy range is very broad (20 MeV - 300 GeV), includes the largely unexplored range between 10 and 100 GeV

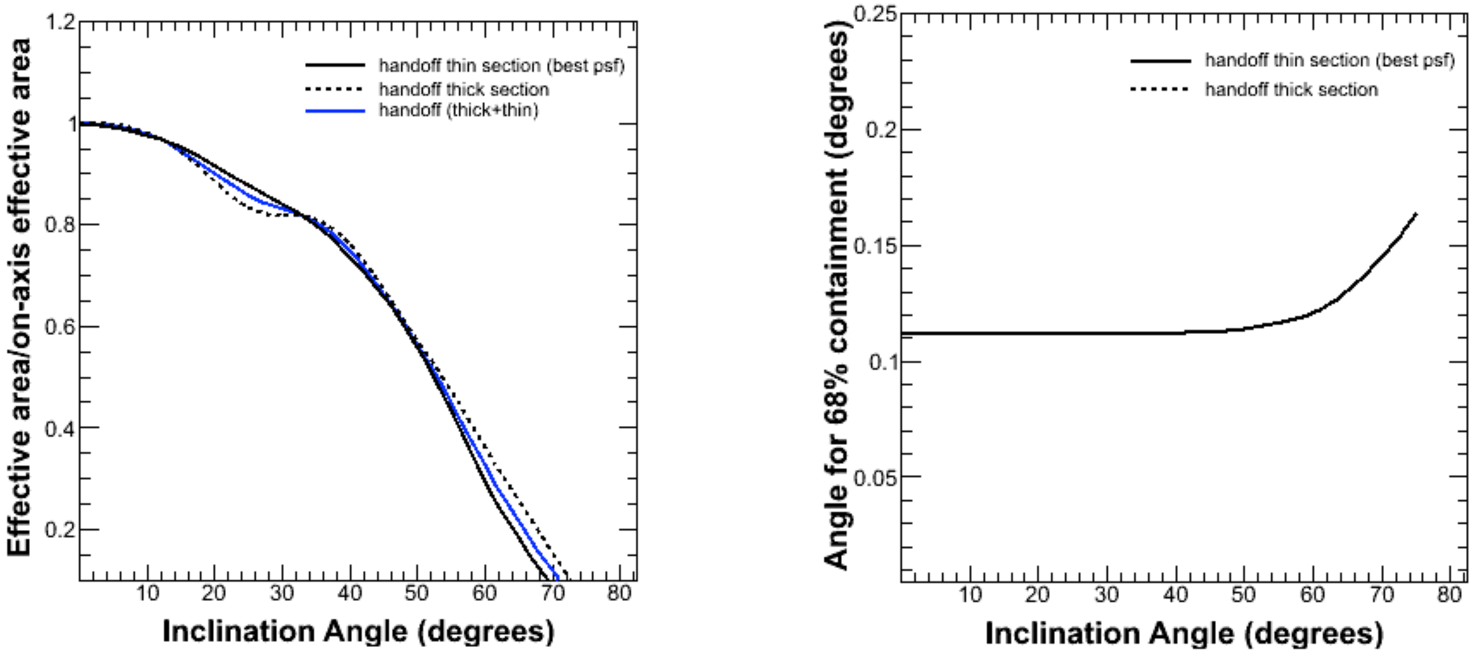
Allows ground-based TeV data to be combined with the space-based GeV data



SED for PKS 2155-304

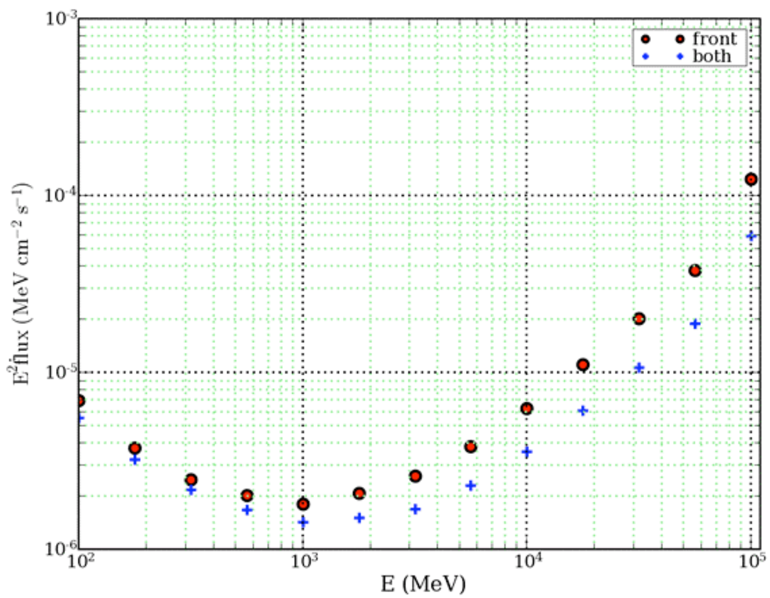
LAT Performance - Field of View

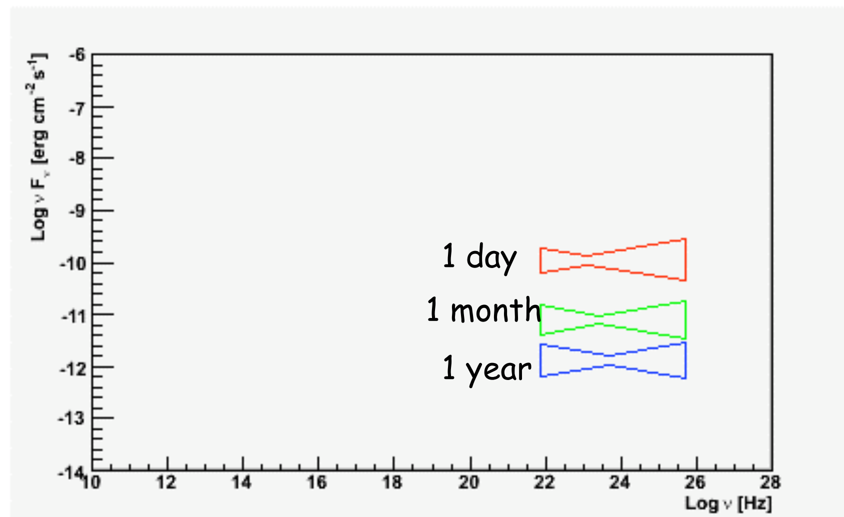
http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm



- **Field of view is HUGE! (>55 deg half angle, >2.2 sr)**
  - **Increases total exposure time (and thus sensitivity)**
  - **Superb at "catching" transients/GRB.**

LAT performance - point source sensitivity

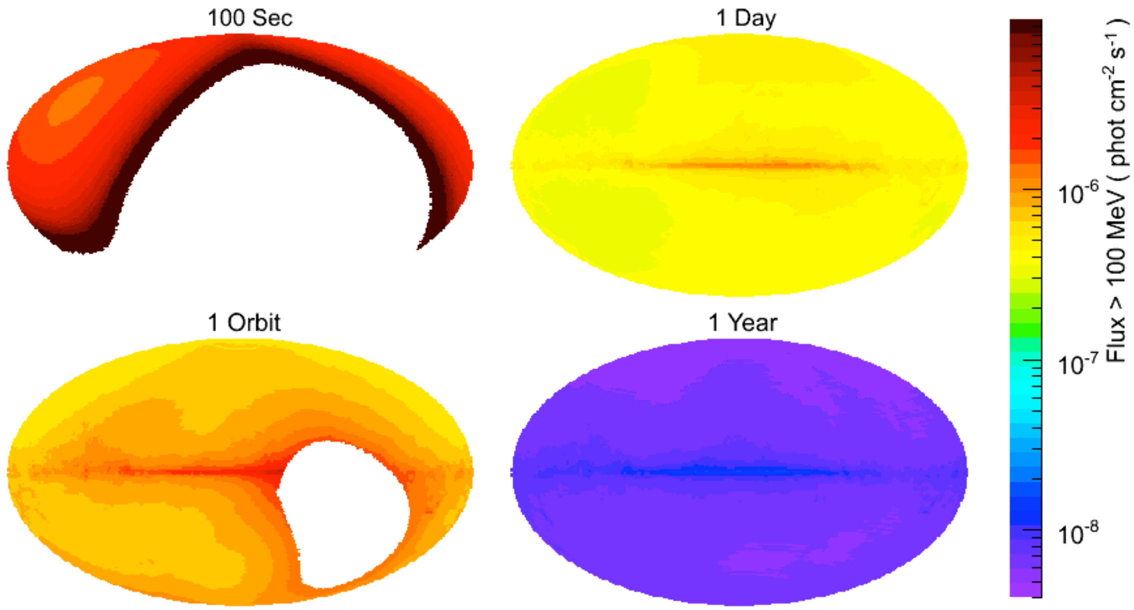




Each point is a 5 sigma detection in 1/4 decade energy band. Use to determine the energy range for interesting spectral measurements (detection threshold is much lower)

Minimum needed for 20% measurement of the flux after one day, one month and one year in sky survey.

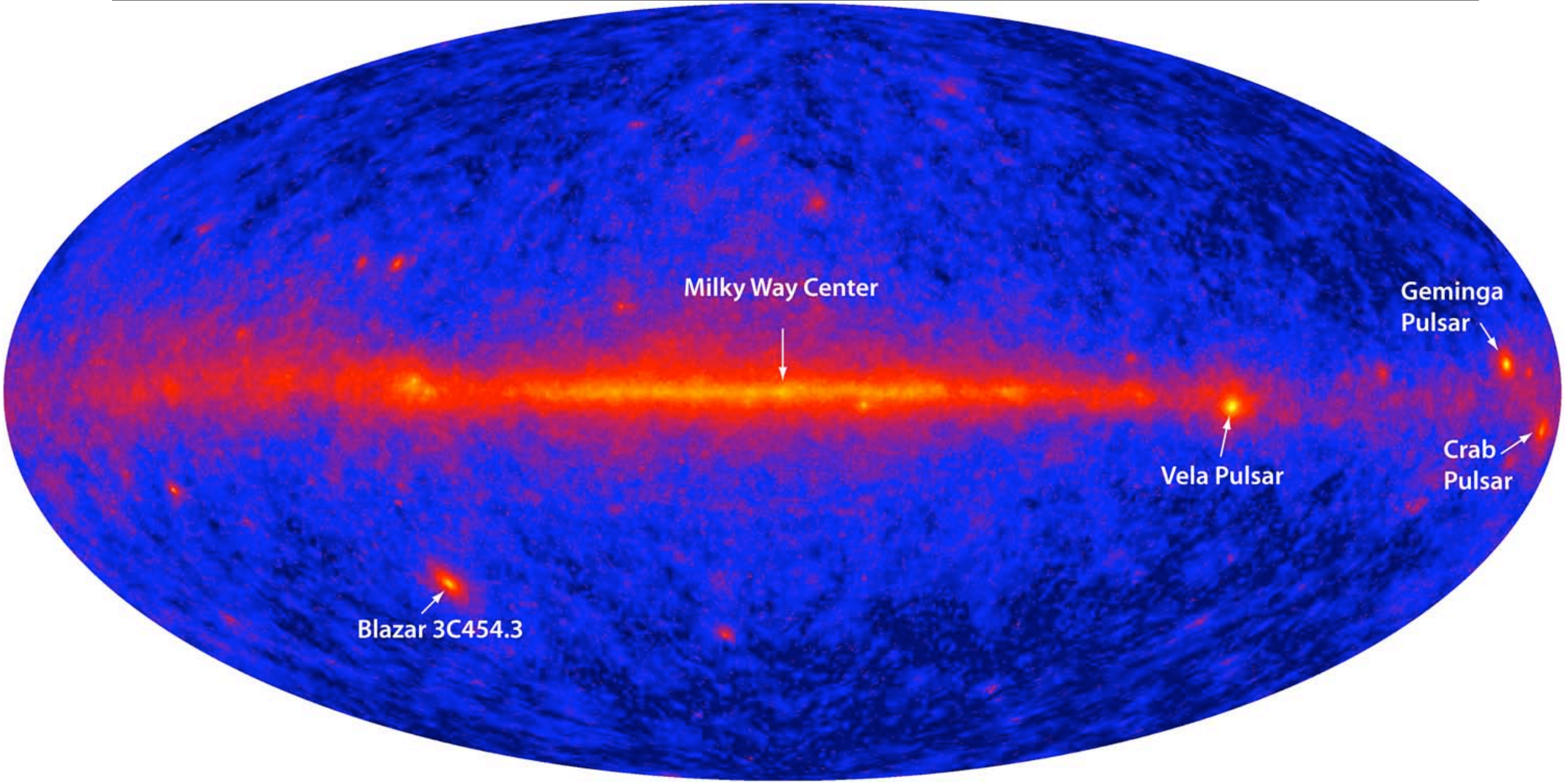
Operating modes - sky coverage



LAT sensitivity on 4 different timescales: 100 s, 1 orbit (96 mins), 1 day and 1 year

- **In survey mode, the LAT observes the entire sky every two orbits (~3 hours), each point on the sky receives ~30 mins exposure during this time**
- **Variations in sensitivity are most strongly determined by the background from diffuse Galactic gamma-ray emission.**
  - **Sensitivity near Galactic plane is ~2-5 times less sensitive that at high latitudes.**
- **GBM sees entire unocculted sky.**

First Light!

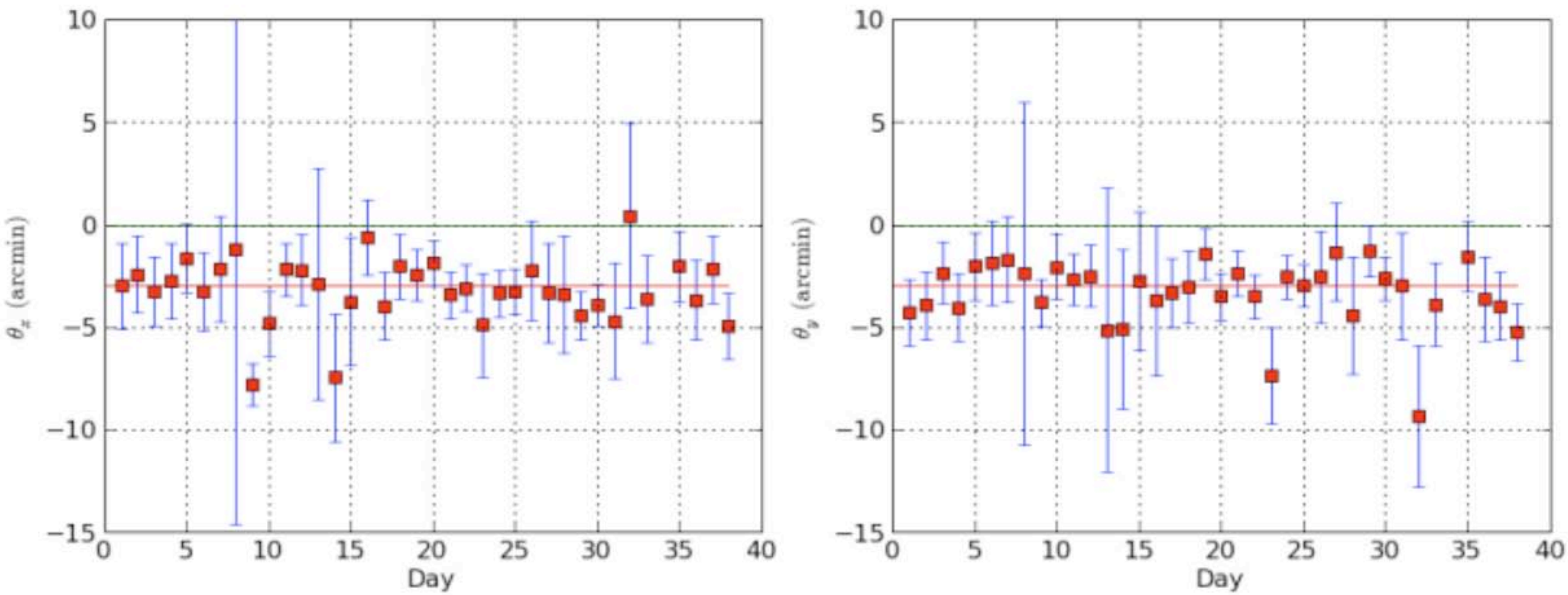


Four days of all-sky survey engineering data.

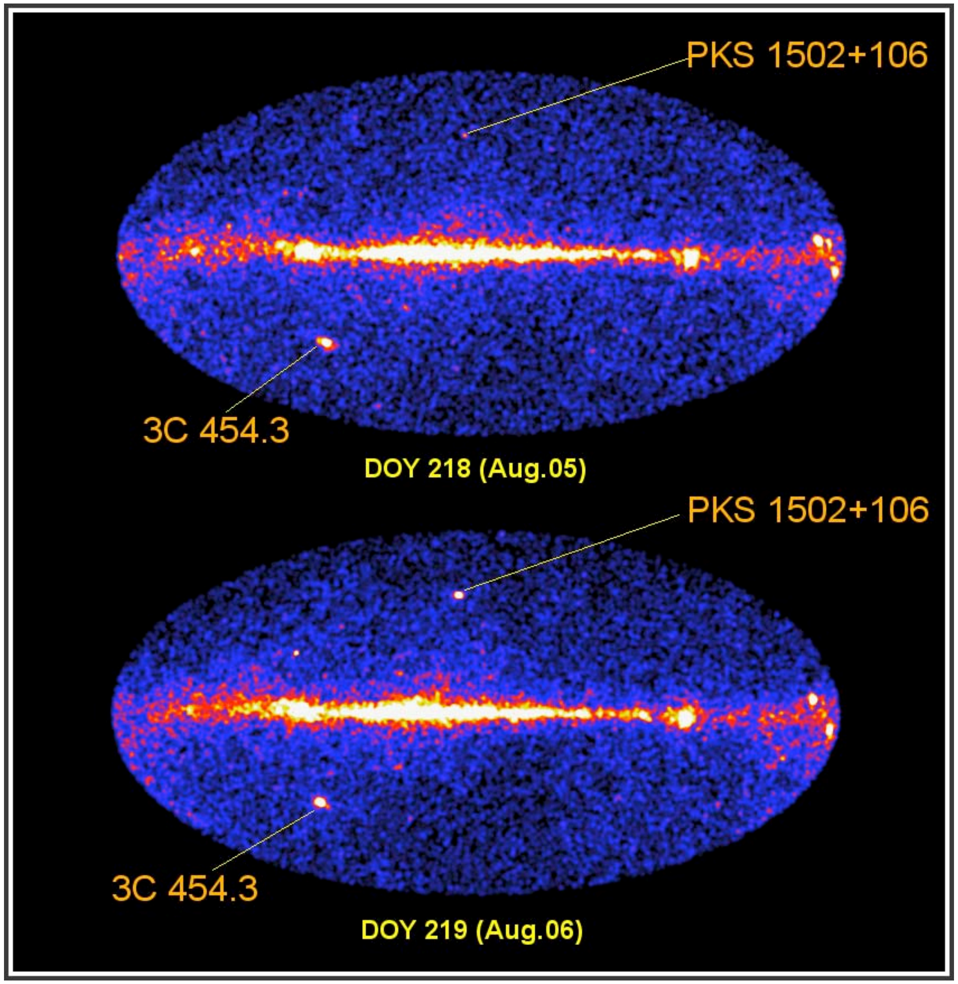
Global Alignment and absolute pointing accuracy

- **The absolute pointing on Fermi is obtained from 2 star trackers mounted on the spacecraft.**
- **Using an ensemble of known gamma-ray sources, calculate (and monitor) the offset between the star tracker and LAT frames. The absolute value is applied as a correction to the data.**
  - **Alignment between star tracker and LAT is stable**
  - **Alignment knowledge is not limiting source location accuracy**

Daily boresight alignment plotted with cumulative mean (red)

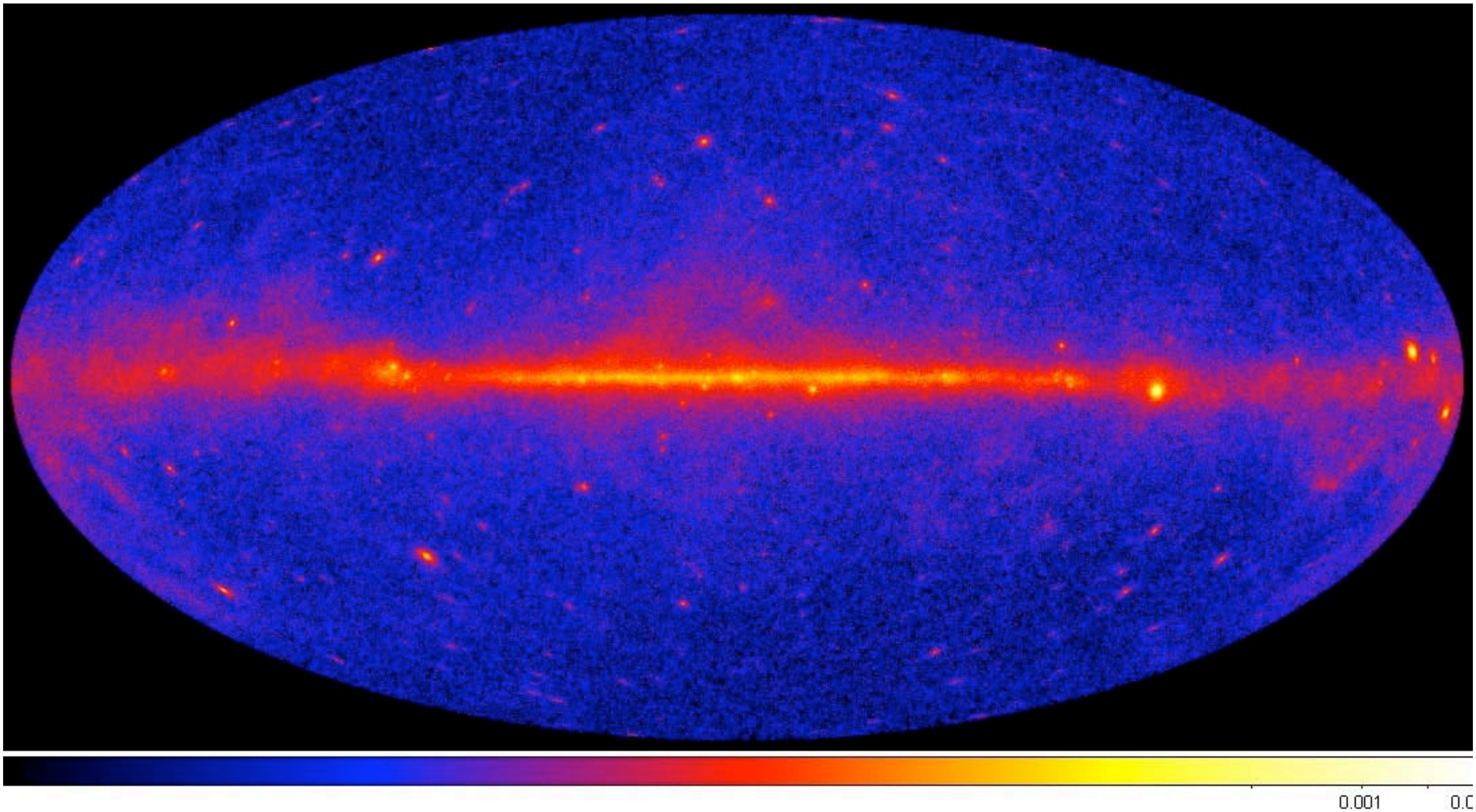


Flaring sources

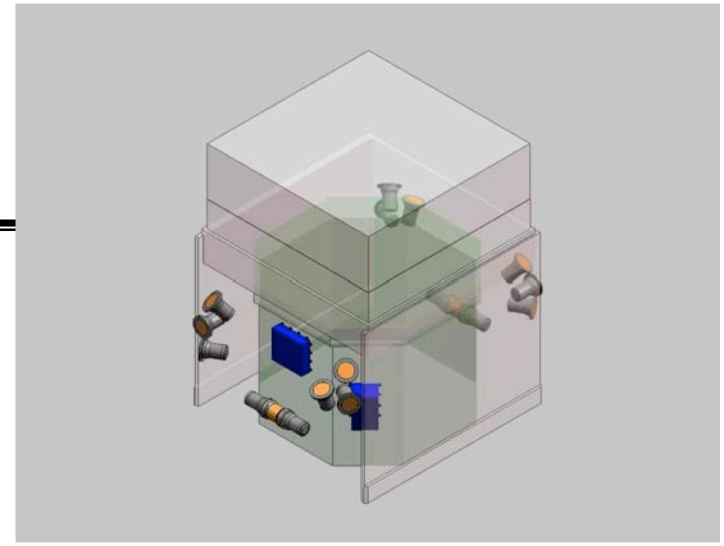


- Automated search for flaring sources on 6 hour, 1 day and 1 week timescales.
- >20 Astronomers telegrams
  - Discovery of new gamma-ray blazars PKS 1502+106, PKS 1454-354
  - Flares from known gamma-ray blazars: 3C454.3, PKS 1510-089,3C273, AO 0235+164, PSK 0208-512, 3C66A, PKS 0537-441, 3C279
  - Galactic plane transients: J0910-5041, 3EG J0903-3531

3 month all-sky image



GBM Collaboration



National Space Science & Technology Center

University of Alabama
in Huntsville

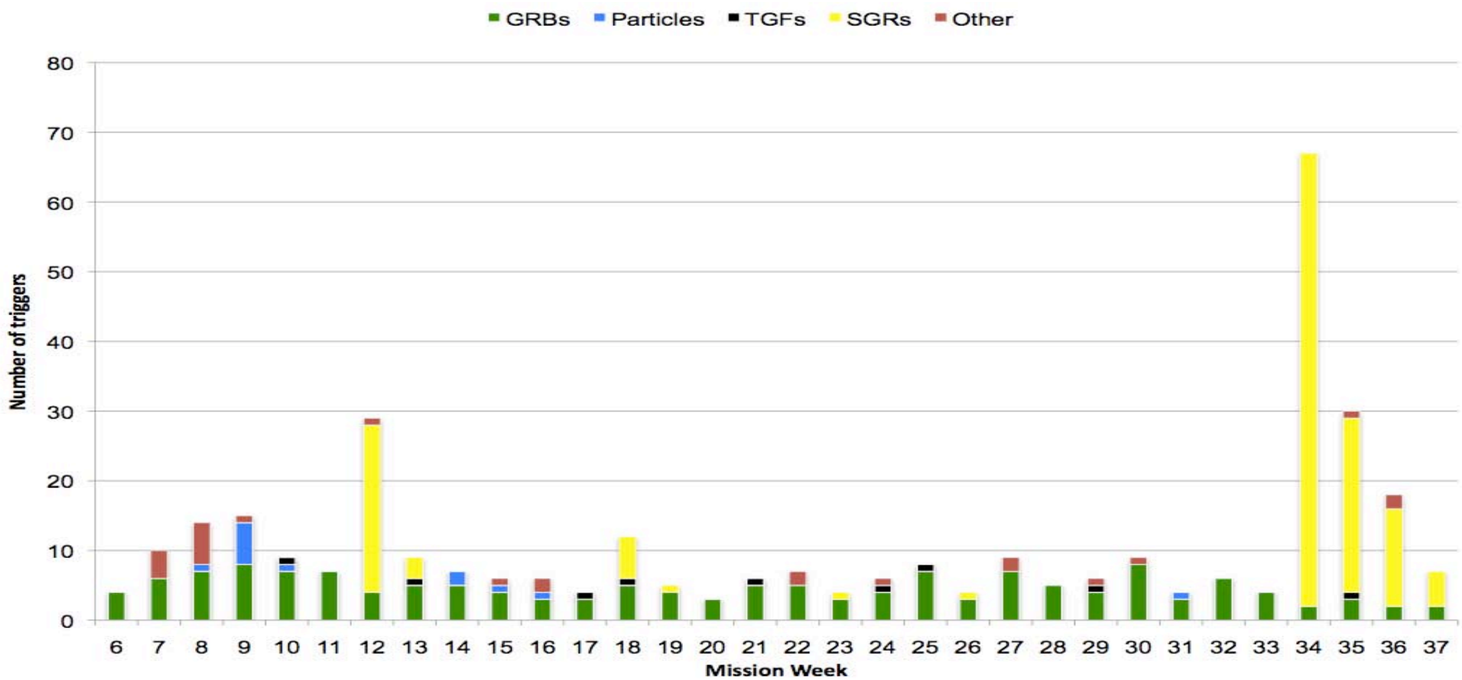
NASA
Marshall Space Flight Center

Max-Planck-Institut für
extraterrestrische Physik

Los Alamos
NATIONAL LABORATORY

Charles Meegan (PI)
Jochen Greiner (Co-PI)

Gamma-ray Burst Monitor



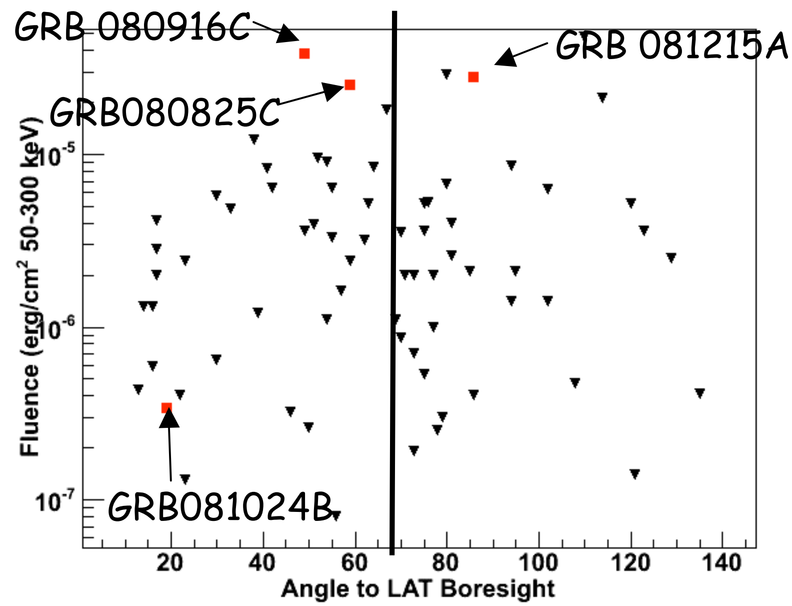
- **GBM is operating well, backgrounds and performance consistent with expectations.**
- **Trigger rate is higher than expected (250/year c.f. 200/year predicted)**
- **Now have over 150 GBM detected GRB, two SGRs (SGR 0501+4516, SGR 1806-20), one AXP (AXP 1E1547.0-5408), over 5 TGFs and a solar flare.**

Fermi-LAT Observed GRBs

- **GBM (since July 14)**
  - **~>150 GRB**

- **5 LAT detections:**

  - **GRB080825C**
  [GCN 8183 – Bouvier, A. et al.,
  GCN 8141, 8184 – van der Horst, A. et al.]
  More than 10 events above 100 MeV

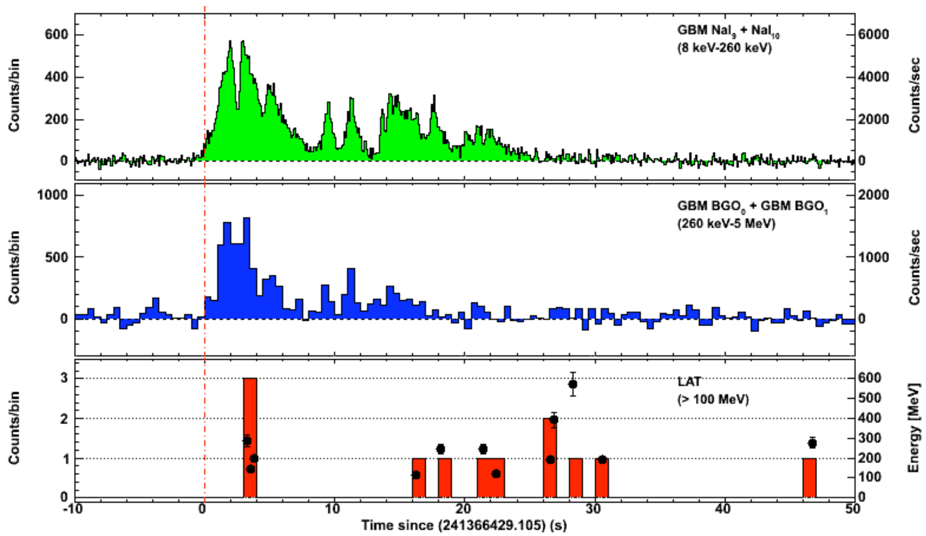


  - **GRB080916C**
  [GCN 8246 – Tajima, H. et al., GCN 8245, 8278 – Goldstein, A. et al.]
  More than 10 events above 1 GeV and more than 140 events above 100 MeV (used for spectral analysis)

  - **GRB081024B**
  [GCN 8407 – Omodei, N. et al., GCN 8408– Connaughton, V. et al.]
  First short GRB with >1 GeV emission

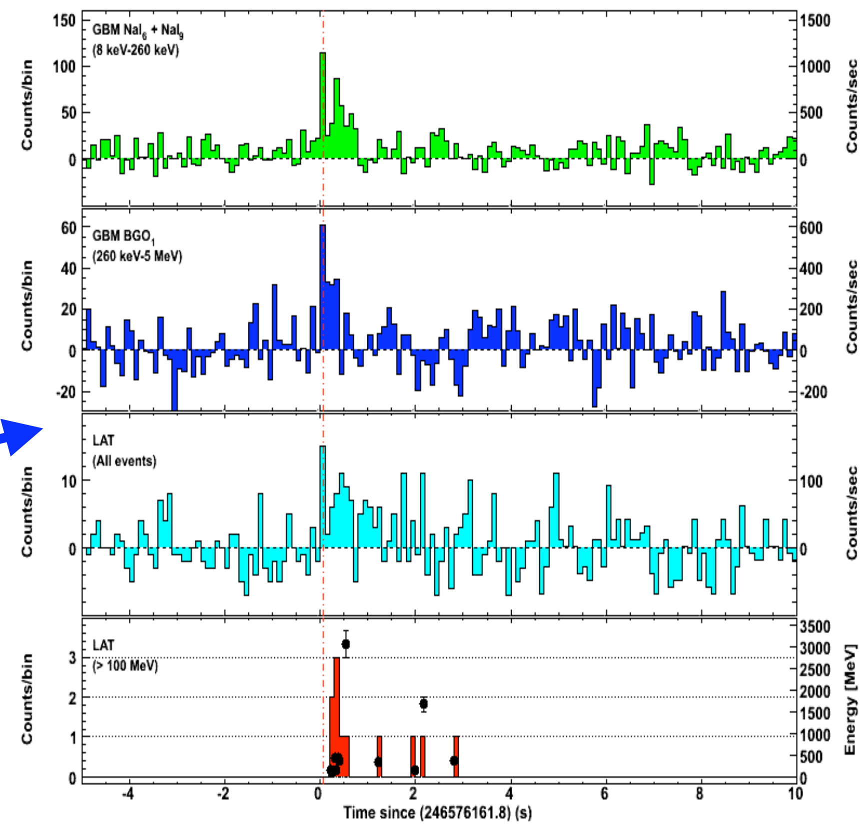
  - **GRB081215A**
  [GCN 8684 – McEnery, J. et al., GCN 8678– Preece, R. et al.]
  At 86 deg to LAT boresight, LAT excess seen in raw count rates

GRB080825C and GRB081024B



GRB080825C

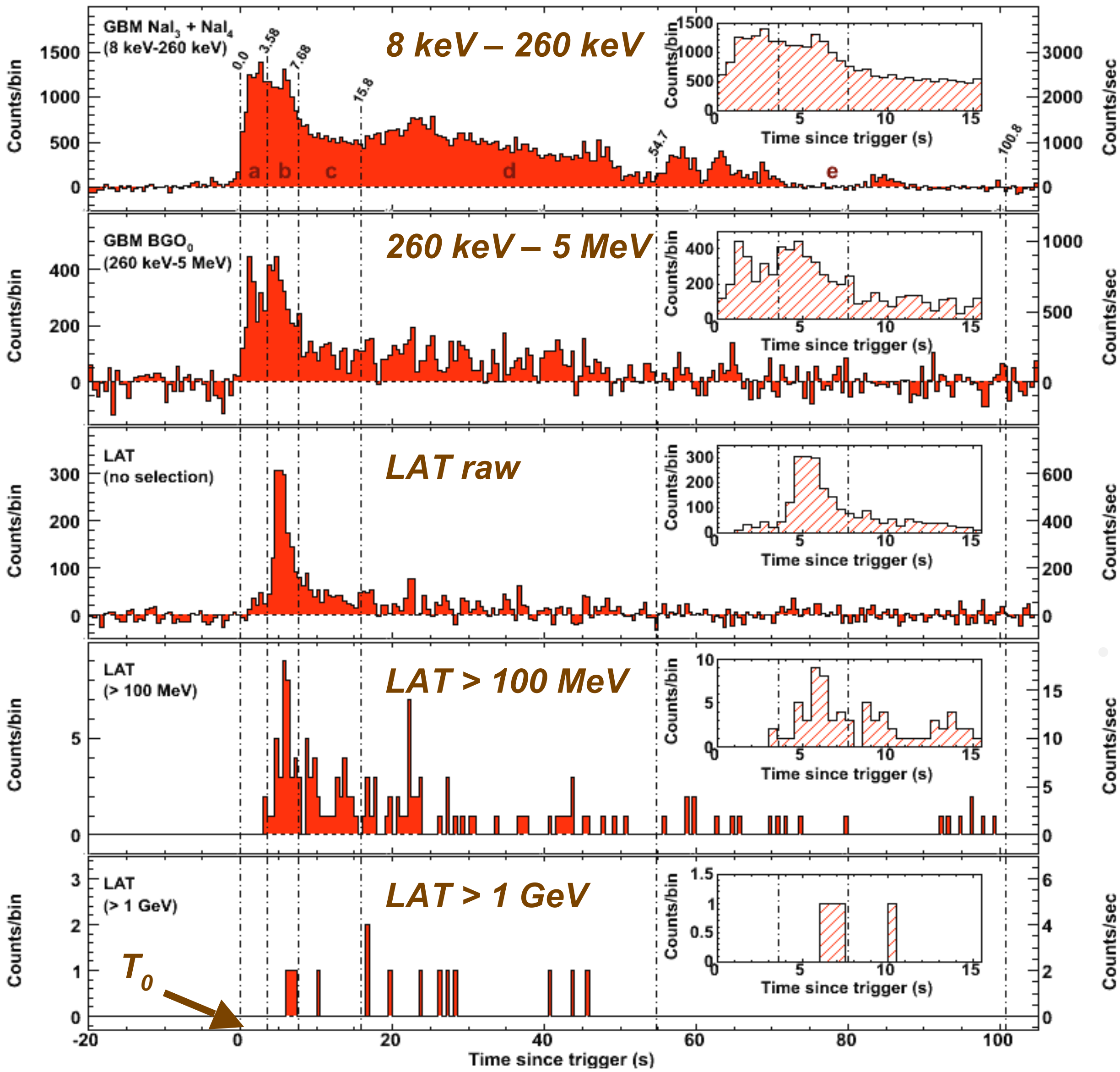
- First LAT events are detected in coincidence with the 2nd GBM peak
- Highest energy event is detected when GBM low energy emission is very weak



GRB081024B

- High-energy LAT emission is delayed with respect to GBM onset and seem to arrive in coincidence with GBM 2nd pulse.
- LAT emission extends few seconds beyond the duration of the typical keV-MeV emission (~0.8 sec).
- First short GRB with >1 GeV photons detected

GRB080916C



First 3 light curves are background subtracted

The LAT can be used as a counter to maximize the rate and to study time structures above tens of MeV

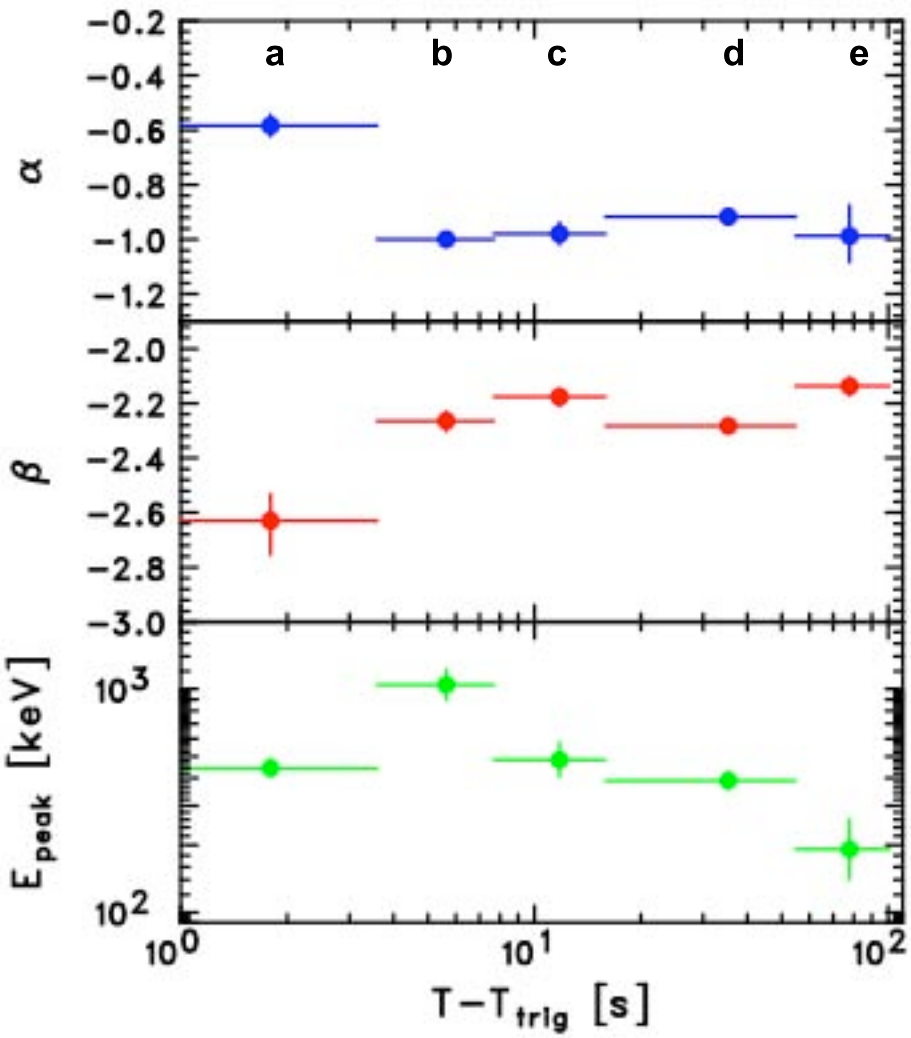
- **The first low-energy peak is not observed at LAT energies**

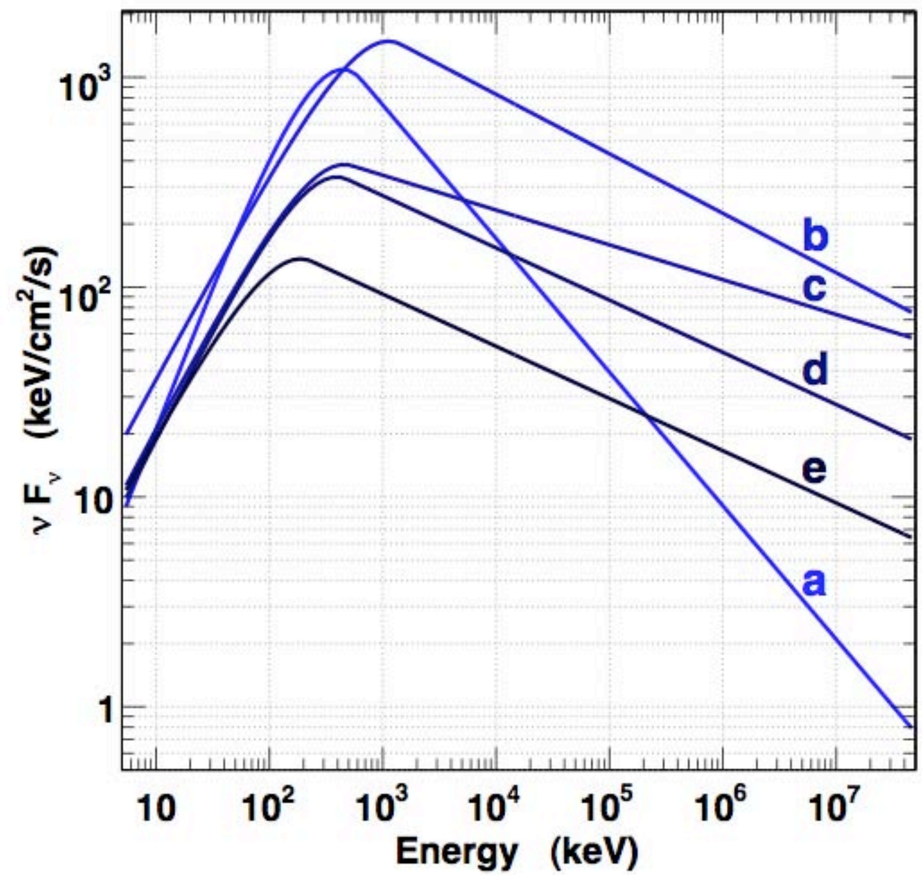
Spectroscopy needs LAT event selection (>100 MeV)

- **5 intervals for time-resolved spectral analysis:**
  0 – 3.6 – 7.7 – 16 – 55 – 100 s
- **14 events above 1 GeV**
- **13.2 +0.7-1.54 GeV photon was was detected in interval d.**

GRB080916C - Spectral evolution

Soft-to-hard, then hard-to-soft evolution



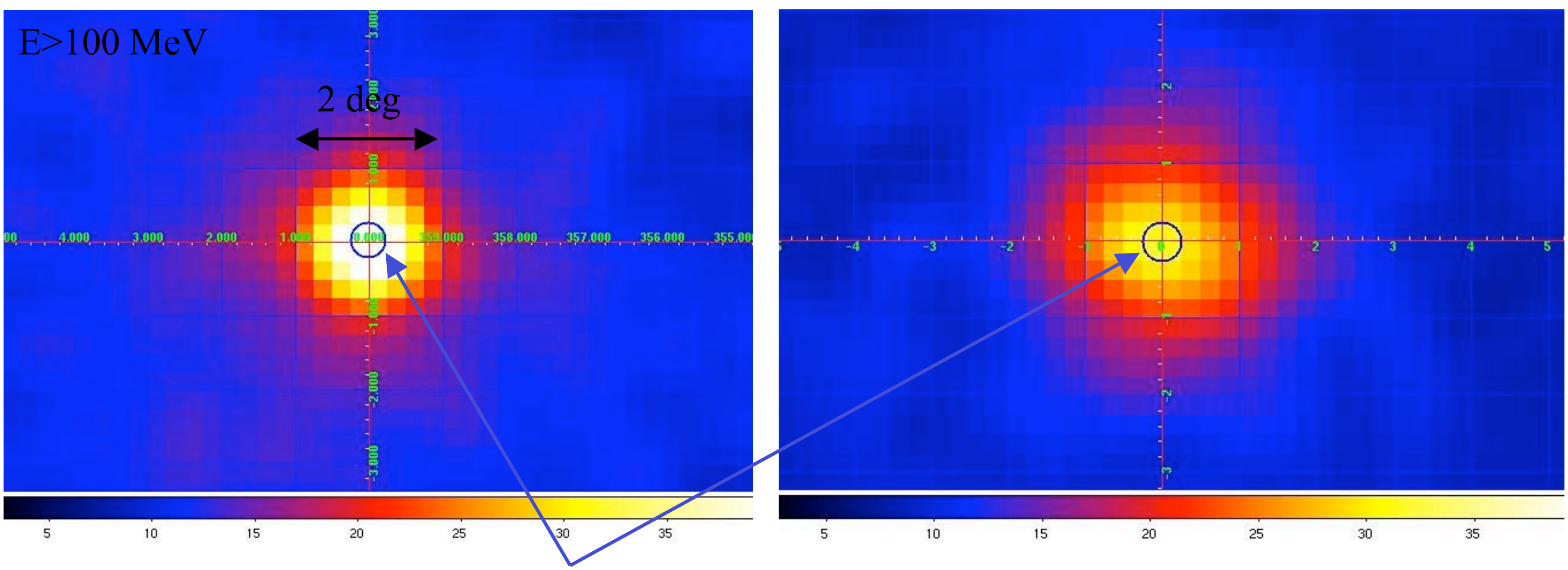


Near home - solar system objects

- **Sun and moon clearly detected above 100 MeV by LAT.**
- **produced by interactions of cosmic rays; by nucleons with the solar and lunar surface, and electrons with solar photons in the heliosphere.**
- **Fermi provides high-quality detections on a daily basis allowing variability and flare searches to be performed.**

The Sun

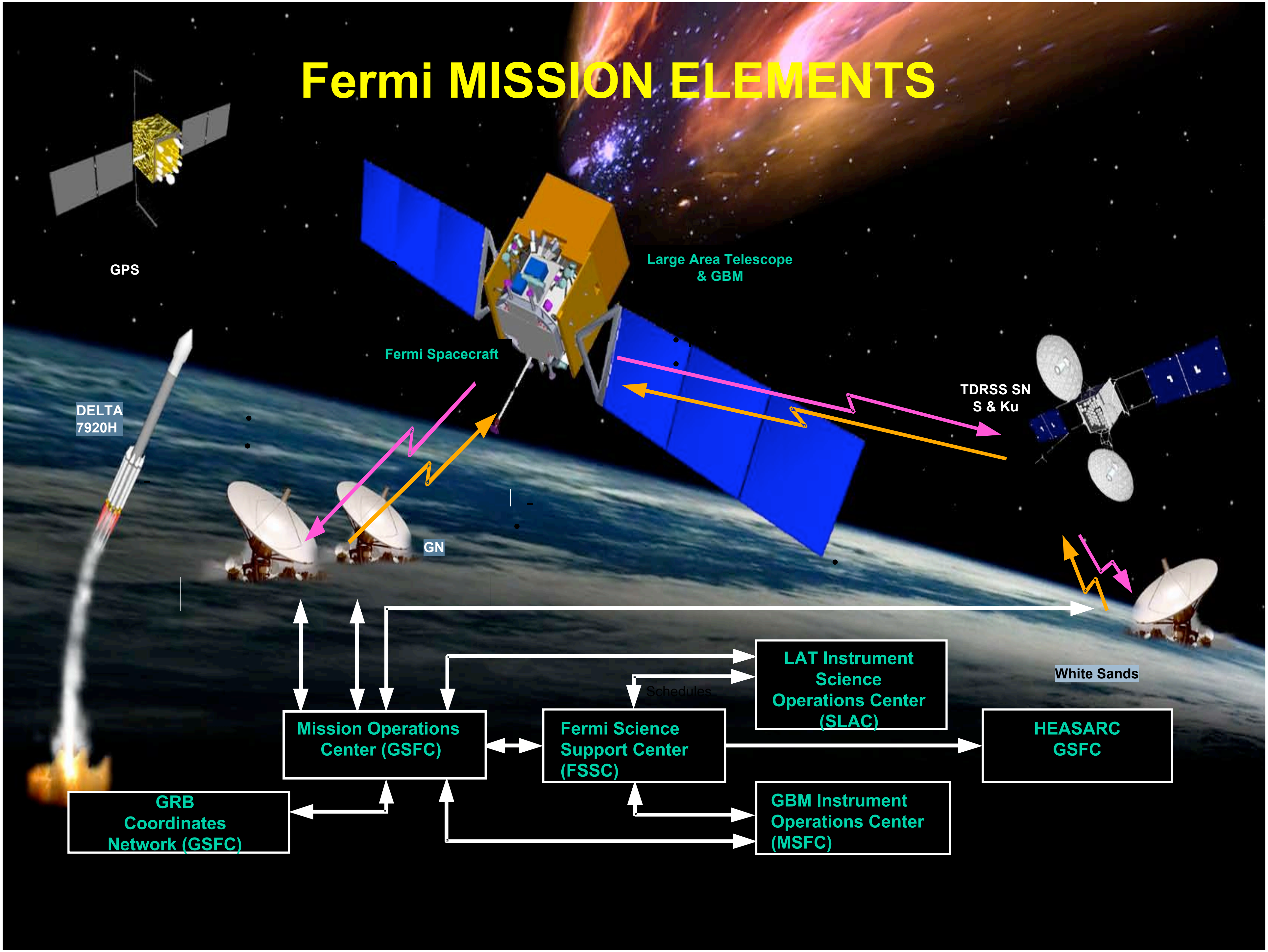
The Moon



Size of Sun/Moon on the sky

Fermi Science Accomplishments

- Mapping and measuring the the entire sky at a unprecedented angular and energy resolution and statistical accuracy
- Detected several pulsars, including all the EGRET ones and many new ones
- Detected several hundred sources above 100 MeV
- Discovered flares from several AGN reported in ATels
- Detected the binary LSI+61 303
- Detected the Sun, moon and the Earth
- Detected over 150 GRB above 8 keV
- Detected five GRBs above 100 MeV; including a bright one above 10 GeV energies, and a short one above 1 GeV.
- Detected two Galactic plane transients
- Resolved the high energy gamma-ray emission from the LMC


Fermi MISSION ELEMENTS
GPS
Large Area Telescope & GBM
Fermi Spacecraft
TDRSS SN S & Ku
DELTA 7920H
GN
White Sands
LAT Instrument Science Operations Center (SLAC)
Schedules
Mission Operations Center (GSFC)
Fermi Science Support Center (FSSC)
HEASARC GSFC
GBM Instrument Operations Center (MSFC)
GRB Coordinates Network (GSFC)

Data Release plan and operations

- First Year observations - Sky Survey
  - After initial on-orbit checkout (60 days), the first year of observations will be a sky survey.
  - Repoints for bright bursts and burst alerts will be enabled
  - Extraordinary ToOs will be supported.
  - First year data will be used for detailed instrument characterization and key projects (catalog, background models etc).
- First Year Data release
  - All GBM data
  - Information on all LAT detected GRB (flux, spectra, location)
  - High level LAT data (time resolved flux/spectra) on ~20 selected sources and on all sources which flare above 2×10^{-6}, continued until the source flux drops below 2×10^{-7} (rate ~ 1-4 such objects per month).
  - The LAT team will produce a preliminary source catalog after ~6 months on a best effort basis
- Subsequent years: Observing plan driven by guest observer proposal selections by peer review. Default is sky survey mode.
  - All data publicly released within 72 hours through the Science Support Center (GSSC).
- See http://glast.gsfc.nasa.gov/ssc/data/policy/ for more details

LAT First Year Source Monitoring List

http://fermi.gsfc.nasa.gov/ssc/data/policy/LAT_Monitored_Sources.html

Flux/spectra as a function of time (daily and weekly integrations) for all sources in the list.

PLUS, same for any source flaring above 2e-6 ph/cm^2/s until the flux drops below 2e-7 ph/cm^2/s (~several per month)

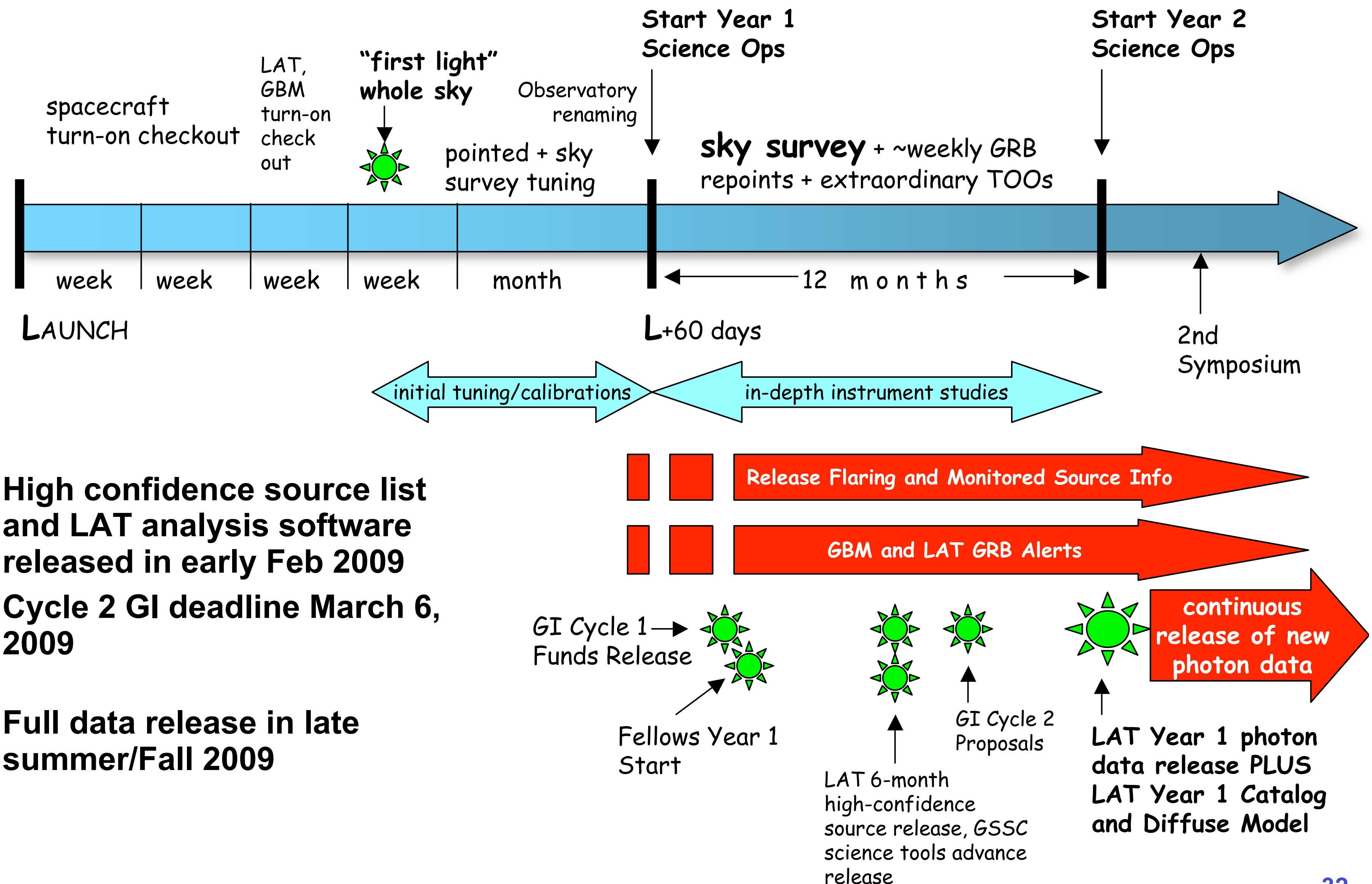
A “quicklook” analysis to get the results out as quickly as possible. Tables will be updated as analysis and calibrations improve.

Source Type	Source Name	EGRET Name	Average or Min. Flux (10^{-8} γ $cm^{-2}s^{-1}$)	Galactic Lattitude	Redshift	TeV Source
Blazar	0208-512	3EGJ0210-5055	85.5 ± 4.5	-61.9	1.003	
	0235+164	3EGJ0237+1635	65.1 ± 8.8	-39.1	0.94	
	PKS 0528+134	3EGJ0530+1323	93.5 ± 3.6	-11.1	2.060	
	PKS 0716+714	3EGJ0721+7120	17.8 ± 2.0	28	0.3	
	0827+243	3EGJ0829+2413	24.9 ± 3.9	31.7	0.939	
	OJ 287	3EGJ0853+1941	10.6 ± 3.0	35.8	0.306	
	Mrk 421	3EGJ1104+3809	13.9 ± 1.8	65.0	0.031	Yes
	W Com 1219+285	3EGJ1222+2841	11.5 ± 1.8	83.5	0.102	
	3C 273	3EGJ1229+0210	15.4 ± 1.8	64.5	0.158	
	3C 279	3EGJ1255-0549	74.2 ± 2.8	57.0	0.538	
	1406-076	3EGJ1409-0745	27.4 ± 2.8	50.3	1.494	
	H 1426+428	NA		64.9	0.129	Yes
	1510-089	3EGJ1512-0849	18.0 ± 3.8	40.1	0.36	
	PKS 1622-297	3EGJ1625-2955	47.4 ± 3.7	13.4	0.815	
	1633+383	3EGJ1635+3813	58.4 ± 5.2	42.3	1.814	
	Mrk 501	NA		38.9	0.033	Yes
	1730-130 NRAO 530	3EGJ1733-1313	36.1 ± 3.4	10.6	0.902	
	1ES 1959+650	NA		17.7	0.048	Yes
	PKS 2155-304	3EG2158-3023	13.2 ± 3.2	-52.2	0.116	Yes
	BL_Lacertae (2200+420)	3EGJ2202+4217	39.9 ± 11.6	-10.4	0.069	Yes
	3C 454.3	3EGJ2254+1601	53.7 ± 4.0	-38.3	0.859	
	1ES 2344+514	NA		-9.9	0.044	Yes
HMXB	LSI+61 303 2CG135+01	3EGJ0241+6103	69.3 ± 6.1	1.0		Yes

Science support center

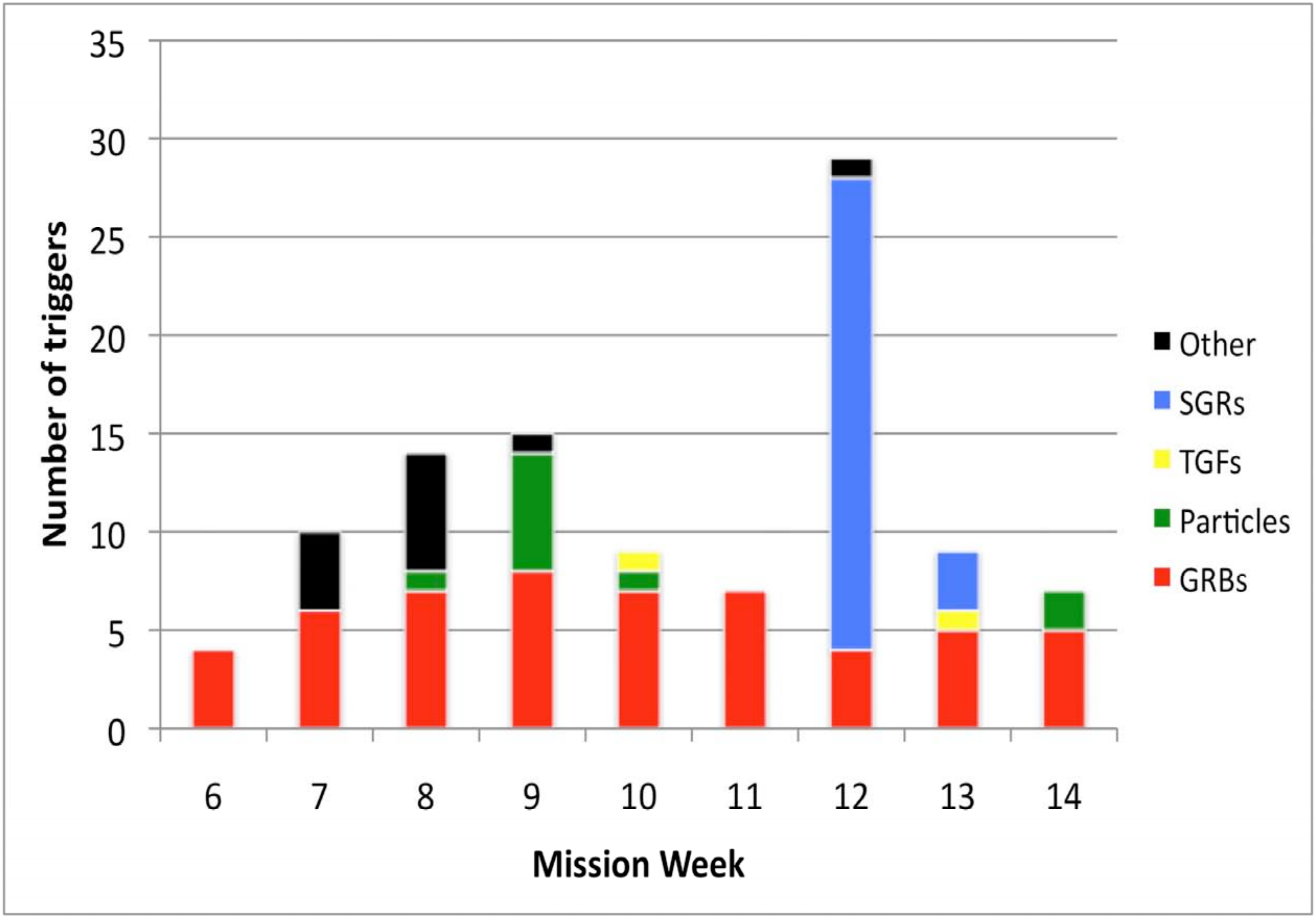
- In nominal mission phase:
  - Survey mode is default observation
  - ToO submission page will be enabled next week (for extraordinary observations)
  - ARR enabled today (repoint to bright GBM detected GRB)
- All GBM data now available, likely to be updates as calibrations improve.
- LAT monitored source list data is available
  - Only those sources that are detected at 5 sigma level on day or week timescales.
- LAT flaring sources also available through the FSSC
  - Some issues with bright steady Galactic sources fluctuating above threshold, so process is not fully automaterd
  - The LAT team is issuing Atel for all sources which flare above 2e-6 ph/cm^2/s
- LAT GRB table also available.

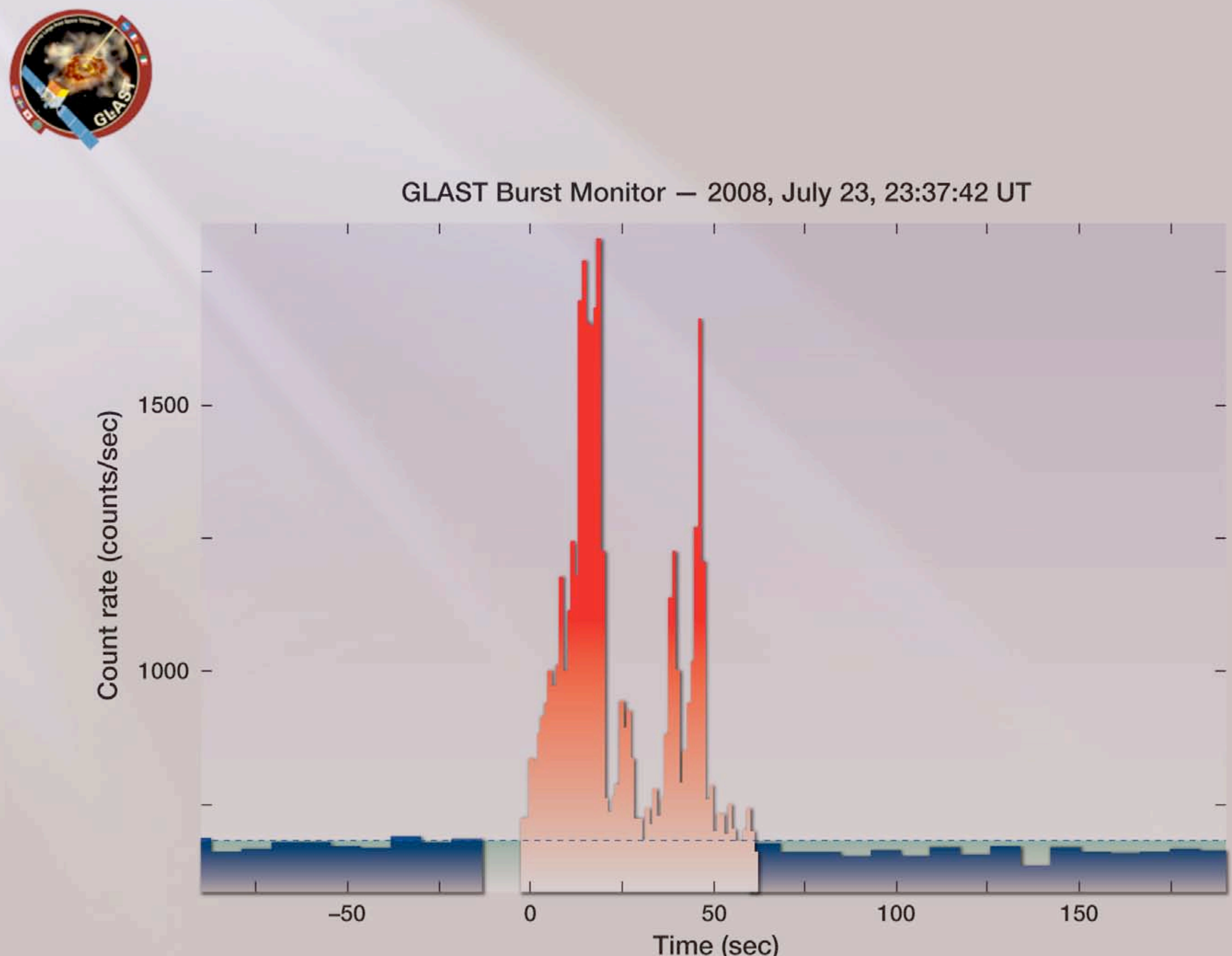
Year 1 Science Operations Timeline Overview



- **High confidence source list and LAT analysis software released in early Feb 2009**
- **Cycle 2 GI deadline March 6, 2009**
- **Full data release in late summer/Fall 2009**

GBM Trigger Rate (weekly)

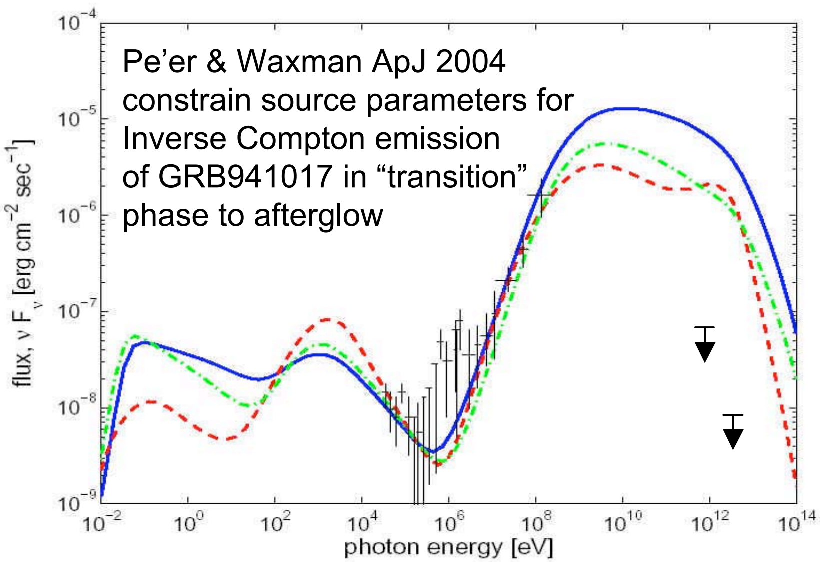


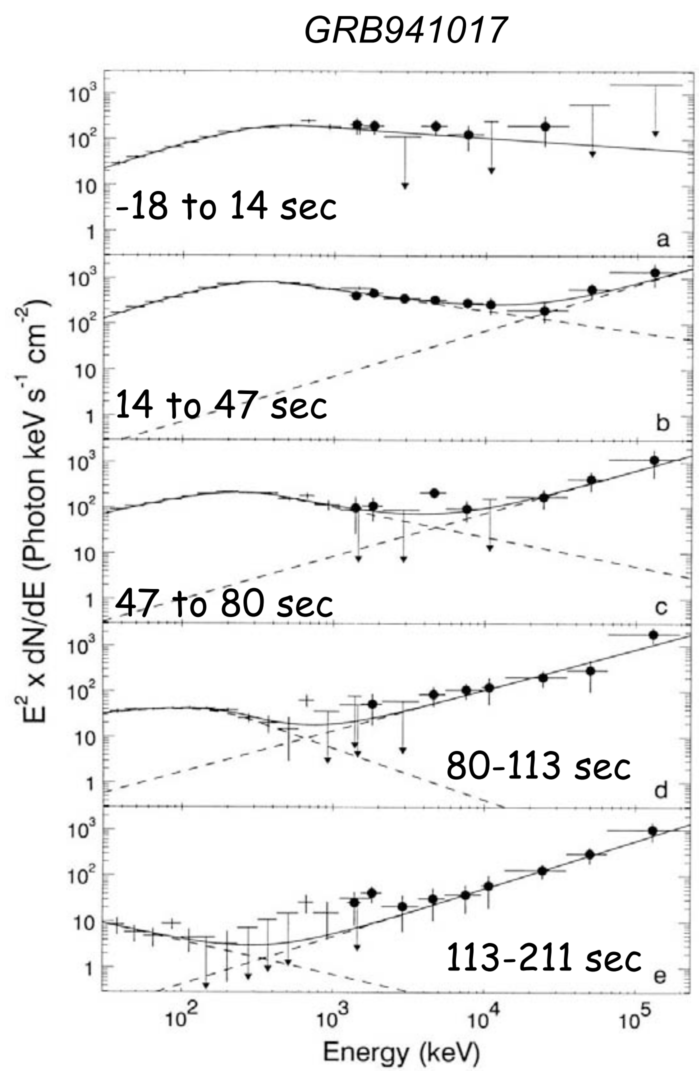

GLAST
GLAST Burst Monitor — 2008, July 23, 23:37:42 UT
Count rate (counts/sec)
1500
1000
–50
0
50
100
150
Time (sec)

GRB 941017 - Separate High Energy Emission Component

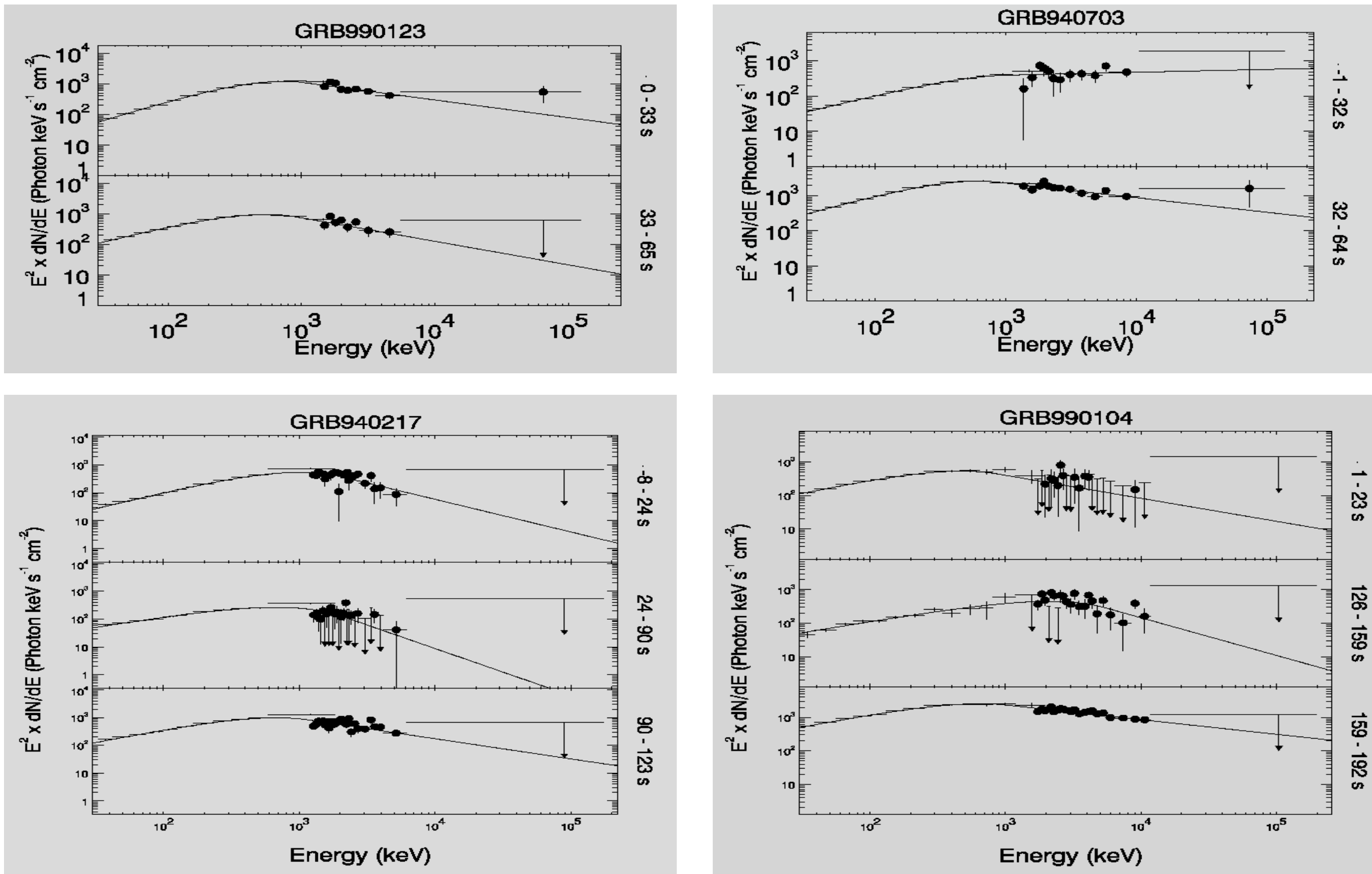
Analysis using EGRET TASC data

- Classic sub-MeV component observed in BATSE data which decays by factor of 1000 and Epeak moves to lower energies
- Higher Energy component observed within 14-47 seconds by EGRET and at later times by both BATSE and EGRET detectors
- Higher Energy Component has
  - $dN_{\gamma}/dE = kE^{-1}$
  - lasts ~200 seconds
  - Increases total energy flux by factor of 3





High Energy Components not always seen



Fermi LAT Overview: Overall Design

Overall LAT Design:

•4x4 array of identical towers
•3000 kg, 650 W (allocation)
•1.8 m × 1.8 m × 1.0 m
•20 MeV – >300 GeV

Anticoincidence Detector:

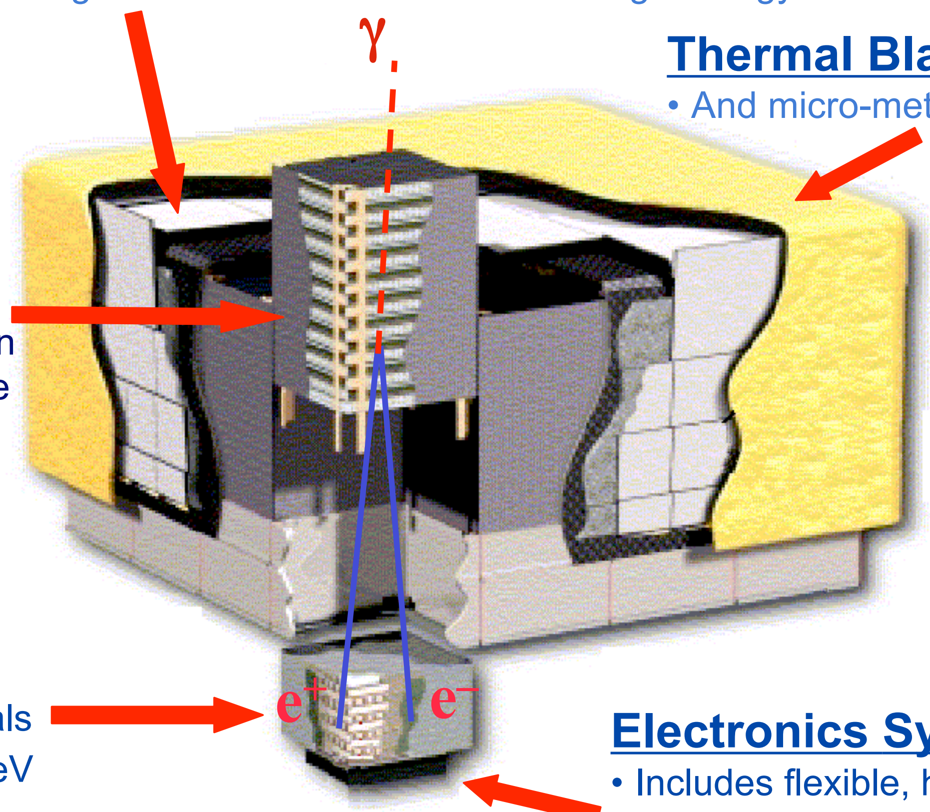
• 89 scintillator tiles
• First step in reduction of large charged cosmic ray background
• Segmentation reduces self veto at high energy

Thermal Blanket:

• And micro-meteorite shield

Precision Si-strip Tracker:

Measures incident gamma direction
18 XY tracking planes. 228 mm pitch. High efficiency. Good position resolution
12 x 0.03 X0 front end => reduce multiple scattering.
4 x 0.18 X0 back-end => increase sensitivity >1GeV



Hodoscopic CsI Calorimeter:

• Segmented array of 1536 CsI(Tl) crystals
• 8.5 X0: shower max contained <100 GeV
• Measures the incident gamma energy
• Rejects cosmic ray backgrounds

Electronics System:

• Includes flexible, highly-efficient, multi-level trigger