Multiwavelength Observations of High Energy Transients

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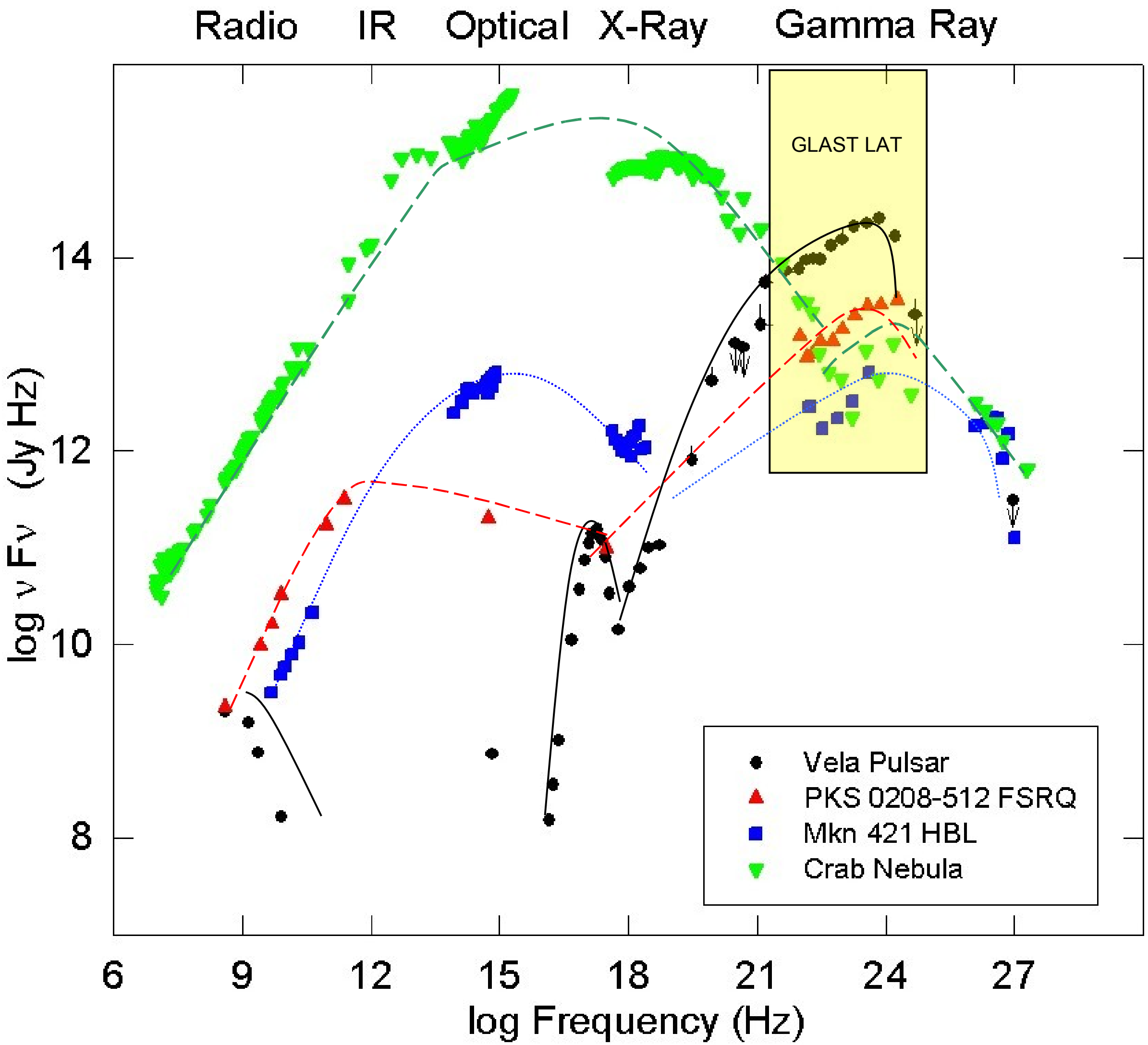
NASA/GSFC

Multiwavelength observations and gamma-ray sources



- Gamma-ray sources are non-thermal - typically produced by interactions of high energy particles.
- Known classes of gamma-ray sources are multiwavelength objects seen across much of the spectrum

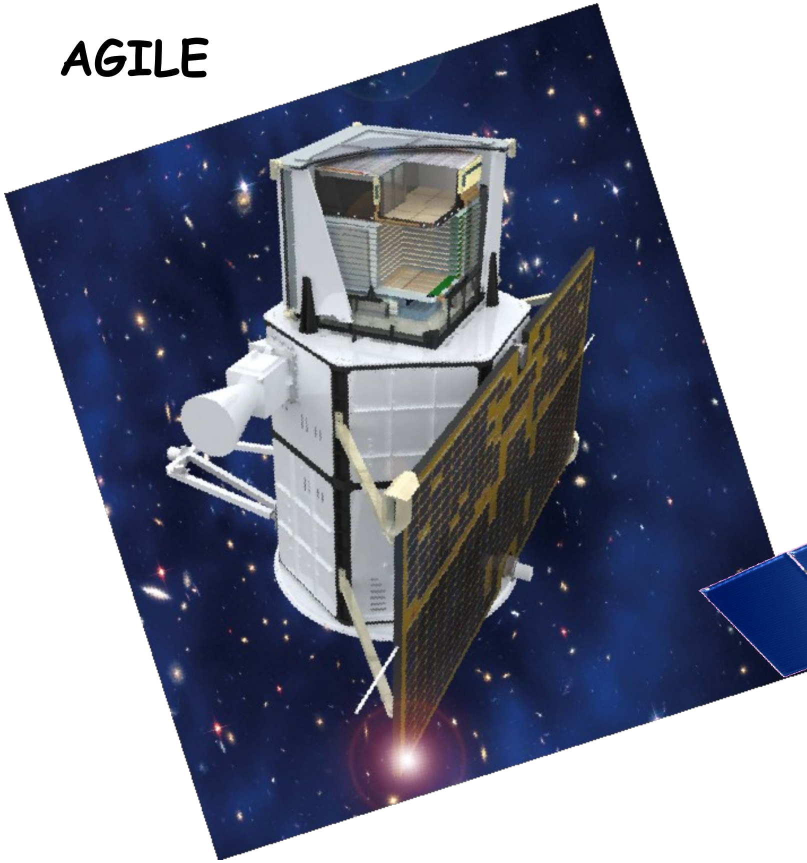
What do MW observations provide?

- View the same region via different emission mechanisms
- Broad band spectra and spectral evolution

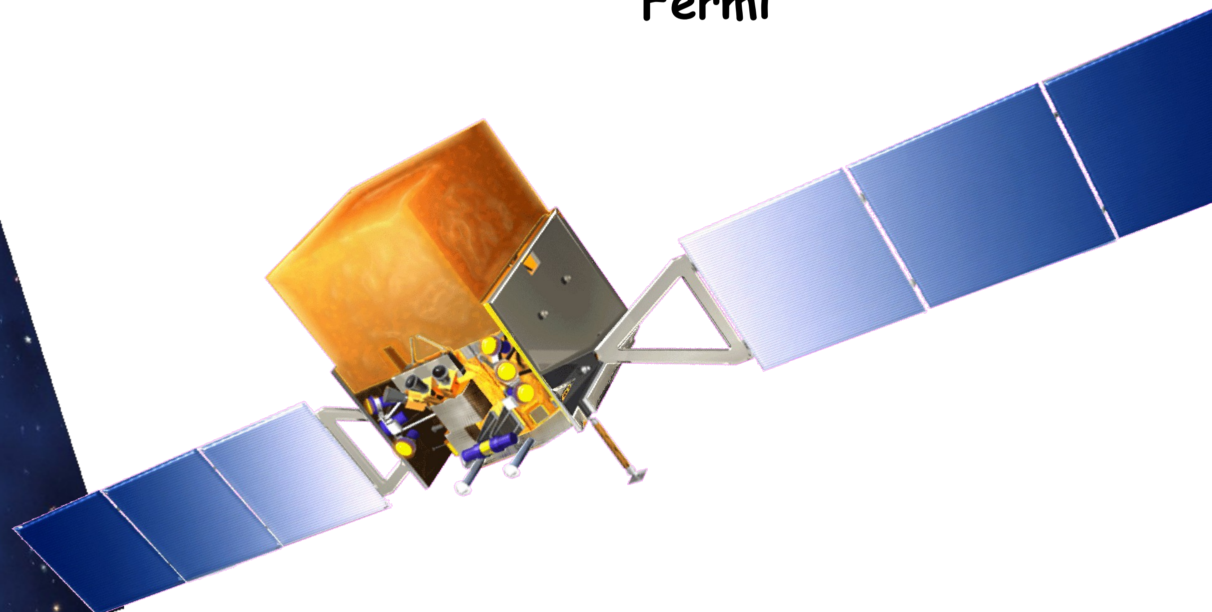
- However, MW observations provide much more….
- Spectroscopy
  - Abundances and conditions near the emission region
  - distance
- Polarimetry
  - explore magnetic fields
- Complementary capabilities
  - Spatial resolution - localization, morphology
  - Temporal resolution
- Timing - provide timing solutions for pulsars
- Source Identification - Guaranteed discovery!

GeV Gamma-ray Observatories

AGILE



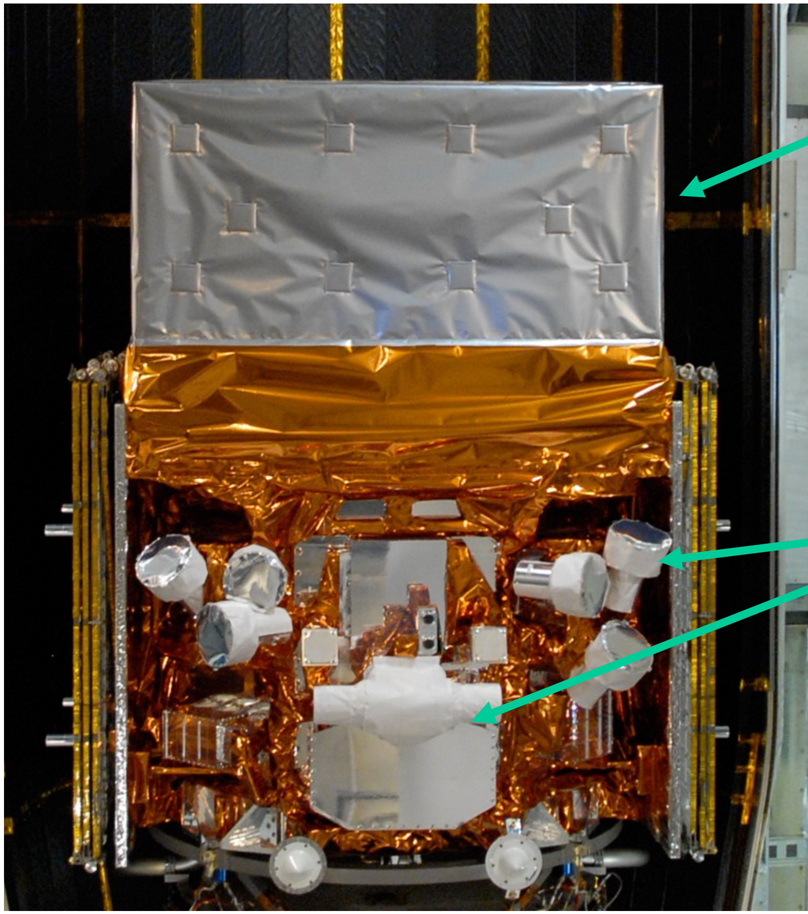
Fermi



- **30 MeV - 30 GeV**
- **2.5 sr FoV, pointed mode observations**
- **Effective area @ 1GeV ~1000 cm^2**

- 20 MeV - 300 GeV
- 2.5 sr FoV, survey mode (covers entire sky every 3 hours)
- Effective area @1 GeV ~8000cm^2

Fermi instruments



Large Area Telescope (LAT):

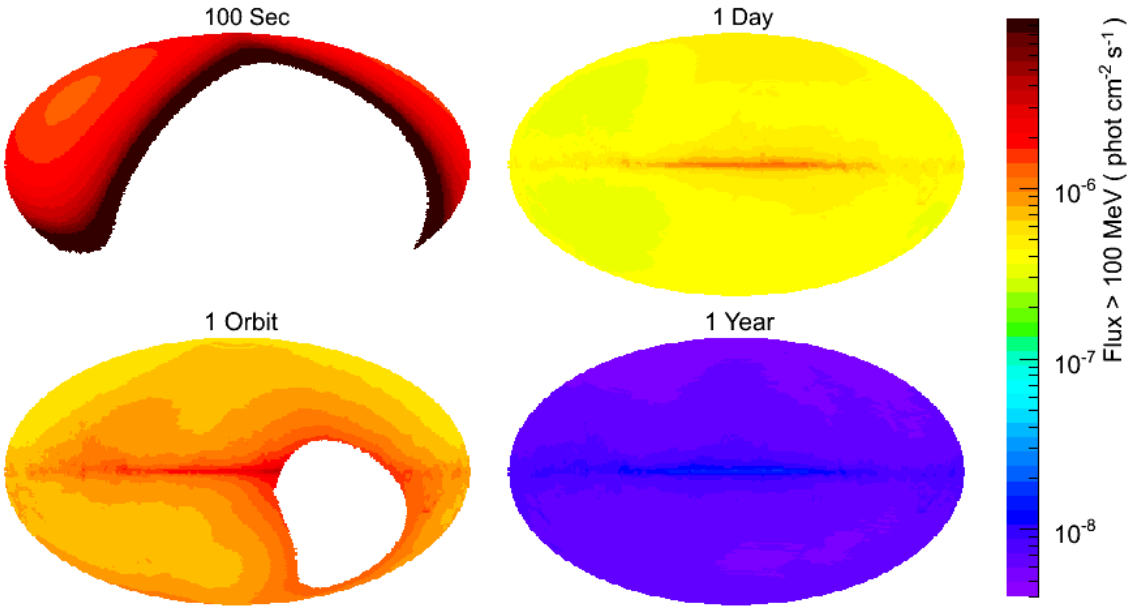
- 20 MeV - >300 GeV (including unexplored region 10-100 GeV)
- 2.4 sr FoV (scans entire sky every ~3hrs)

Gamma-ray Burst Monitor (GBM)

- 8 keV - 40 MeV
- views entire unocculted sky

- **Large leap in all key capabilities, transforming our knowledge of the gamma-ray universe. Great discovery potential.**

Operating modes

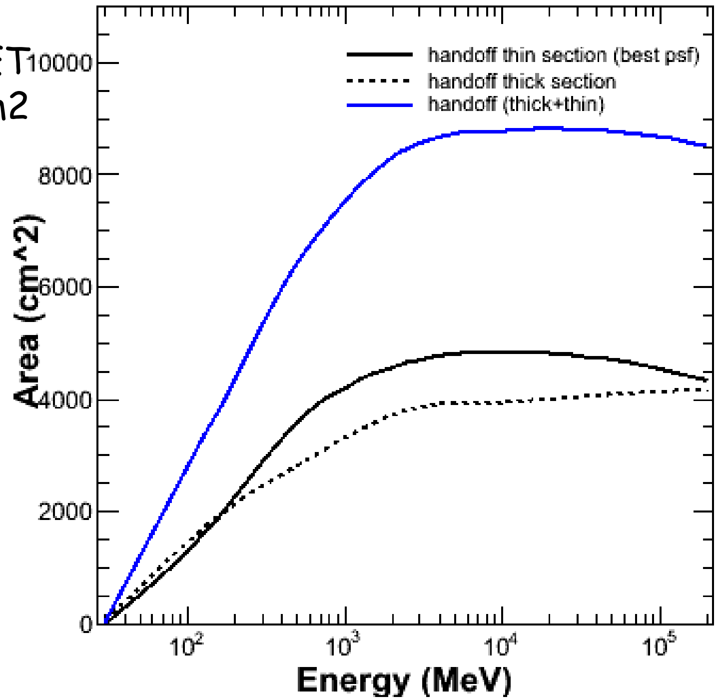


LAT sensitivity on 4 different timescales: 100 s, 1 orbit (96 mins), 1 day and 1 year

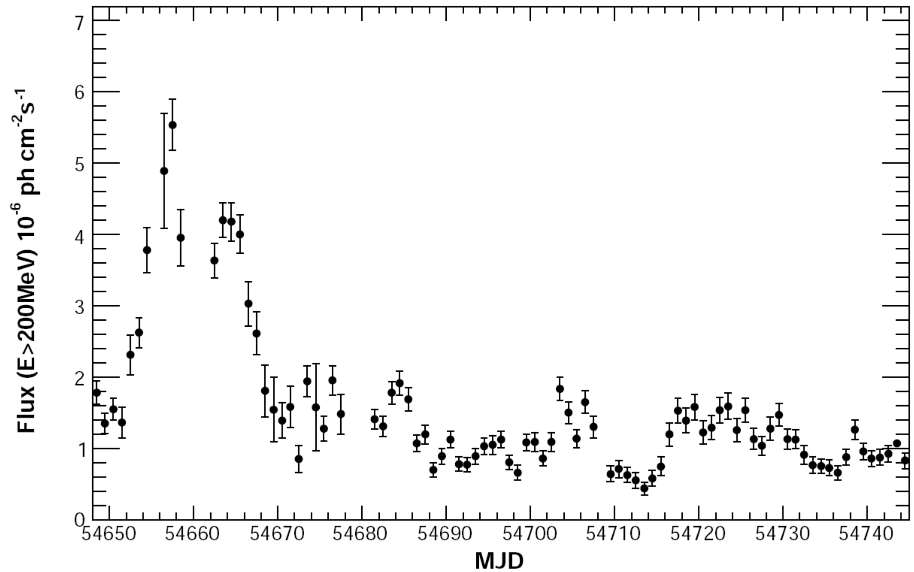
- In survey mode, the LAT observes the entire sky every two orbits (~3 hours), each point on the sky receives ~30 mins exposure during this time.
- GBM sees entire unocculted sky.
- Multiwavelength observations in coordination with the LAT will be limited only by the ability to coordinate to other observations in other wavebands.
- Can also perform pointed observations of particularly interesting regions of the sky.

LAT performance - effective area

c.f. EGRET ~1500 cm2

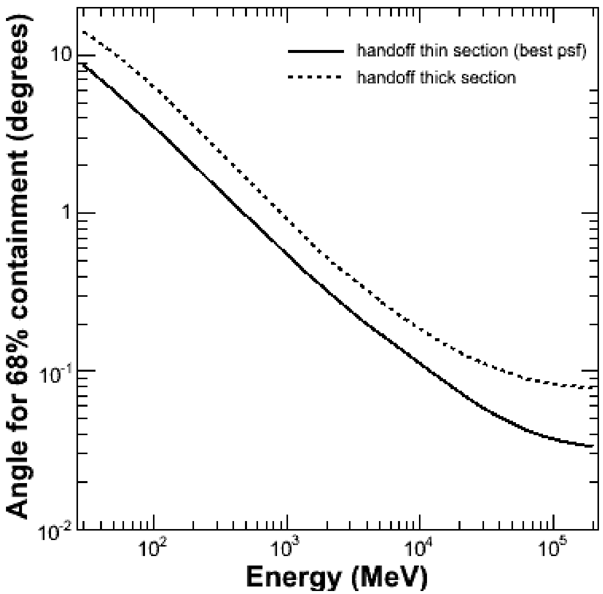


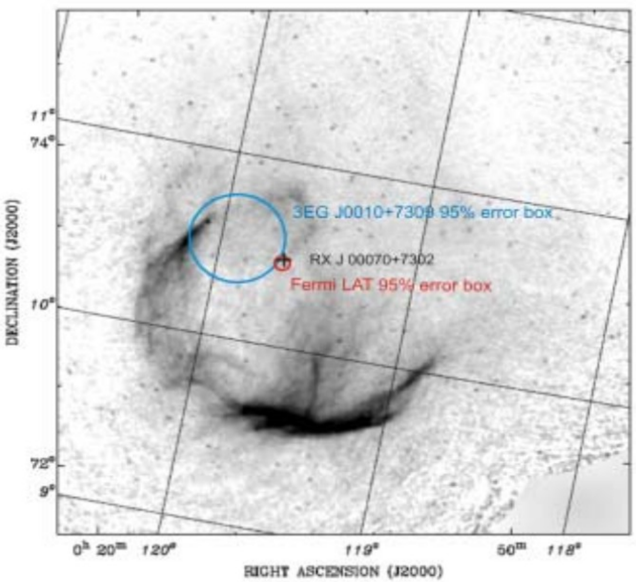
3C 454.3



- Large effective area means that more gamma-rays are detected by LAT for a given source brightness.
- 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



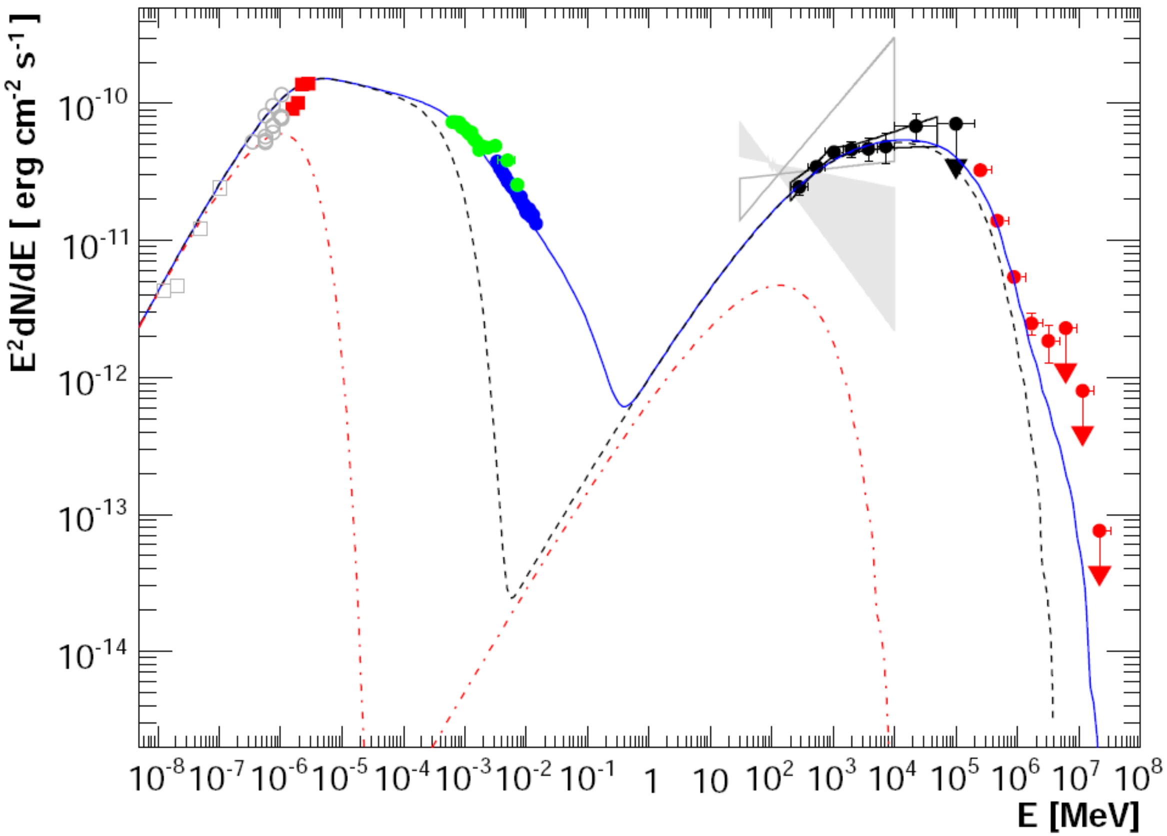


- Angular resolution rapidly improves with increasing energy.
- Improved sensitivity (less background); greatly improved source locations, reduced source confusion - particularly for hard spectrum sources.
- Source localizations 5-10's arcmin typically for bright catalog sources, 0.05-0.5 deg for transients - can follow up with MW observations.
  - Everything is better when we know where to look!

LAT Performance - Energy range

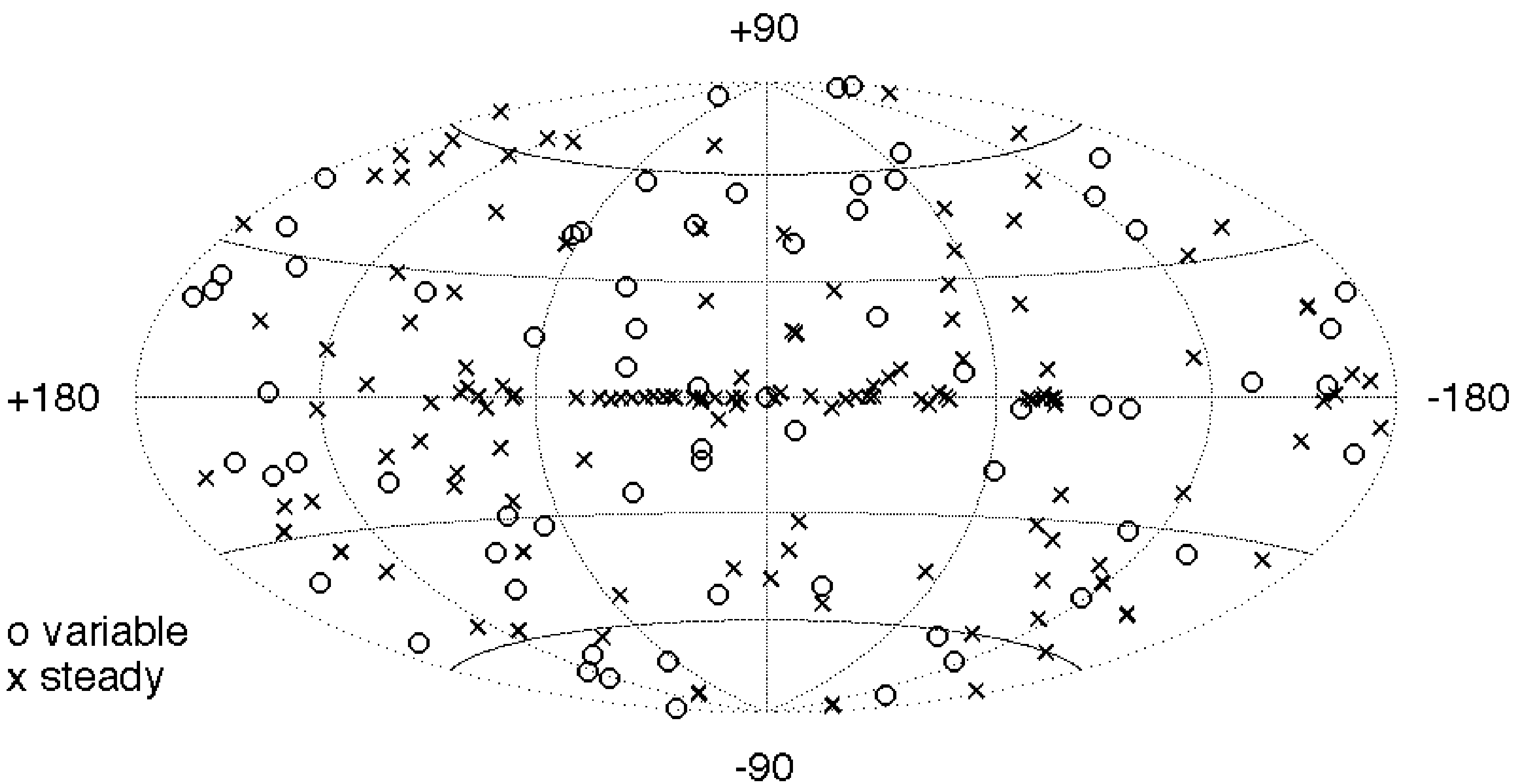
LAT energy range is very broad (20 MeV - 300 GeV), includes the largely unexplored range between 10 and 100 GeV

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



SED for PKS 2155-304

Variable sources in the LAT Bright Source List



- Based on 1 week time scales
- 68 show variability with probability > 99%
- Isotropic distribution ⇒ blazars

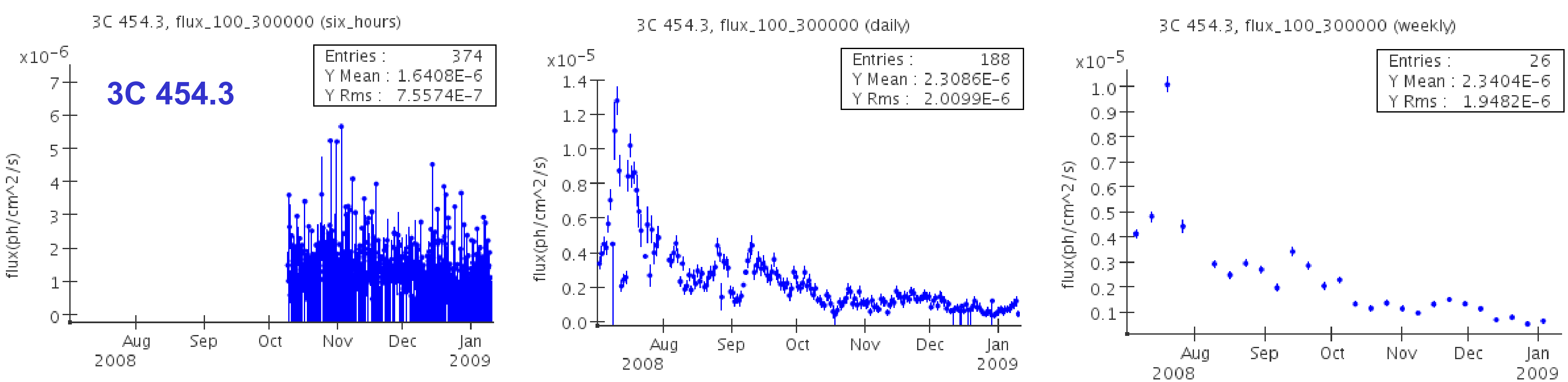
LAT Transient Searches

	Transient timescale	Localisation	Reporting timescale
Onboard GRB	Upto several seconds	~0.2-~1.0 deg	10-15 seconds, GCN
Ground GRB	Upto several minutes	~0.1-~0.5 deg	8-24 hours, GCN
Source Monitoring	6 hours - 1 week	~0.05 - ~0.5 deg	24-48 hours, ATel

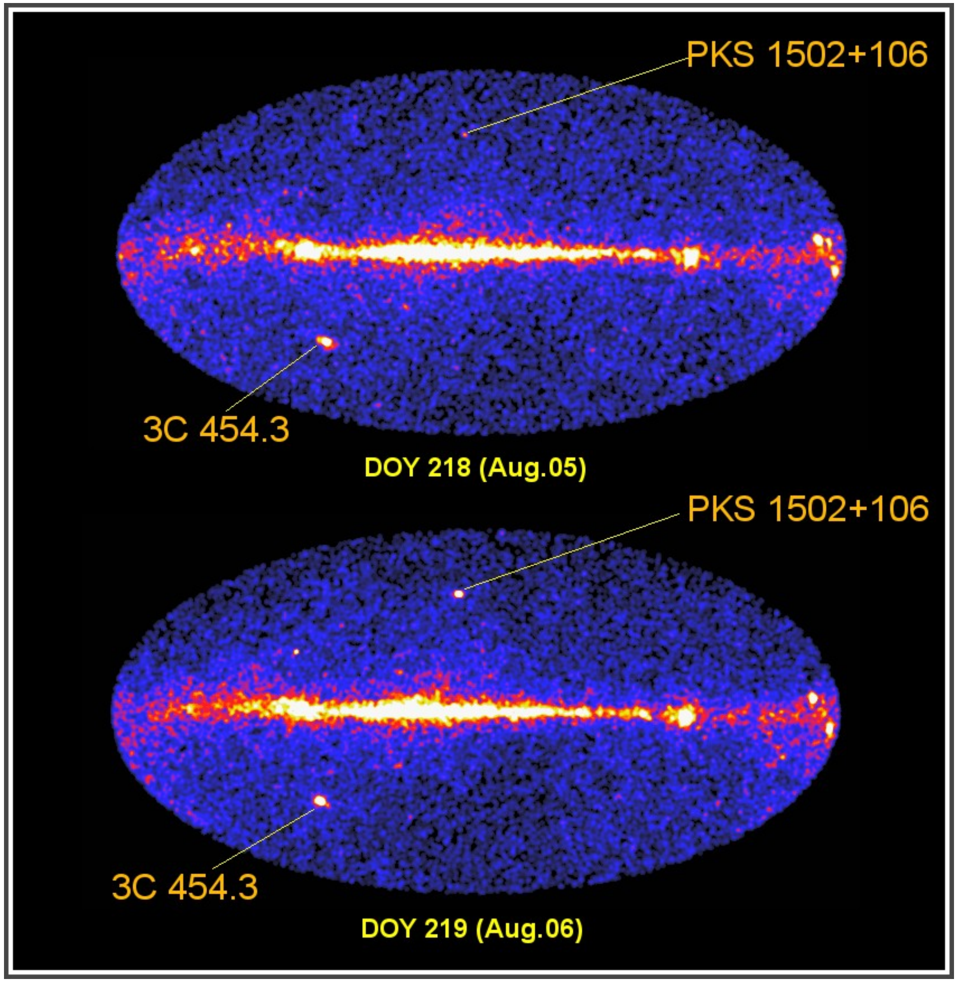
- **Typical transient localisations good enough to enable Swift XRT, VLA, Swift XRT, some optical follow up.**

Source Monitoring Activities

- Automated Science Processing (ASP)
  - Transient detection: Uses source detection (pgwave) to find all point sources in data from each epoch (6hr, day, week)
  - Follow-up monitoring: Runs full likelihood analysis on list from source detection step + "Data Release Plan" (DRP) sources
  - 1×10^{-6} ph cm^{-2} s^{-1} threshold (daily) for public release of non-DRP
- Flare Advocates:
  - LAT scientists from Galactic and Extragalactic groups examine output from ASP pipeline and perform follow-up analyses, produce ATels, and propose ToOs



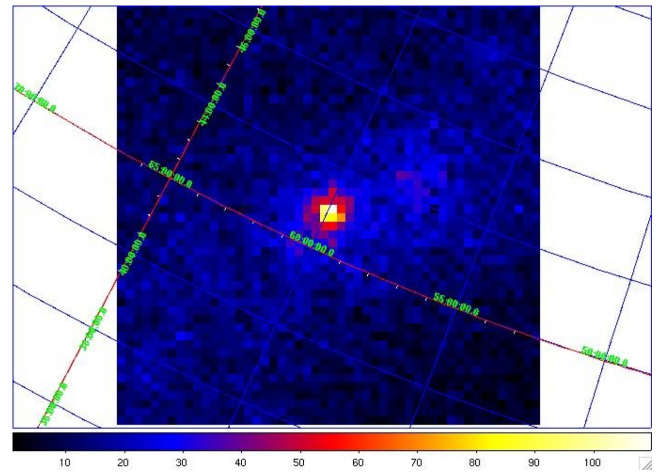
The flaring and variable sky

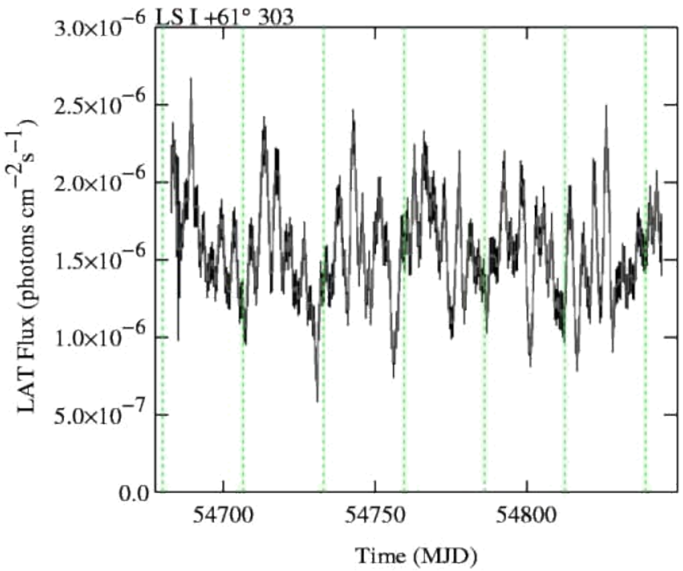


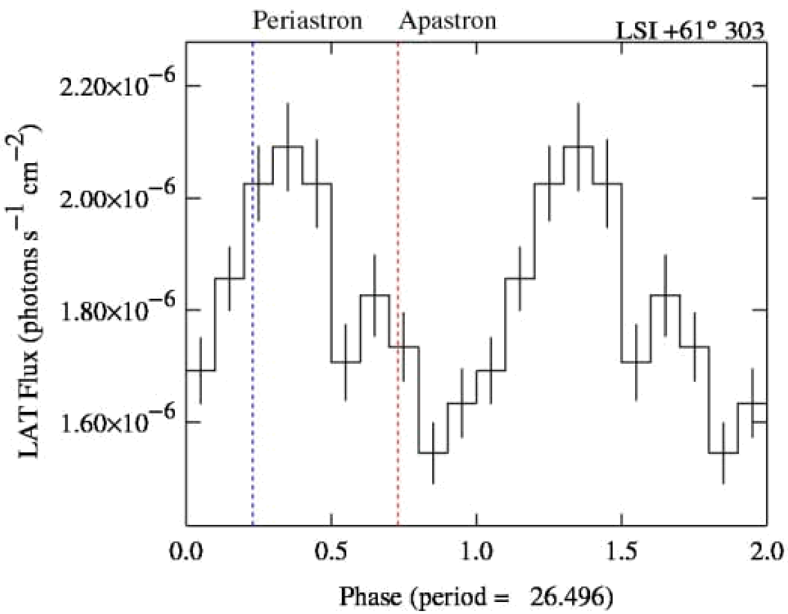
- >30 Astronomers telegrams
  - Discovery of new gamma-ray blazars PKS 1502+106, PKS 1454-354…
  - Flares from known gamma-ray blazars: 3C454.3, PKS 1510-089,3C273, AO 0235+164, PSK 0208-512, 3C66A, PKS 0537-441
  - Galactic plane transients: J0910-5041, 3EG J0903-3531, J1057-6027
  - Note: the reported position is usually that of the associated counterpart.

Fermi-LAT view of LSI +61 303

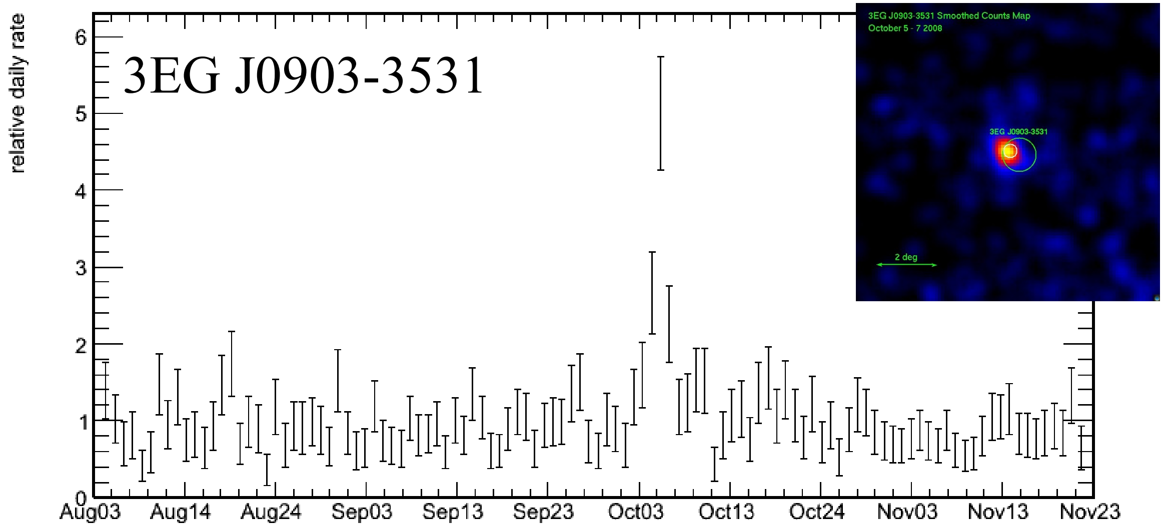
- LS I +61°303 has been fitted to R.A.=40.076, Dec.=61.233 with 95% error radius of 1.8'. This location is consistent with the known position of the optical counterpart.
- Flux variability is also clearly evident
- Detected periodicity in the LS I +61°303 light curve at 26.4±0.5 days
- Folded light curve indicates peaks of emission around periastron.

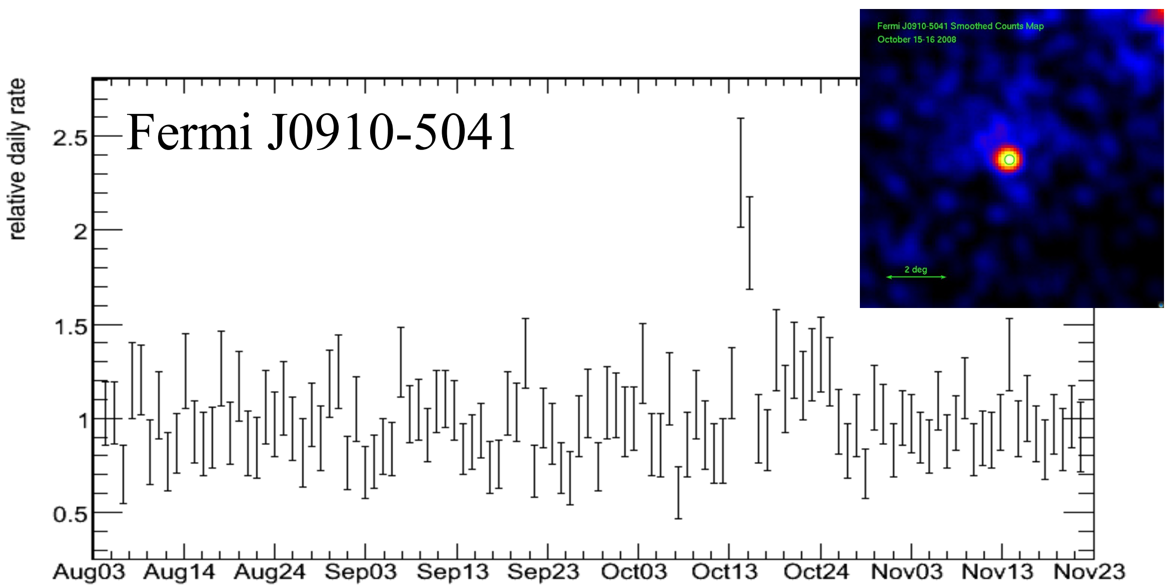






Two LAT Unidentified Transients





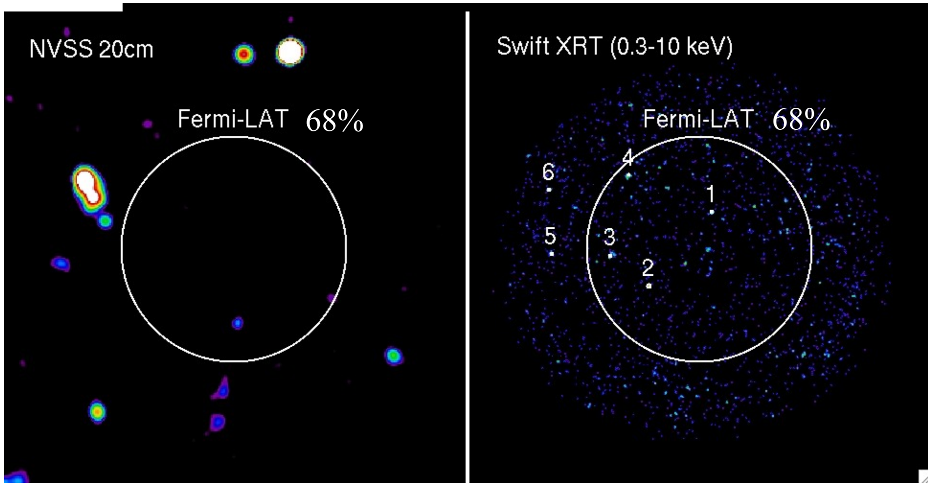
High confidence >10 sigma

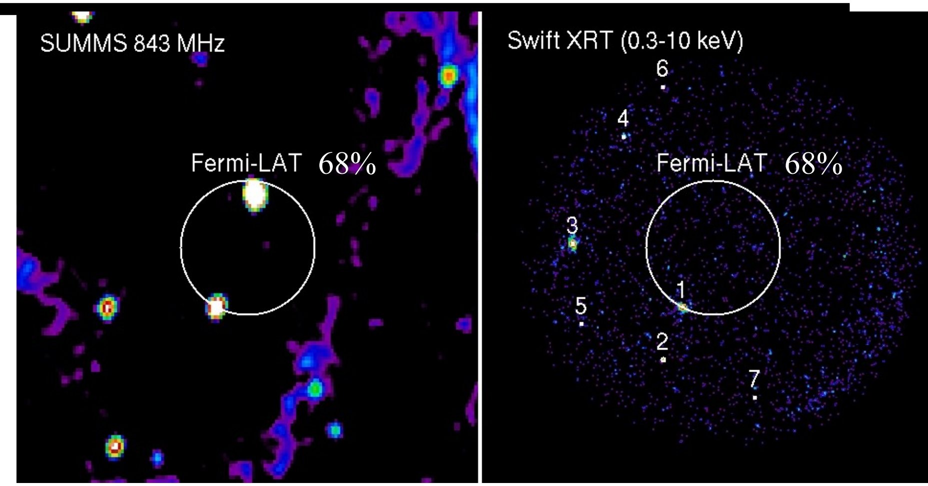
Preliminary 68% error circles 0.12 deg, 0.07 deg

Daily rates

- counts (E>200 MeV) within 2 deg radius
- exposure corrected
- scaled to background rate

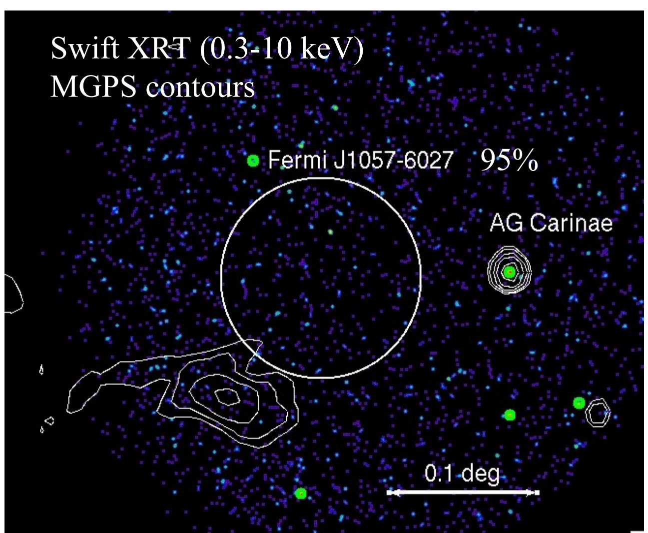
Multiwavelength Observations of LAT Transients in the Galactic Plane





3EG J0903-3531 (October 5, 2009)
- Brightened over 3 days
- 5x above 3EG flux

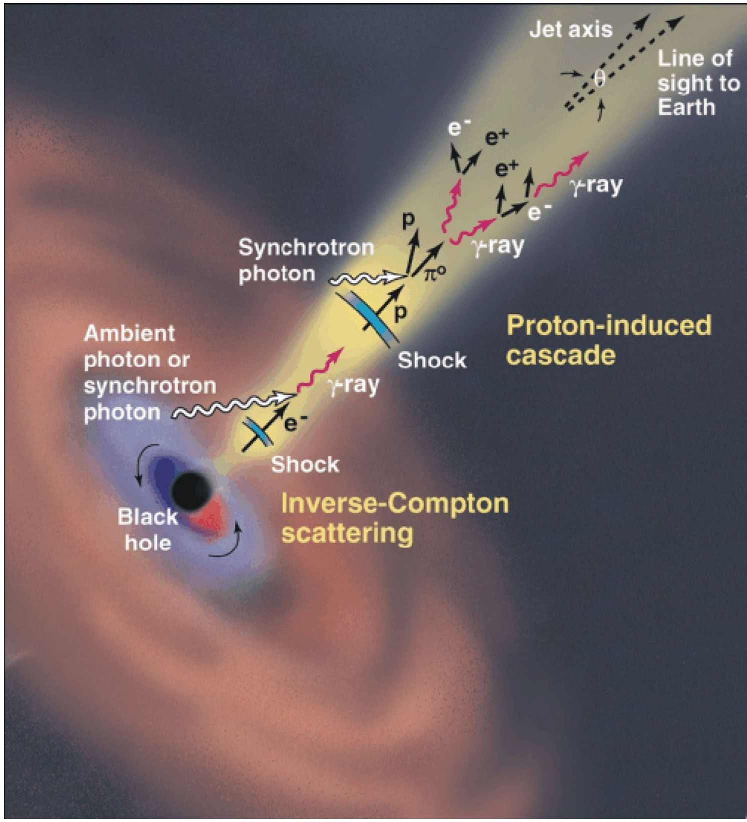
Fermi J0910-5041
(October 15, 2009)
- Brightened over 2 days
- XRT source plus SUMMS and AT20G candidate counterpart



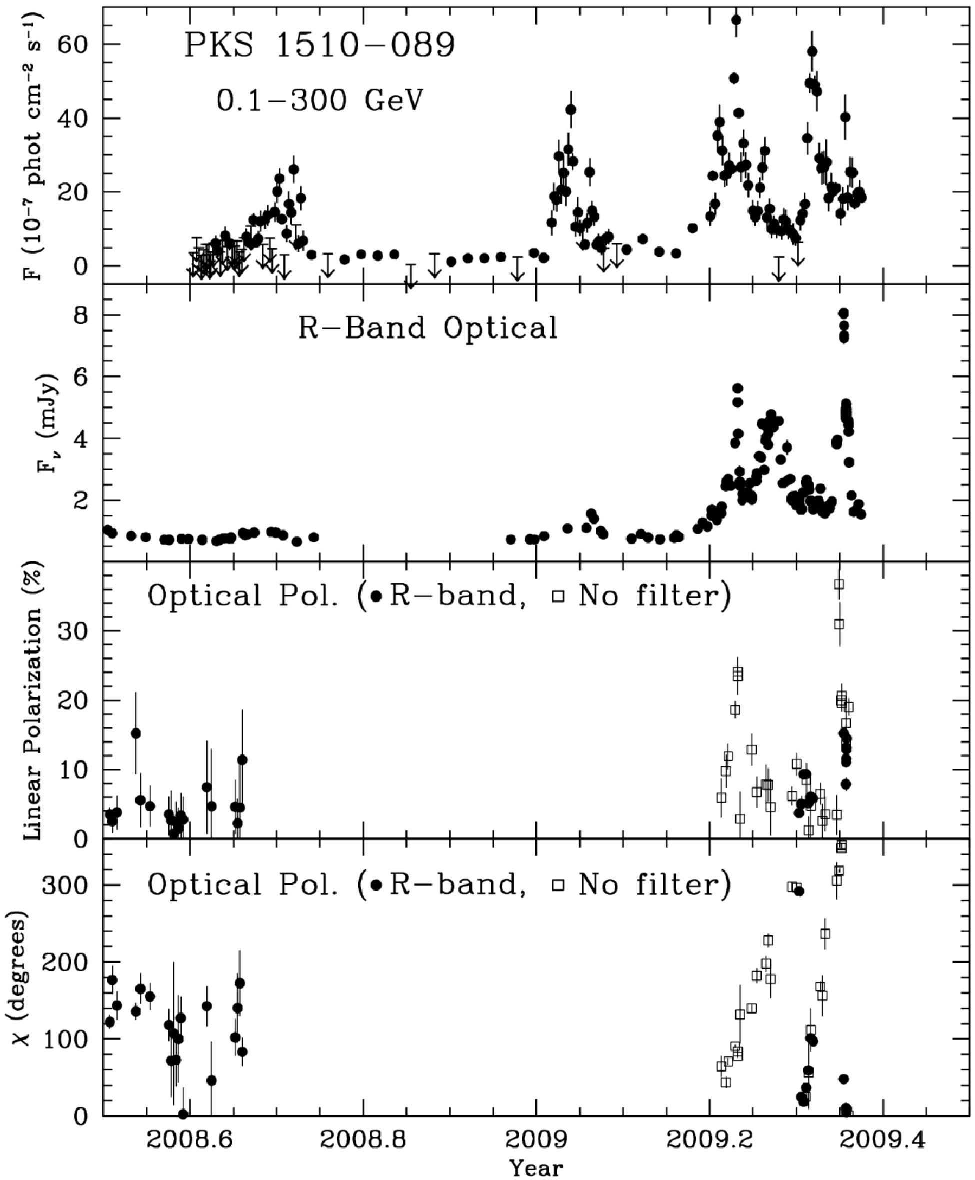
Fermi J1057-6027 (June 11, 2009)
- Brightened over 1 day
- Coincident with known LAT source
-10x above LAT flux

Gamma-ray bright AGN

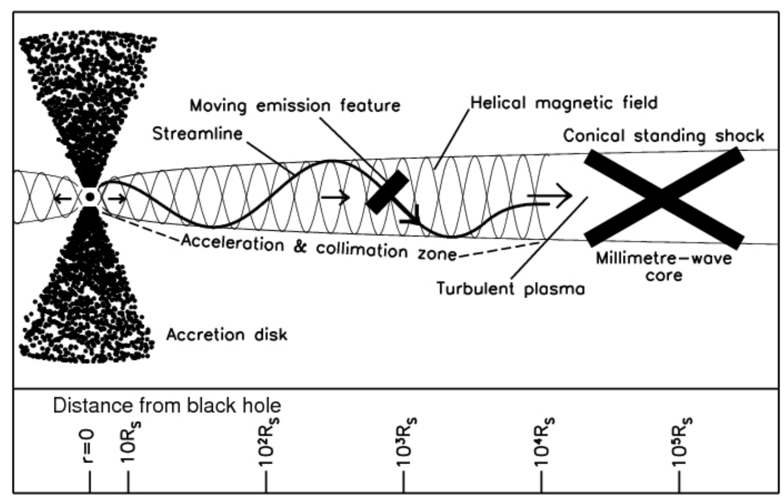
- Blazars dominated the extragalactic gamma-ray sky in the EGRET era
- Many key open questions
  - Emission mechanisms (especially for high energy component)
  - Emission location
  - Particle acceleration mechanisms
  - Jet composition
  - Jet confinement
  - Accretion disk—black hole—jet connection
  - Blazars as probes of the extragalactic background light (EBL)
  - Effect of blazar emission on host galaxies and galaxy clusters
- Which can be addressed by answering some observational questions
  - How does the emission in various bands behave during flares/outbursts?
  - How do the gamma-ray flares relate to the emergence of superluminal blobs?
  - And to the polarization properties?



PKS 1510-089 flux and optical polarization

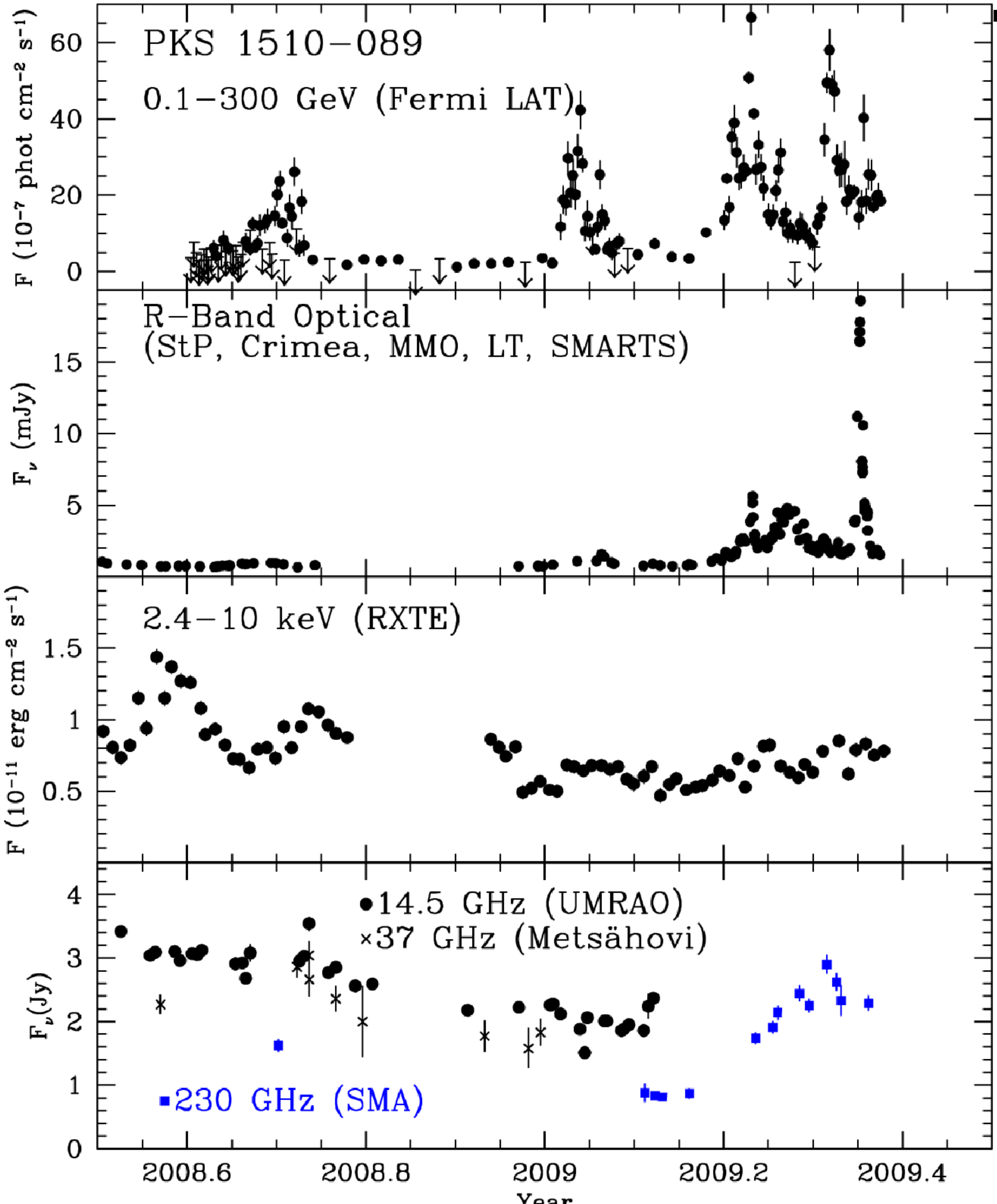


Rotation of polarization position angle of nearly 4pi during huge outburst.



Alan Marscher

PKS 1510-089 - multiwavelength fluxes



A puzzle - why is the X-ray so quiet in spring '09 while all the other wavebands are in strong outburst?

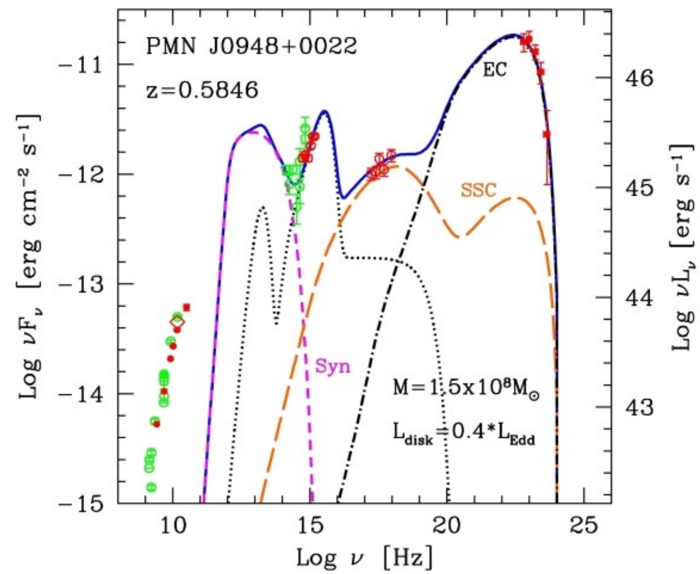
Continue radio observations of this object to look for the emergence of a radio "blob" associated with this outburst.

Narrow-Line Quasar PMN J0948+0022

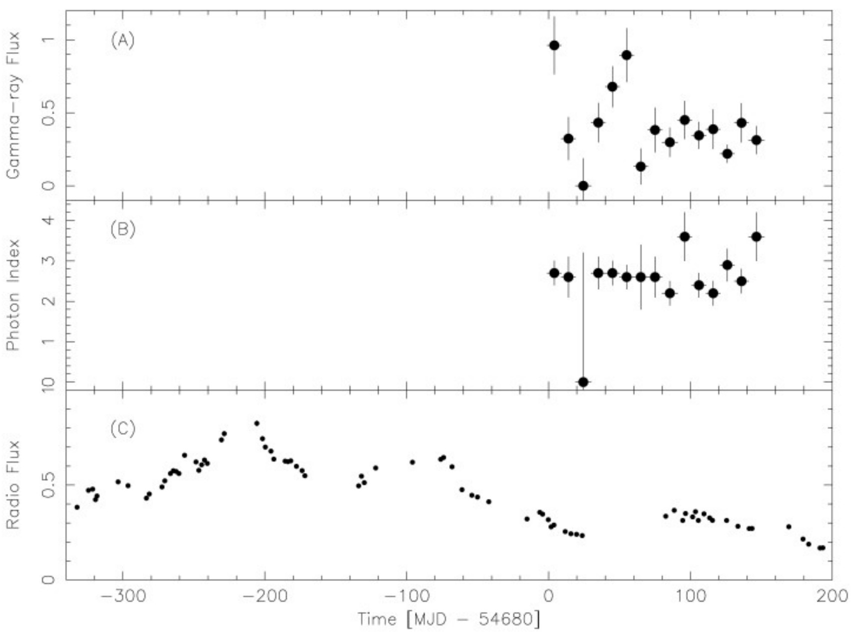
(Abdo et al., 2009, ApJ in press)

Optical spectrum of narrow-line Seyfert 1 type (usually radio quiet).

Radio emission is strongly variable and with flat spectrum -> suggests Doppler boosting, now confirmed by LAT.



First γ-ray detection of such an object



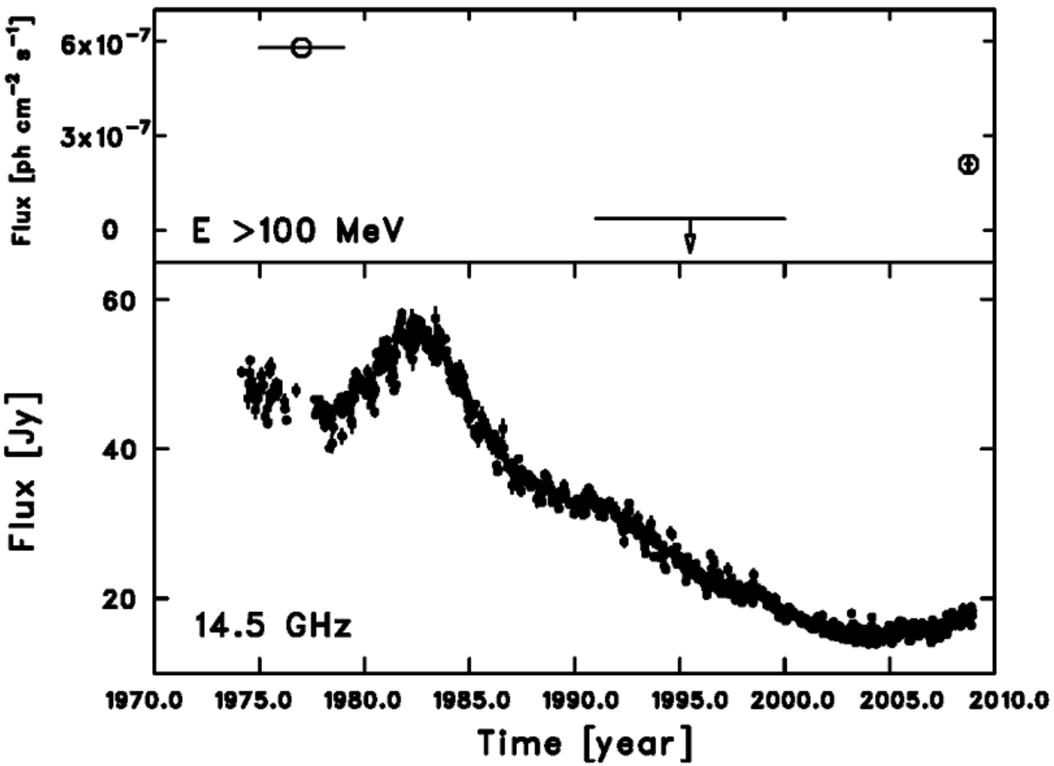
SED modeling shows this is a typical FSRQ, although with a relatively low power.

Many questions open:

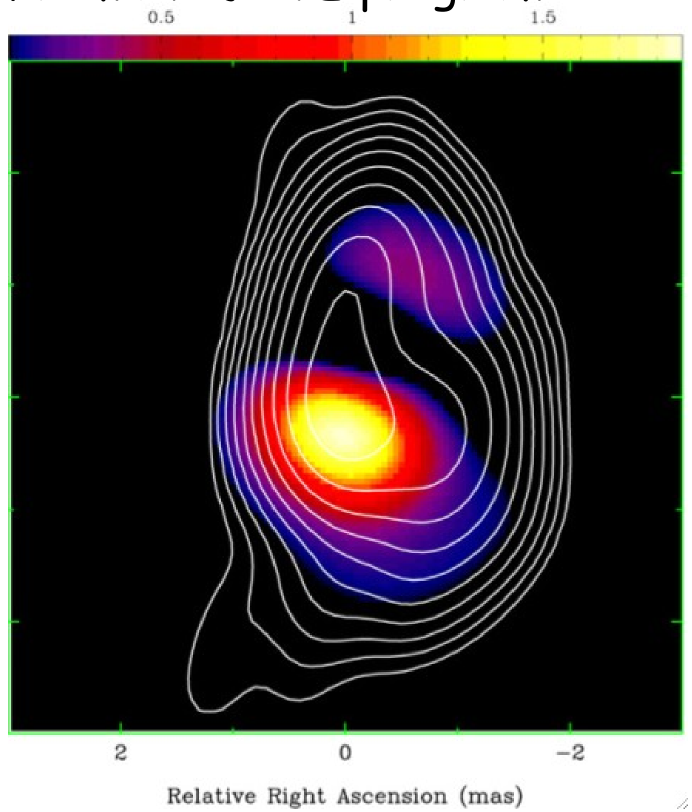
Is this a new type of γ-ray emitting AGN?
Are there other sources of this type?
What is the impact of narrow-lines?

(Contact authors:L. Foschini)

NGC1275: Long Term γ-ray variability & Correlation with Radio?



Contours: Aug '08 VLBA 15 GHz
Color: Sep '07 map subtracted
From MOJAVE program



- LAT flux 6x brighter than EGRET limit
- Historical COS-B detection while radio in high radio state
- Radio light curve rising during the Fermi observations with pc-scale outburst seen in MOJAVE maps

http://fermisky.blogspot.com/

FERMI GAMMA-RAY SKY

WEDNESDAY, JUNE 3, 2009

Fermi LAT Weekly Report N. 52

Covered period: 2009.May.25 - 2009.May.31

- Candidate blazar **4C31.03** (see ATel #2054) seen in day timescales with flux levels reaching 0.8e-6 ph/cm^2/s.
- **PKS 1510-089** remains in the 1e-6 to 2e-6 daily flux range (>100MeV)
- **PKS 1502+106** shows a steady trend with daily fluxes (>100MeV) around 1e-6 ph/cm^2/s.
- **3C 454.3** showed consistent daily flux levels (>100MeV) just below 1e-6 ph/cm^2/s.

LAT DATA

LAT Monitored Source List Light Curves

LAT Bright Source List

Browse interface to monitored source data

BLOG ARCHIVE

- ▼ 2009 (8)
  - ▼ June (1)
    - Fermi LAT Weekly Report N. 52
  - ▶ May (4)
  - ▶ April (3)

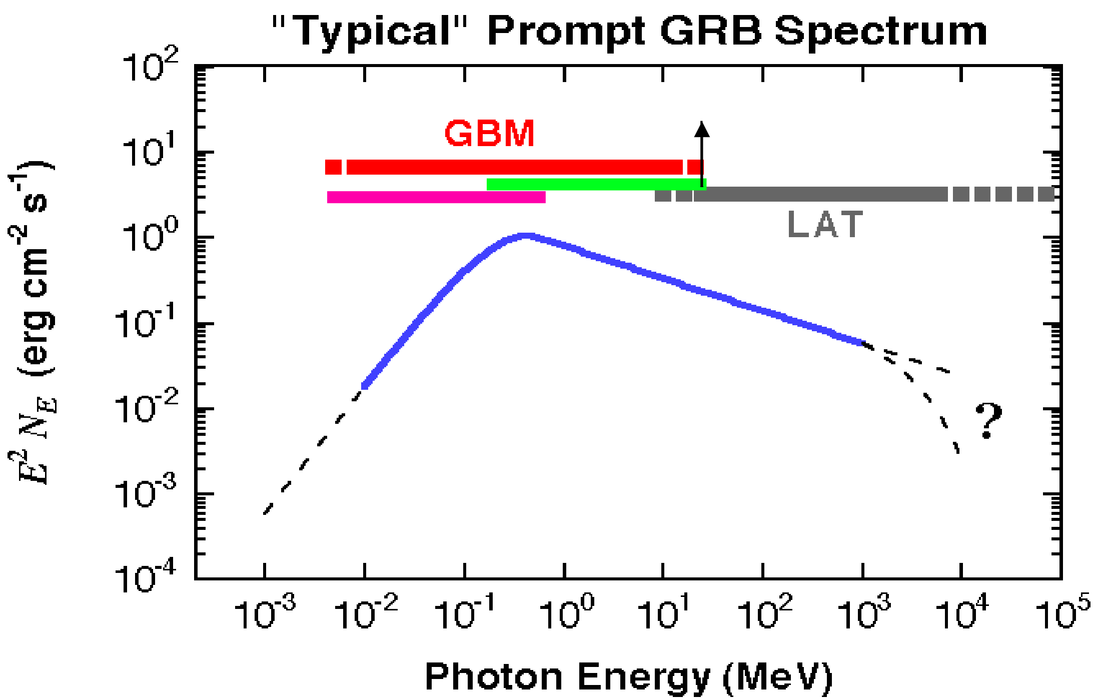
CONTRIBUTORS

Flare Advocate

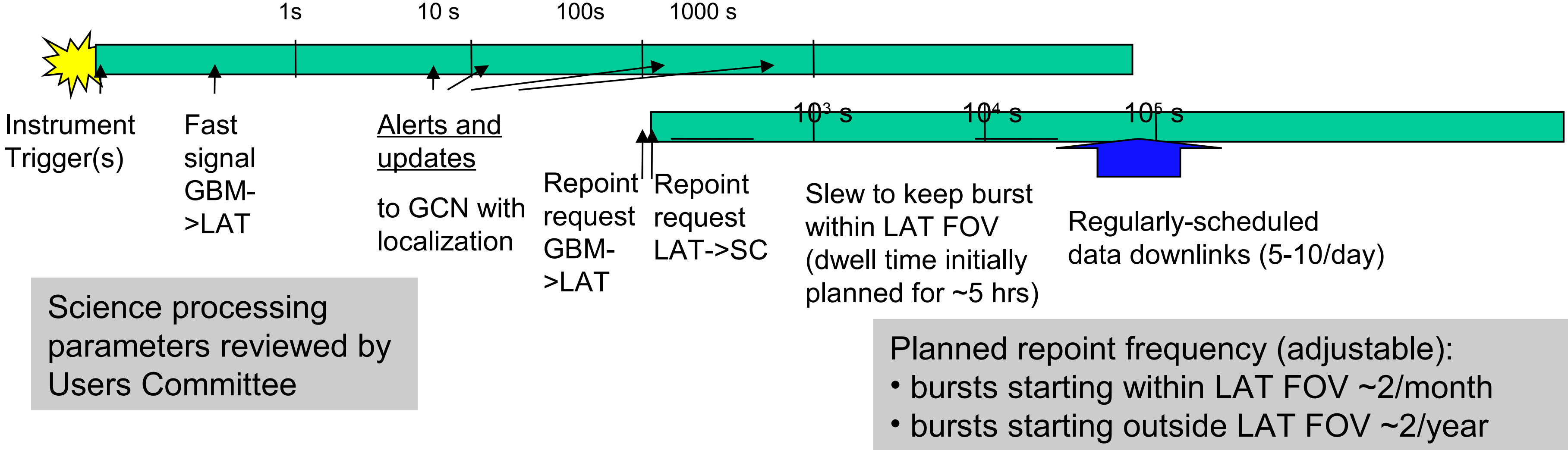
Fermi and GRB

- LAT: <20 MeV to >300 GeV. With both onboard and ground burst triggers.
- GBM: 12 NaI detectors— 8 keV to 1 MeV. Used for onboard trigger, onboard and ground localization, spectroscopy: 2 BGO detectors— 150 keV to 40 MeV. Used for spectroscopy.
- Total of >7 energy decades!
- ~250 GRB/year with observations from 8 keV to 30 MeV, ~80 GRB/year with observations from 8 keV to 300 GeV (# high energy detections is less than this)

Exceptionally good spectral observations of the prompt phase of lots of GRB

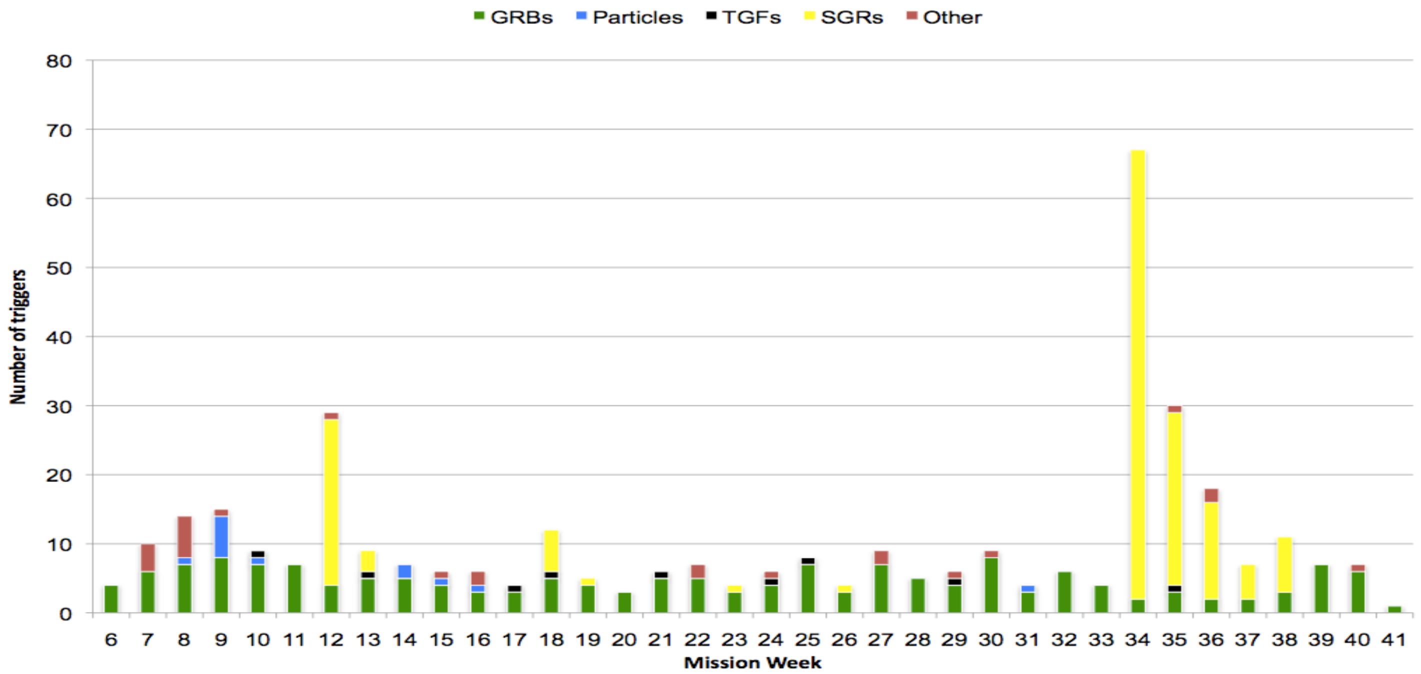


Alerts and Data Flow



- Onboard processing (both LAT and GBM) - GCN alerts: location, intensity (cnts), hardness ratio, trigger classification etc
- LAT ground processing (5-24 hours): updated location, high energy spectrum, flux (or upper limit), afterglow search results
- Final ground processing (24-48 hours): GBM model fit (spectral parameters, flux, fluence), joint LAT-GBM model fit, raw GBM data available. Year 2 and beyond - LAT count data available.

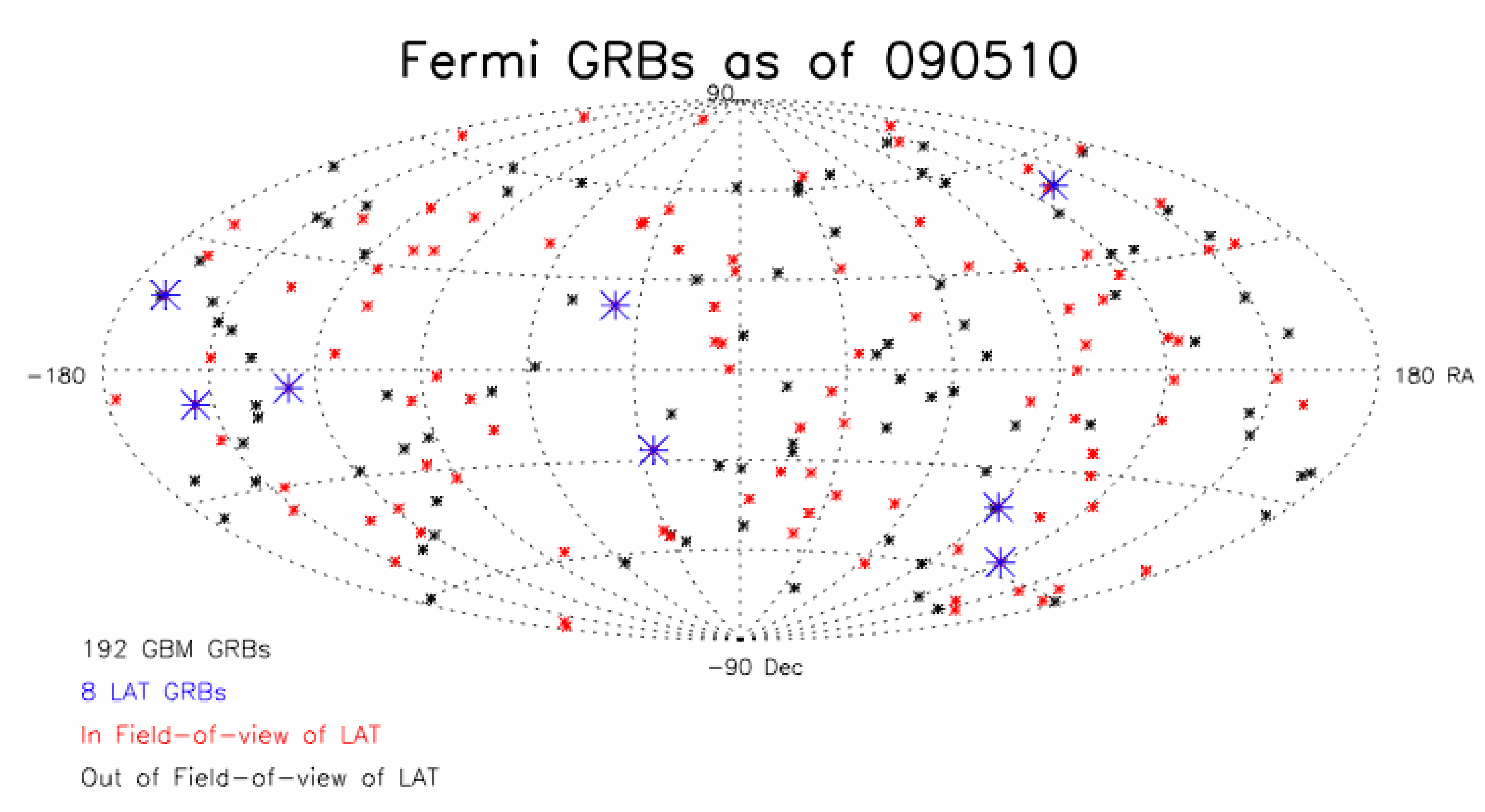
Gamma-ray Burst Monitor



- Since July 2008, GBM has detected over 190 GRB (250/year c.f. 200/year predicted)

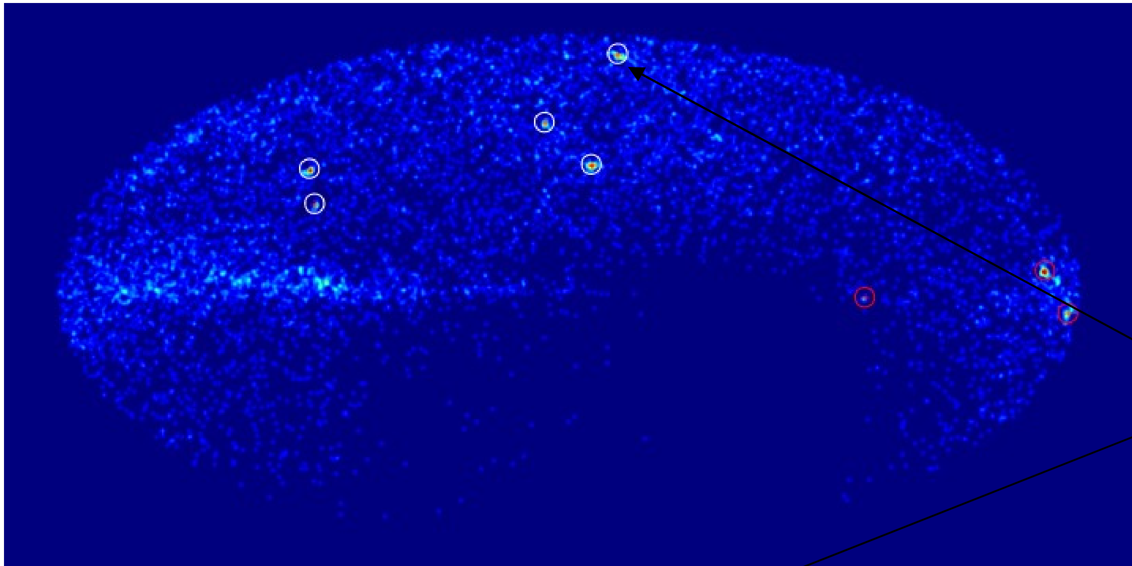
- Also sees four SGRs (SGR 0501+4516, SGR 1806-20, SGR 0418+5729 and SGR 1E1547.0-5408), >10 TGFs and a solar flare.

Gamma-Ray Bursts at High Energies



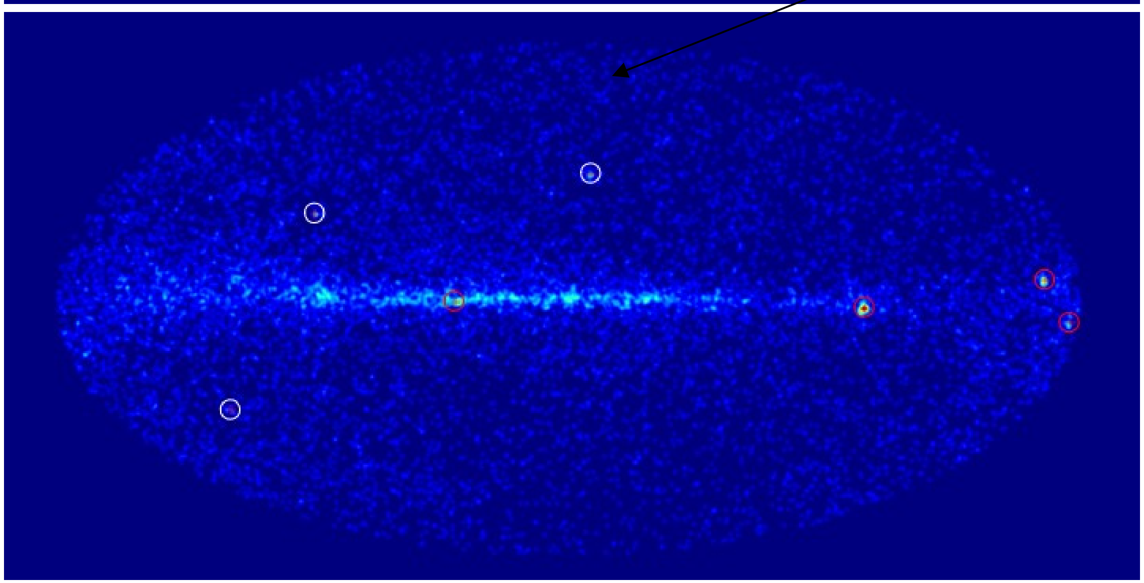
- Swift XRT has detected X-ray afterglows from the 4 brightest LAT bursts, each of these detections has ultimately resulted in the determination of the burst redshift/distance.

GRB 090323 clearly seen in LAT 6 hour automatic search



March 23 00:00:00 - 06:00:00

Burst location: ra, dec 190.69, 17.08 +- 0.09 (68%, stat) reported to the community via GCN circular



March 23 06:00:00 - 12:00:00

Neither GRB 090323 nor GRB 090328 were found in the short GRB searches, but both were detected in the six hour source monitoring runs.

GRB 090323 Afterglow observations

- On March 23 19:27 UT, Swift made observations at the LAT location and found an uncataloged X-ray point source at: ra, dec 190.70940, 17.05390 +- 2.7 arcseconds
- On March 24, 02:50 UT, GROND made optical observations and refined the location to within 0.5 arcseconds, they reported the redshift to be z=4.0 +-0.4
- Mar 24 04:20 UT, P60 optical observations confirm the afterglow.
- March 24 05:58 UT, Gemini south measure a spectroscopic redshift of 3.6
- Many observatories are continued to measure the afterglow at optical, x-ray and radio bands.

GRB080916C - Bright LAT burst

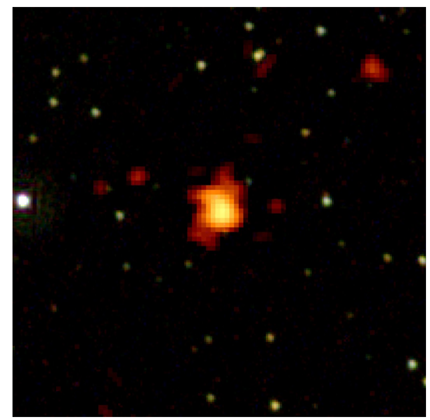
- At 00:12:45 UT (T_0) on 16 September 2008: The GBM flight software triggered on GRB 080916C
  - Large signal recorded in 9 NaI and 1 BGO detectors

LAT

QuickTime™ and a Animation decompressor are needed to see this picture.

- GBM on-ground analysis [GCN 8245]
  - T_{90}=66 s (50-300 keV), several peaks

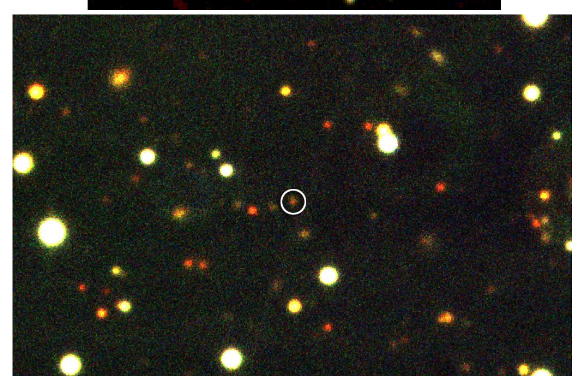
- LAT on-ground position [GCN 8246]
  - Good enough location to enable Swift observations
  - Fluence 10 keV - 10 GeV: 2.4 x 10-4 erg/cm^2



Swift (X-ray)

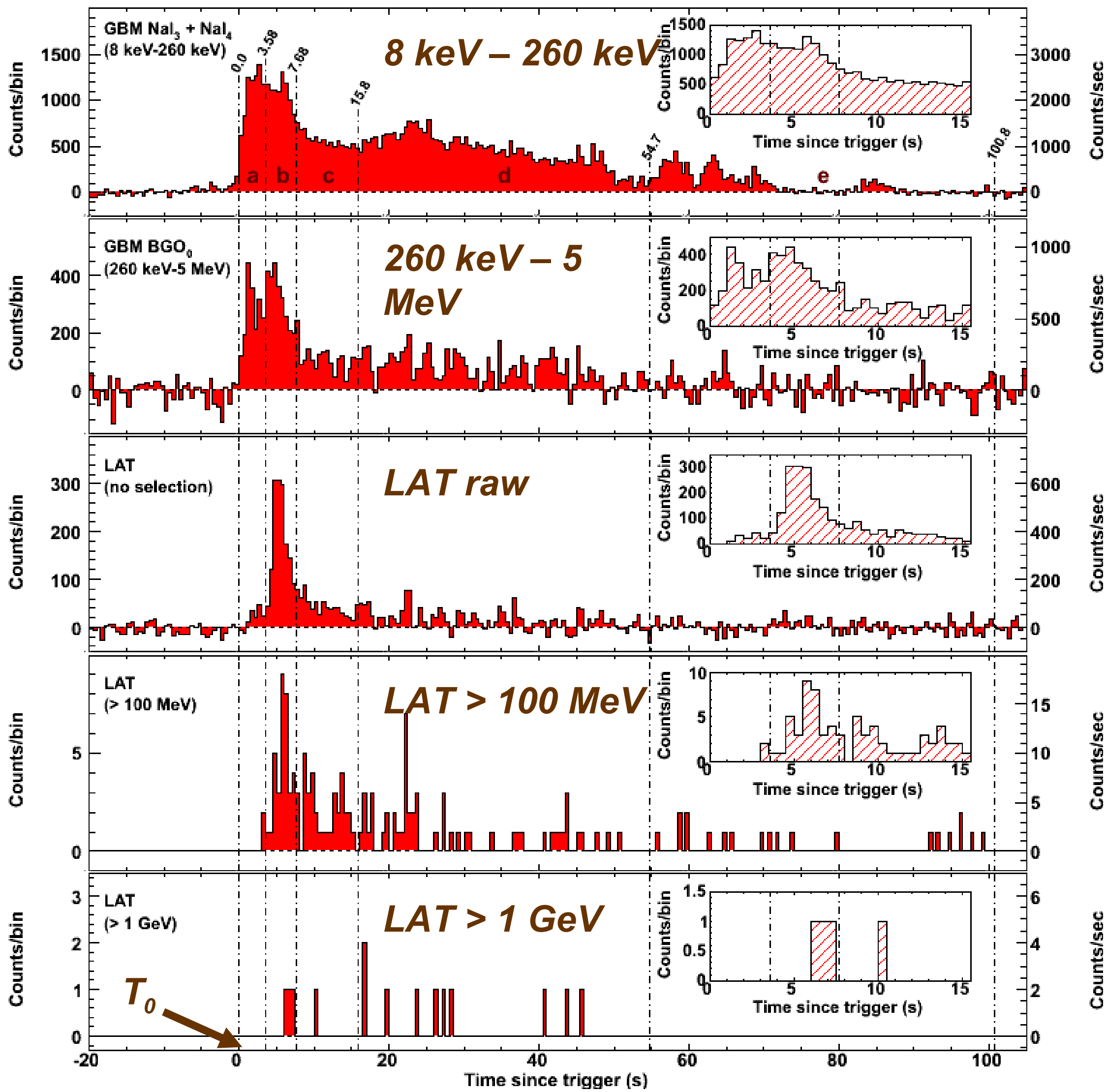
- Swift/XRT follow up after T_0+17h [GCN 8261]
  - Accurate location

- GROND optical follow up T+31h [GCN 8257, 8272]
  - Distance/redshift measurement
  - Redshift of z=4.35 +/- 0.3



GROND (Optical)

GRB 080916C



For a few hundred seconds was by far the brightest object in the gamma-ray sky.

>100 MeV emission started a few seconds later than the GBM trigger.

High energy spectra consistent with a band function (smoothly broken power law) across 7 decades of energy.

What does it all mean?

- All spectra fit with a band function
  - single emission mechanism over 7 decades in energy.
- No cutoff or softening
  - Implies that the bulk Lorentz factor is very high (to allow the high energy gammas to escape).

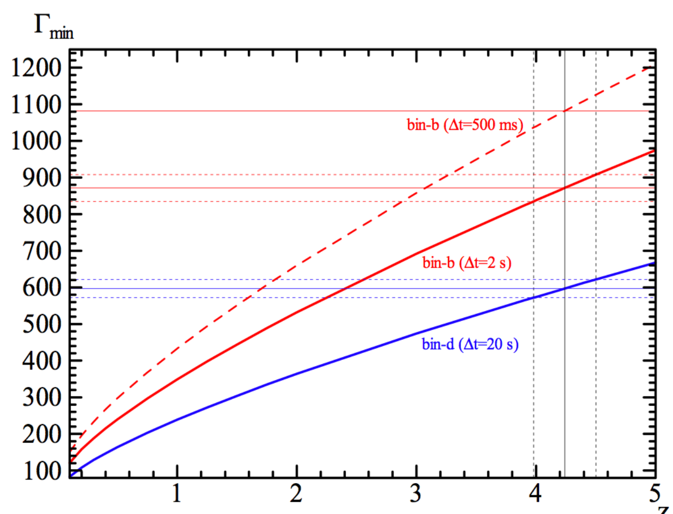
    $\forall\ \Gamma_{min}$ ~887 +/-22 (bin b)
- GRB Energetics:
  - Fluence (10 keV - 10 GeV) ~ 2.4 x 10^{-4} ergs.cm^{-2} & z~4.35:

    ➔ E_{iso}~8.8x10^{54} ergs! - Strongly suggest narrow jet collimation
- 5 second delay between onset of GeV emission w.r.t. the MeV emission
  - First and second peaks might originate in spatially distinct regions (with different physical conditions).

Γ_{min} ~887 +/-22 (bin b)

Γ_{min} ~608 (bin d)

Most relativistic GRB!



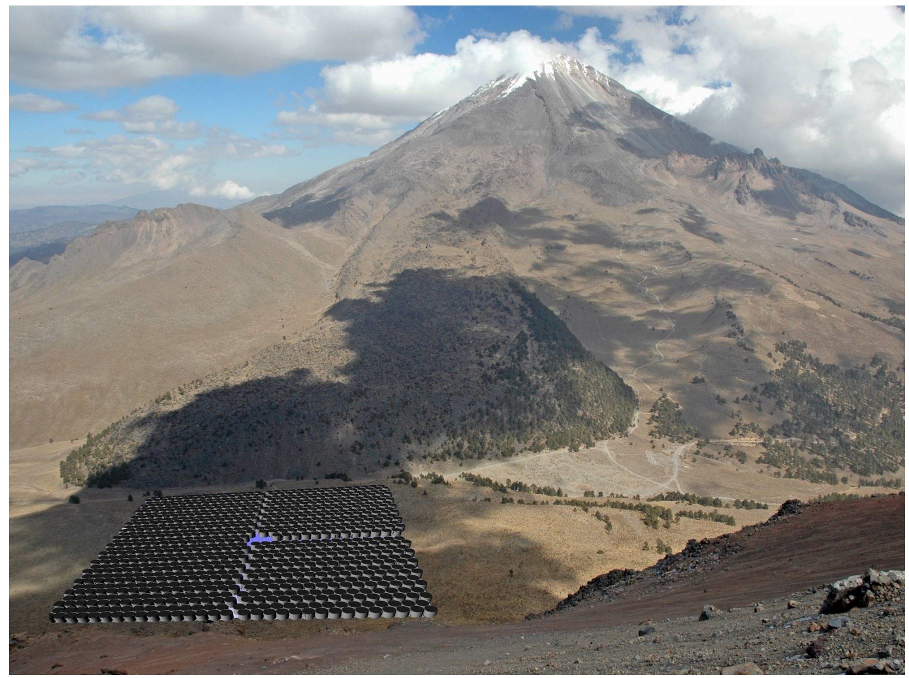
Want to know more about Fermi?

- Fermi symposium
  - Washington DC, Nov 2-5
- http://fermi.gsfc.nasa.gov/s
  - General news
  - Multiwavelength
  - Data/software

The Future at TeV Energies

In addition to continuing GeV observations by Fermi and AGILE, new wide-field TeV instruments are coming online.

ARGO (currently online)
4300m asl (YBJ, Tibet)
RPC carpet
10-15σ /$\sqrt{}$year on Crab



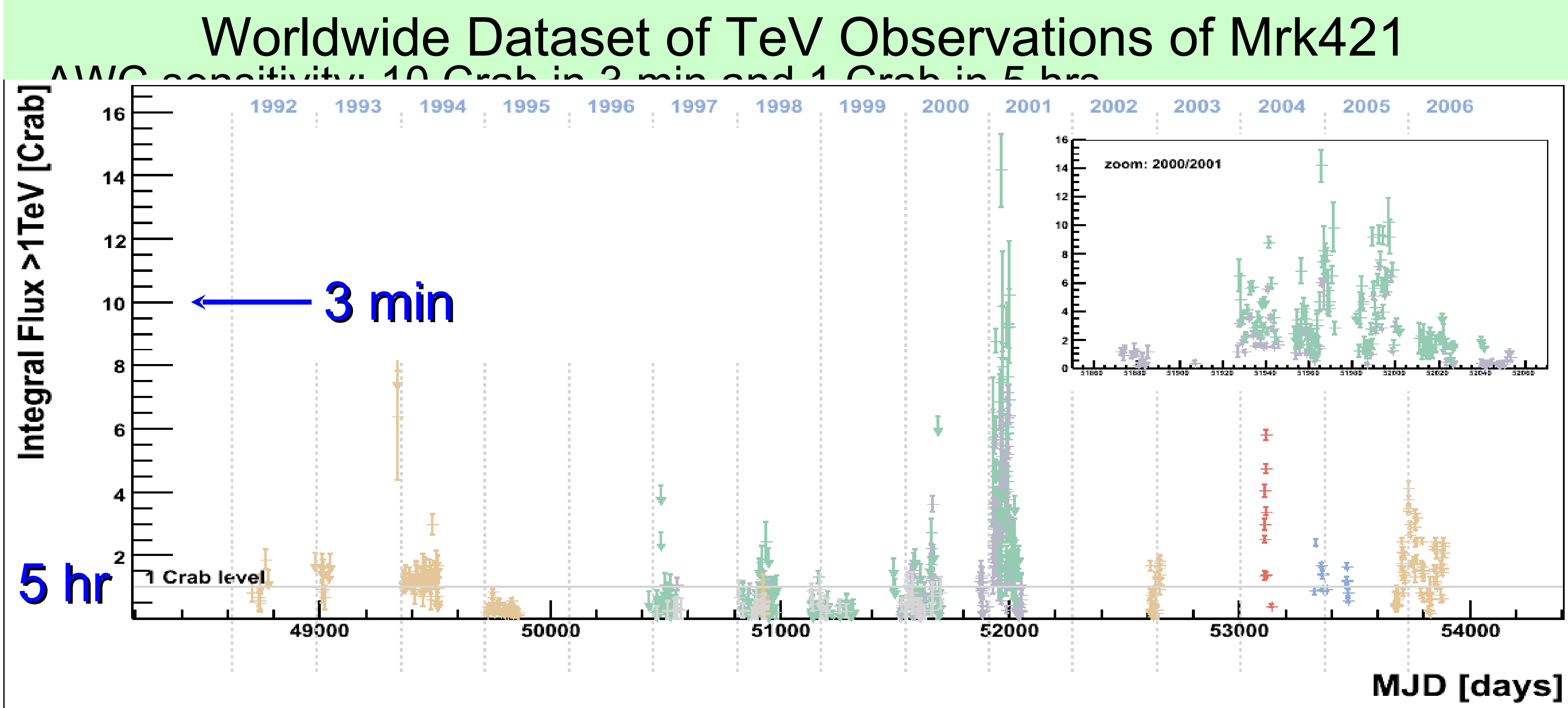
HAWC (proposal submitted)
>4100m asl (Tibet or Mexico)
Water Cherenkov
100 σ /$\sqrt{}$year on Crab

Transient Phenomena: AGN Flares

AWC will obtain TeV duty factors, search for orphan flares, & notify other observers in real time.

ll sources within ~2 π sr would be observed every day for ~ 5 hrs.

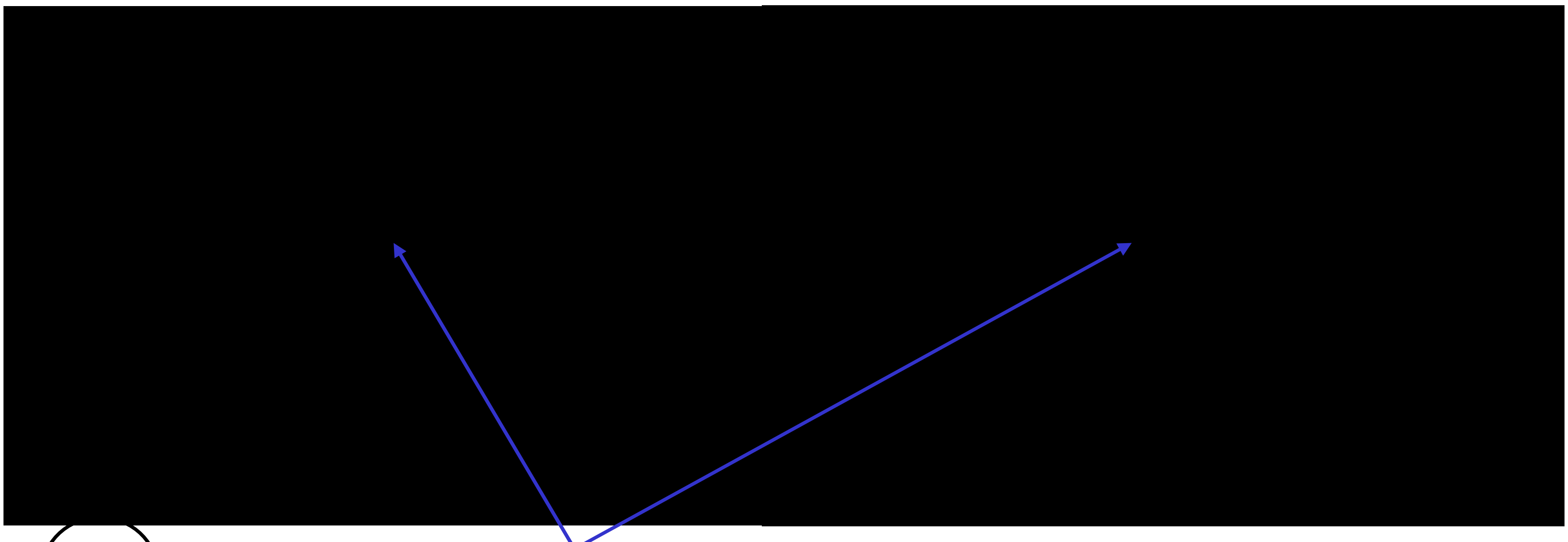
AWC sensitivity: 10 Crab in 3 min and 1 Crab in 5 hrs



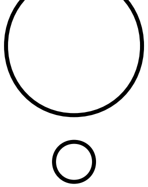
Solar system objects

- 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.

The Sun The Moon



Size of Sun/Moon on the sky



PSF at 1 GeV

PSF at 10 GeV

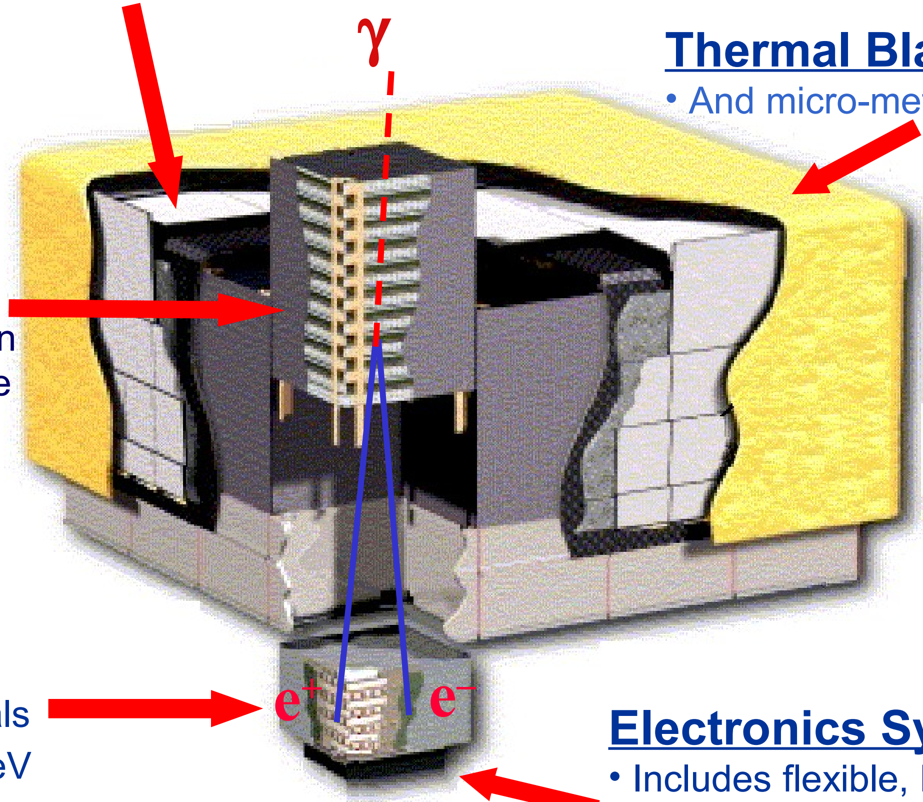
Fermi LAT Overview: Overall Design

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

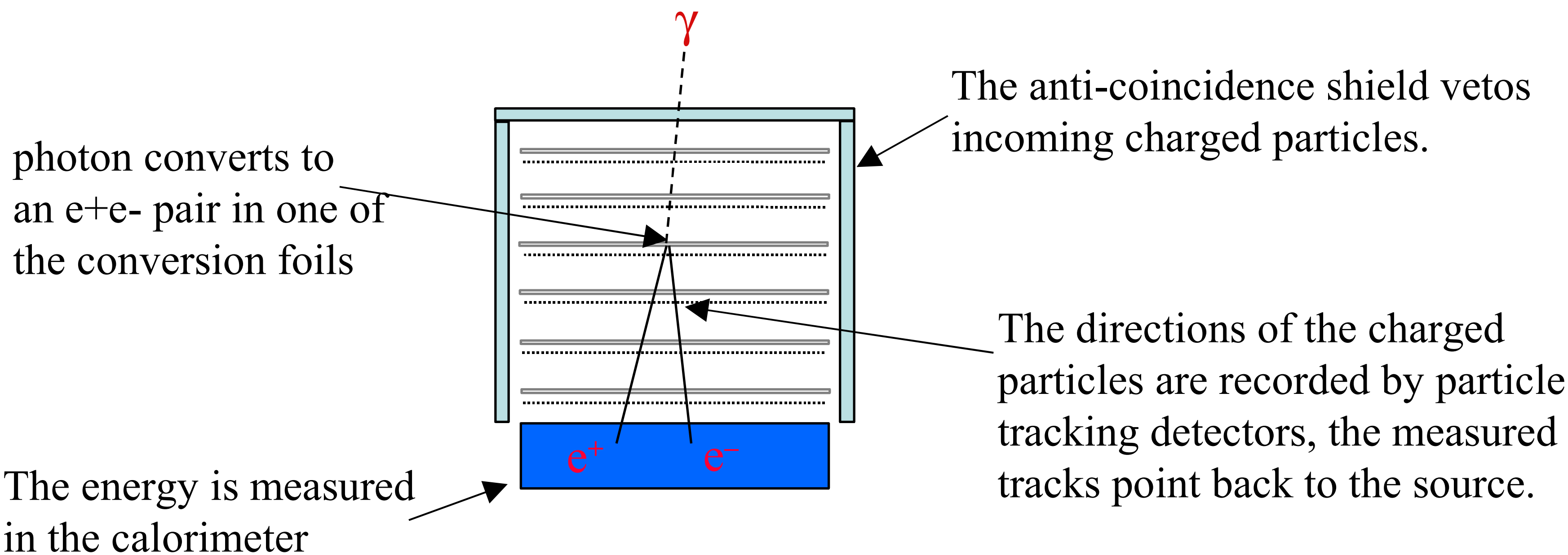
Hodoscopic CsI Calorimeter:

- Segmented array of 1536 CsI(TI) 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

Pair Conversion Technique



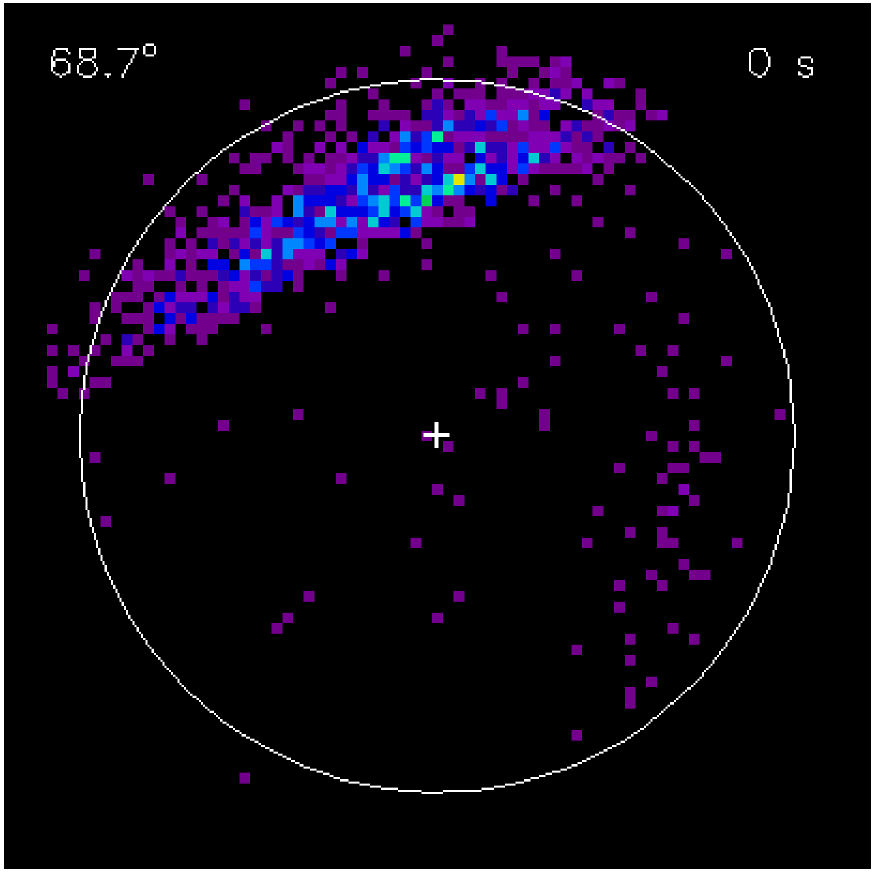
Tracker: angular resolution is determined by:
multiple scattering (at low energies) => Many thin layers
position resolution (at high energies) => fine pitch detectors

Calorimeter:
Enough X_0 to contain shower, shower leakage correction.

Anti-coincidence detector:
Must have high efficiency for rejecting charged particles, but not veto gamma-rays

The Earth

- **Observation of the Earth limb (Sept 29)**
  - Bright, narrow gamma-ray source (from cosmic-ray interactions in the atmosphere)
  - Allow detailed studies of efficiency/Aeff as function of inclination, energy and orbit location



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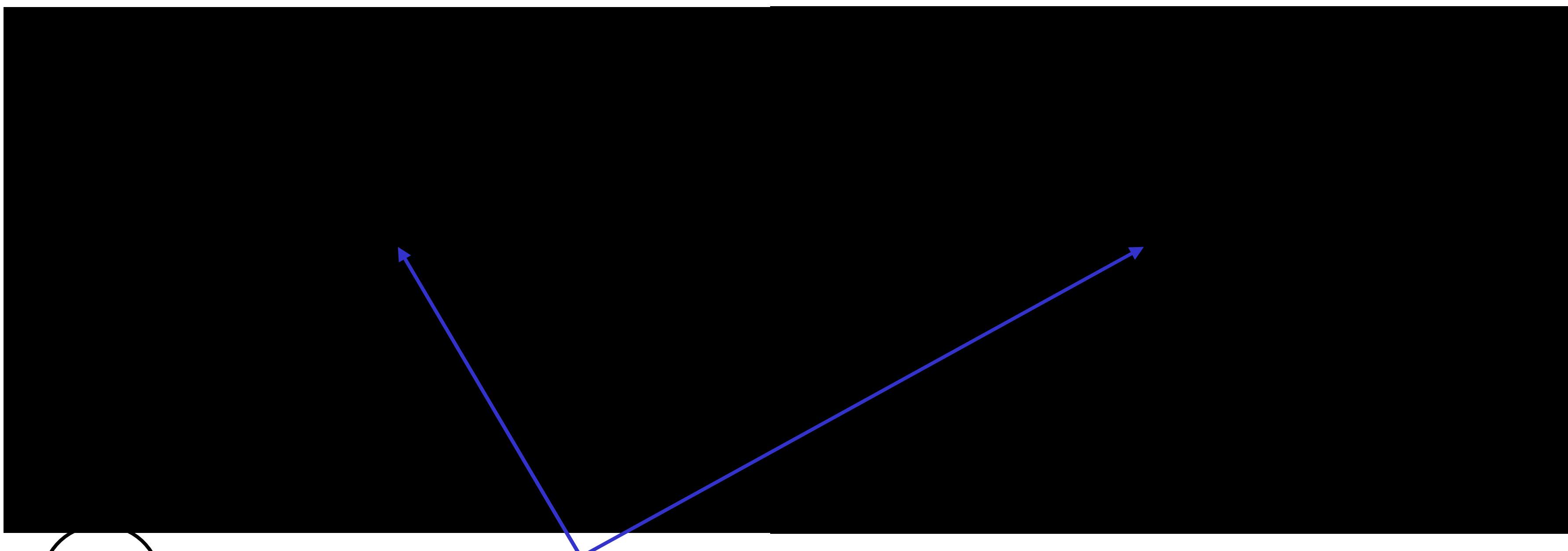

Size of Sun/Moon on the sky

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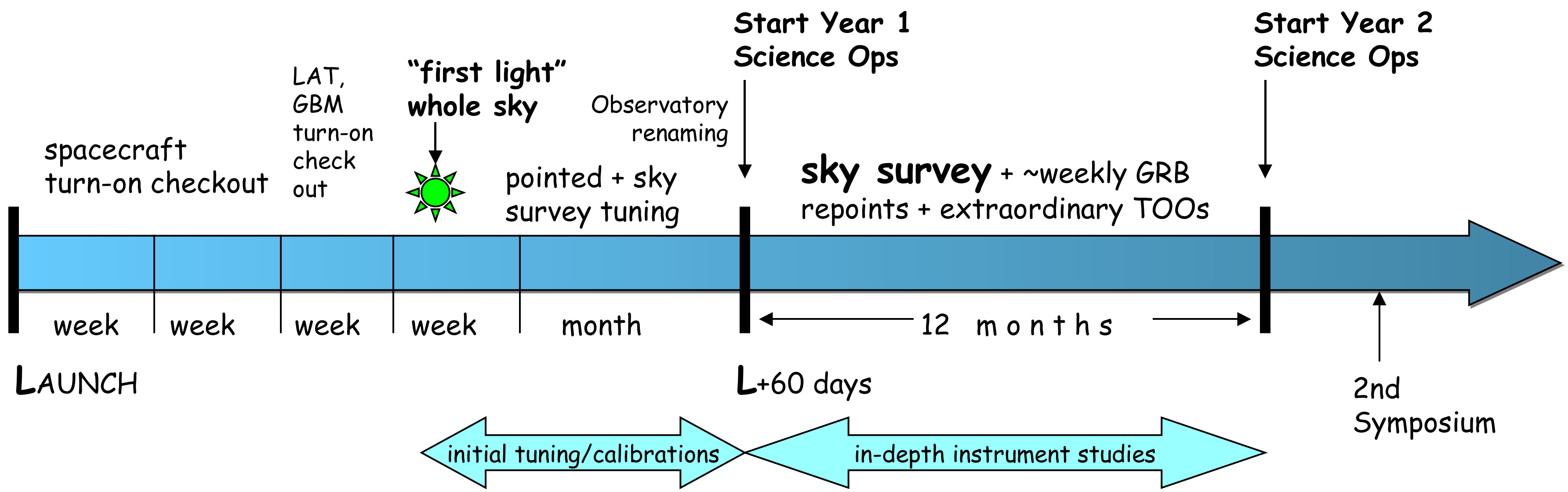
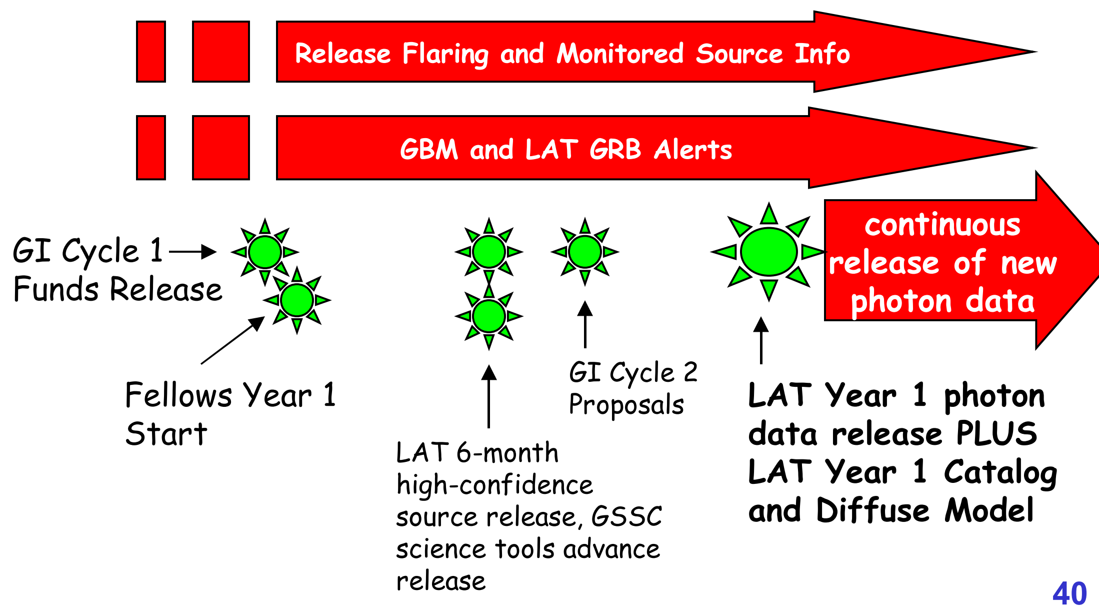
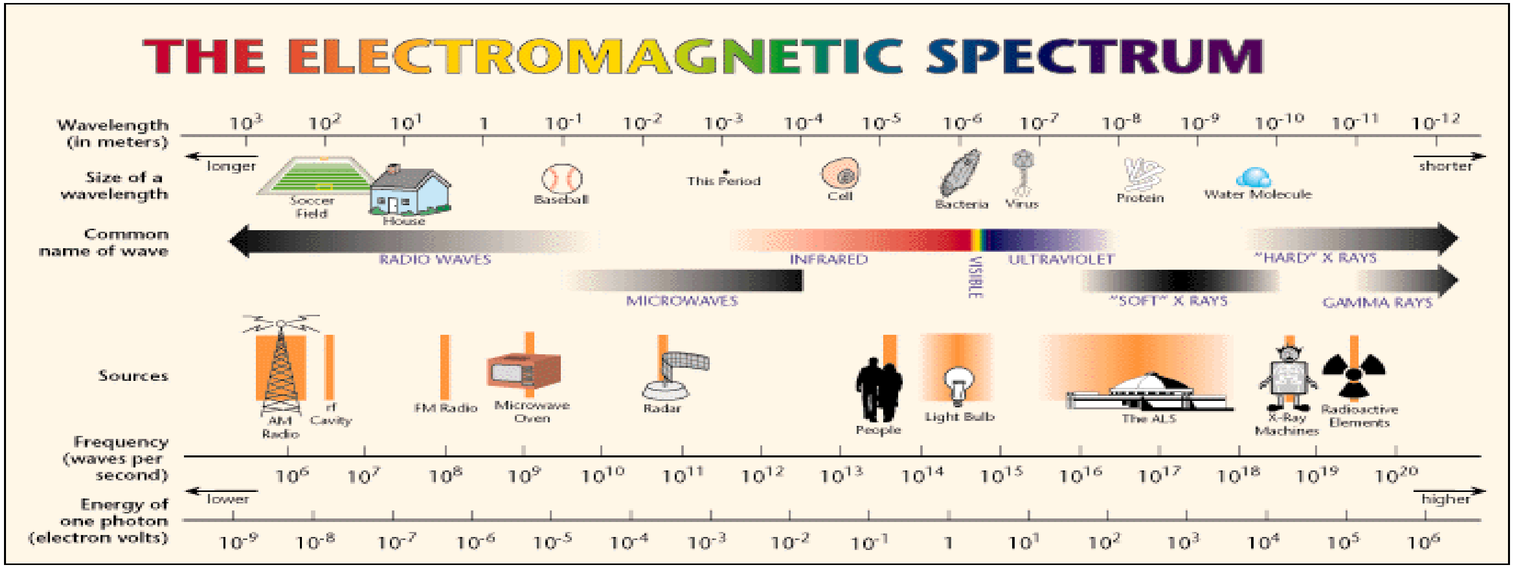
Year 1 Science Operations Timeline Overview

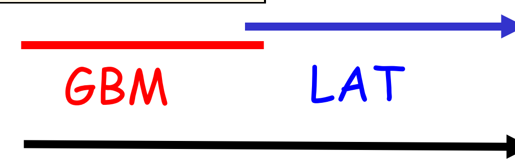


- **High confidence source list and LAT analysis software released in early Feb 2009**
- **Cycle 2 GI deadline March 6, 2009**
- **Full data release in late summer/Fall 2009**



Gamma-Ray Astrophysics





- The Fermi energy range falls at the energetic end of this scale!
- Very energetic photons require even more energetic particles to produce them -- HE gamma-ray astrophysics does not probe quiet parts of the Universe.
- High energy gamma-rays explore nature's accelerators - "Where the energetic things are"
  - natural connections to UHE cosmic-ray and neutrino astrophysics

LAT GRB Observations - 8 detections

- GRB080825C [GCN 8183 – Bouvier, A. et al.]
More than 10 events above 100 MeV

- GRB080916C (z=4.35) [GCN 8246 – Tajima, H. et al.]
Bright!

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

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

- GRB090217 [GCN 8903 – Ohno. et al., GCN 8902, von Kienlin. et al.]
fairly weak LAT detection, high energy emission delayed by ~6 s w.r.t. keV emission

- GRB090323 (z=3.6), GRB090328 (z=0.7) [GCN 9021 – Ohno et al; GCN 9044 McEnery et al.,]
Very long duration LAT emission/afterglow

- GRB090510 (z=0.9), [GCN 9021 – Ohno et al; GCN 9350 Omodei et al.,]
Short, extremely intense, first LAT GCN notice

Typical LAT Localisations 0.1-1.0 deg