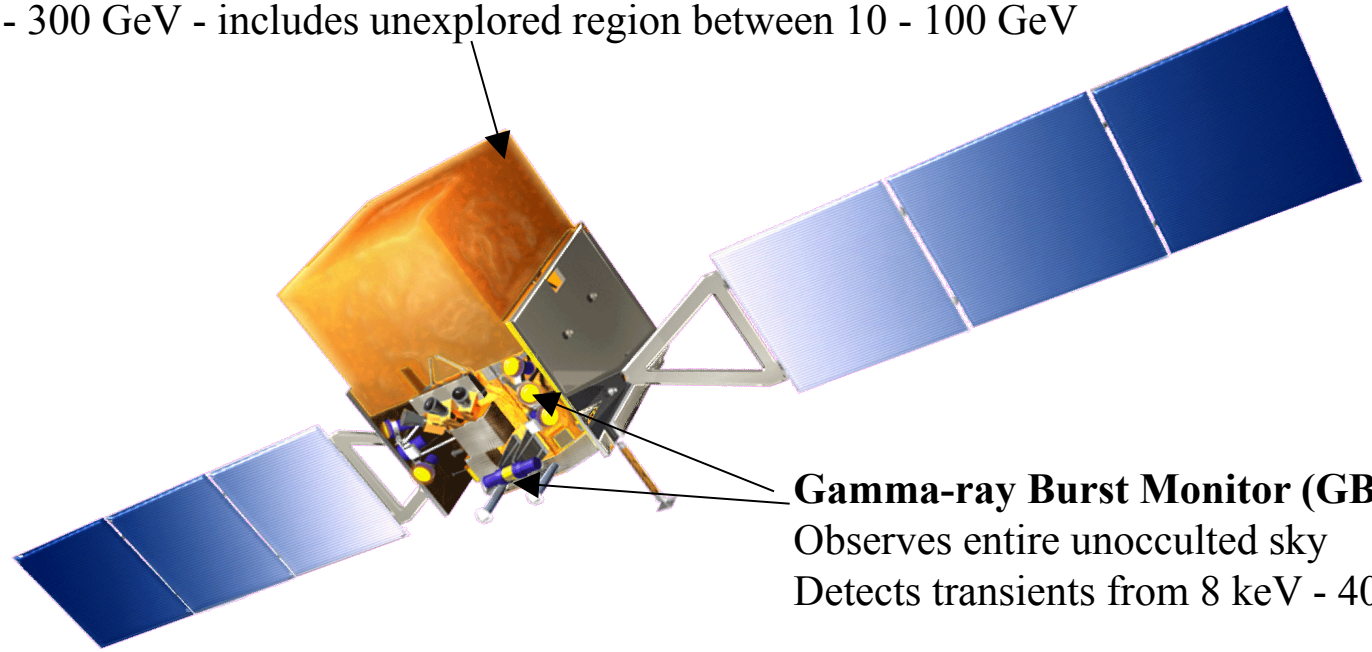
The Fermi Gamma-ray Space Telescope: Spacecraft, operations and mission

Julie McEnery
NASA/GSFC

The Fermi Observatory

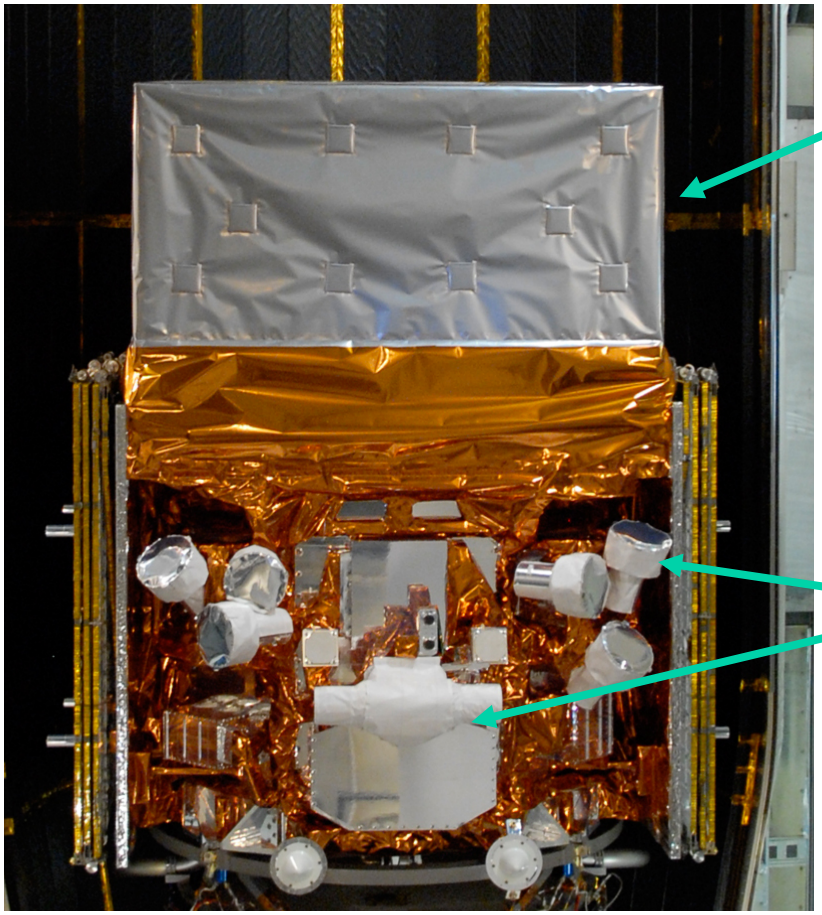
Large Area Telescope (LAT)
Observes 20% of the sky at any instant, views entire sky every 3 hrs
20 MeV - 300 GeV - includes unexplored region between 10 - 100 GeV



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

- **Huge improvement over previous missions in this waveband**
  - **Increased effective area**
  - **Improved angular resolution**
  - **Broader energy range**
  - **Wide field of view**

Fermi Observatory



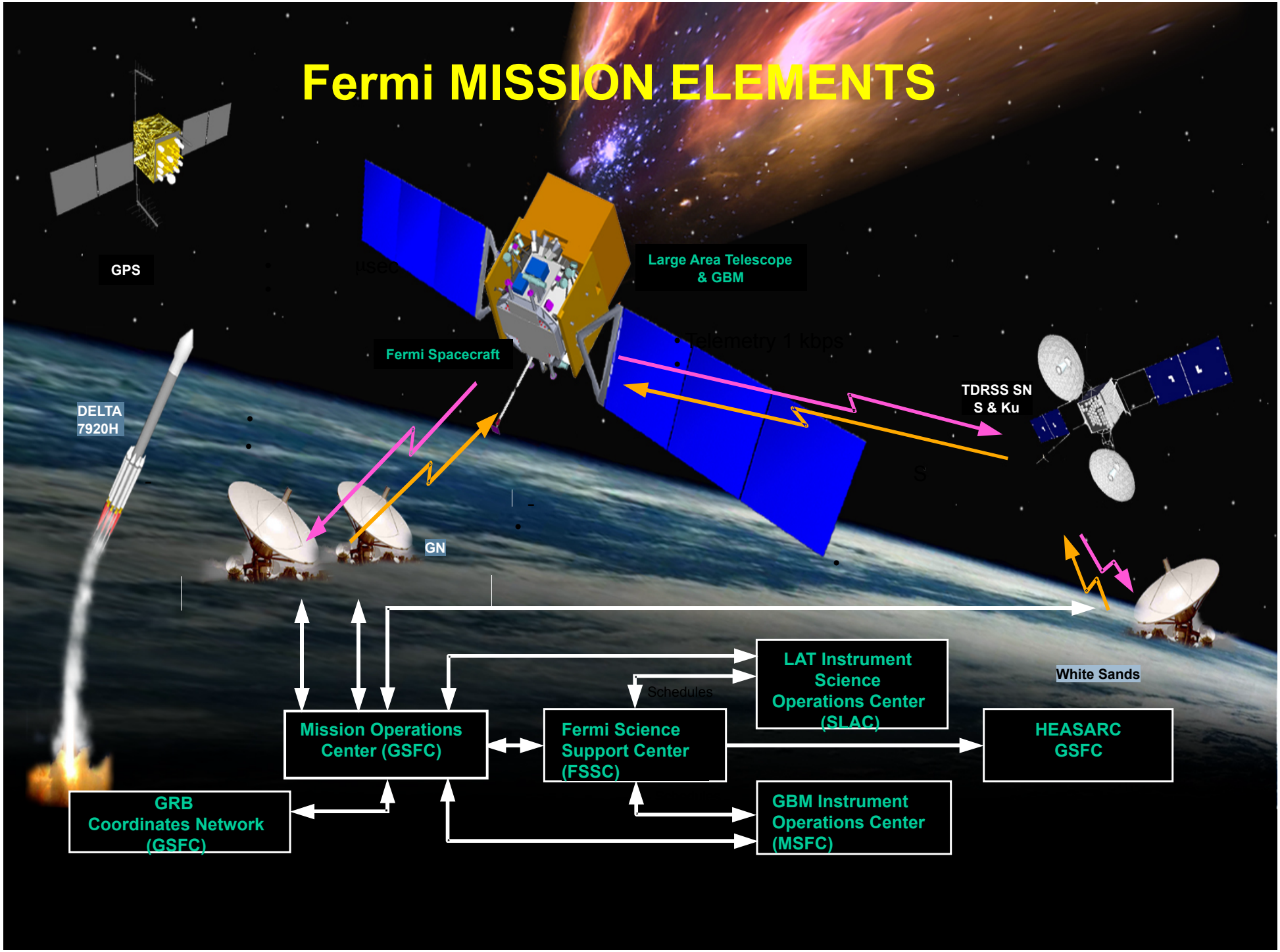
Large Area Telescope (LAT):

- 20 MeV - >300 GeV
- 2.4 sr FoV (scans entire sky every ~3hrs)

Gamma-ray Burst Monitor (GBM)

- 8 keV - 40 MeV
- views entire unocculted sky

Launched on June 11, 2008


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
GRB
Coordinates Network
(GSFC)
GBM Instrument
Operations Center
(MSFC)

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.
- Communications:
  - Science data link via TDRSS Ku-band (40 Mbps, 8-10, 10 min contacts per day)
  - S-band via TDRSS (8kbps) or ground stations (1.26 Mbps)

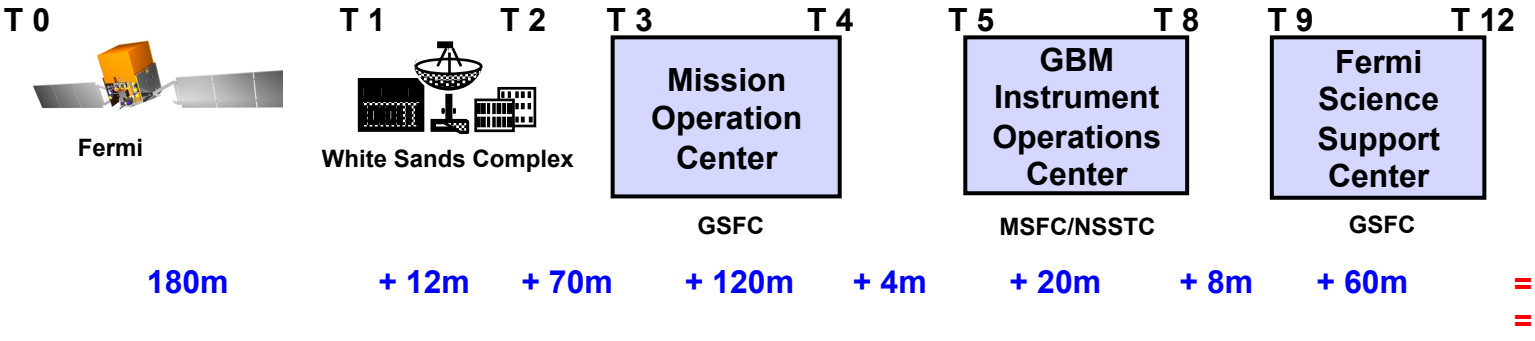
Raw Data

- Data consists of
  - 1.2 Mbps LAT data
  - 26 kbps GBM data
  - 51 kbps housekeeping data (from SC, LAT and GBM)

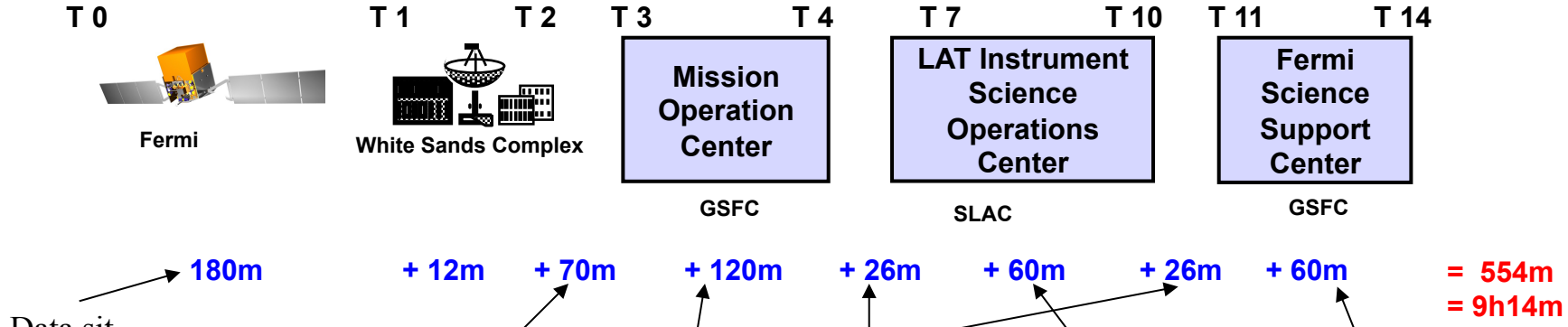
- The onboard solid state recorder (SSR) has two partitions, read out in parallel
  - Science (LAT+GBM data)
  - Housekeeping

Data Latency

GBM DATA PATH



LAT DATA PATH



Data sit on SSR

4.3Mbps, unlikely (at the moment) to do much better than this.

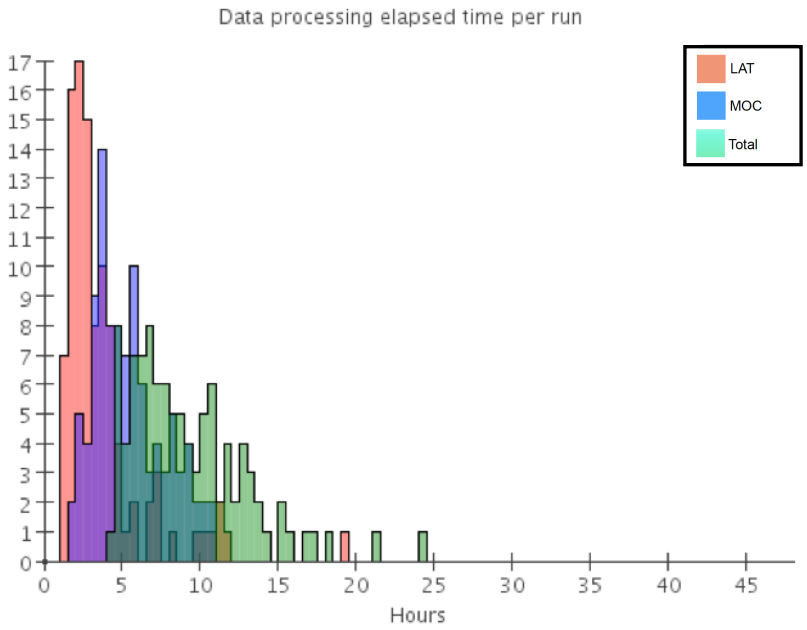
Level 0 processing conservative estimate.

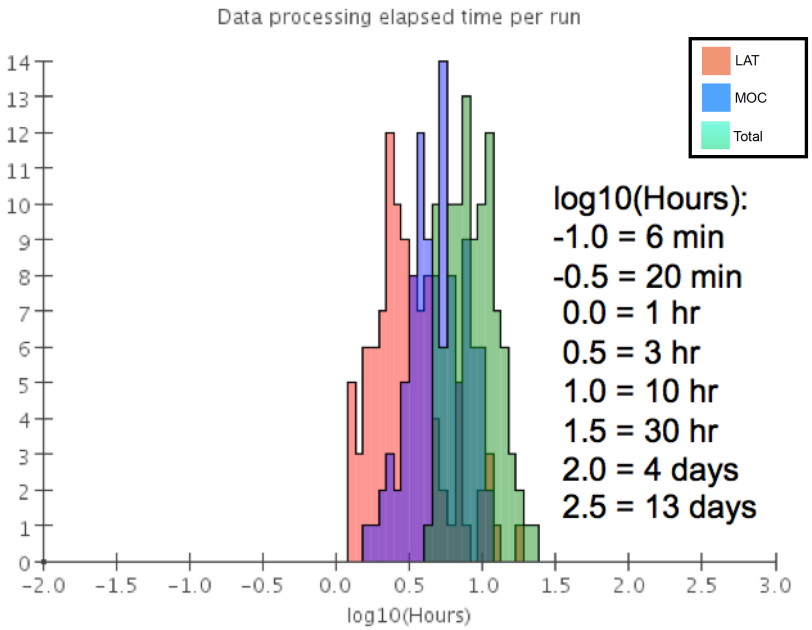
sometimes achieve higher bandwidth.

Nominal case, assuming no manual intervention or new calibrations.

Data ingest, conservative estimate

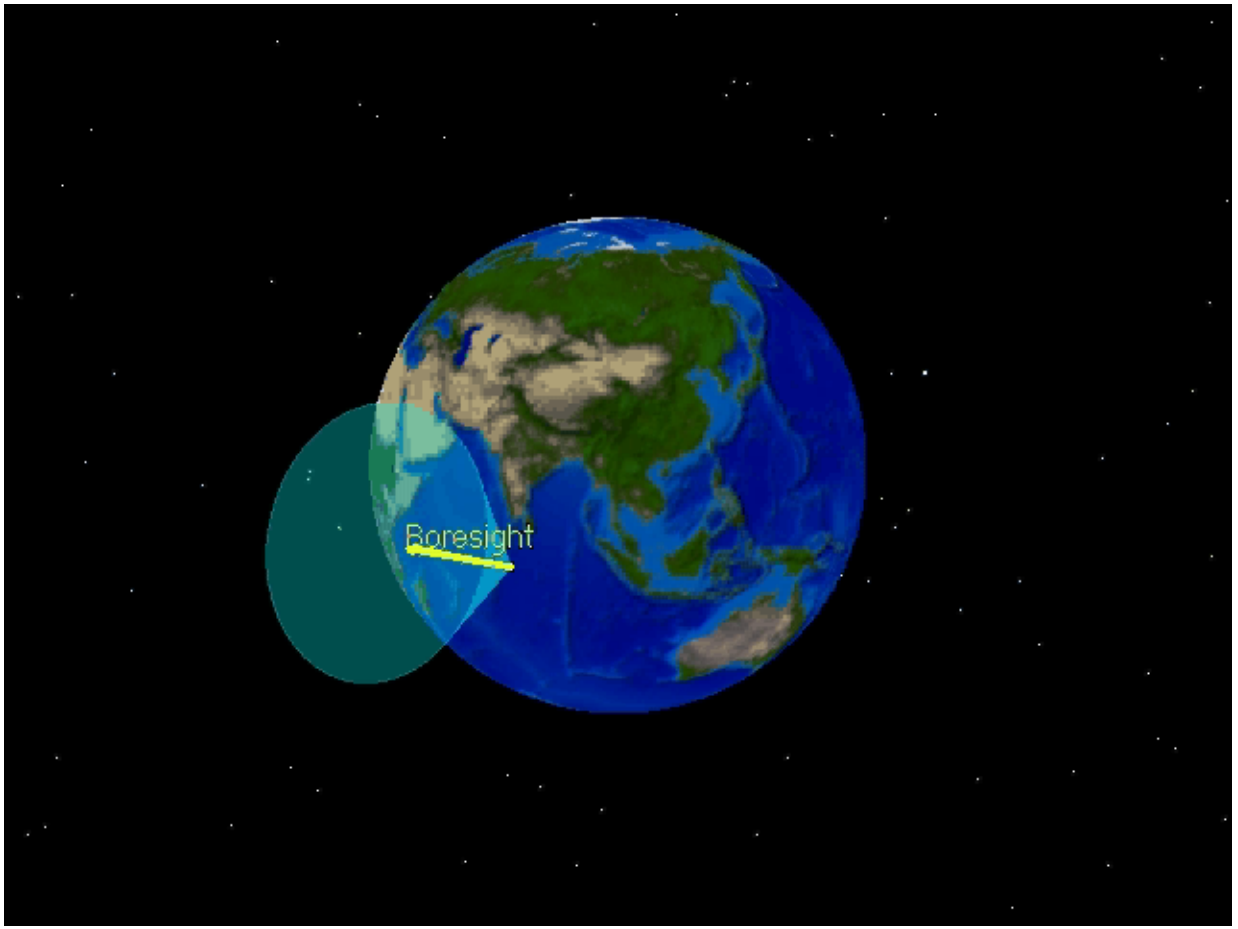
Data Latency





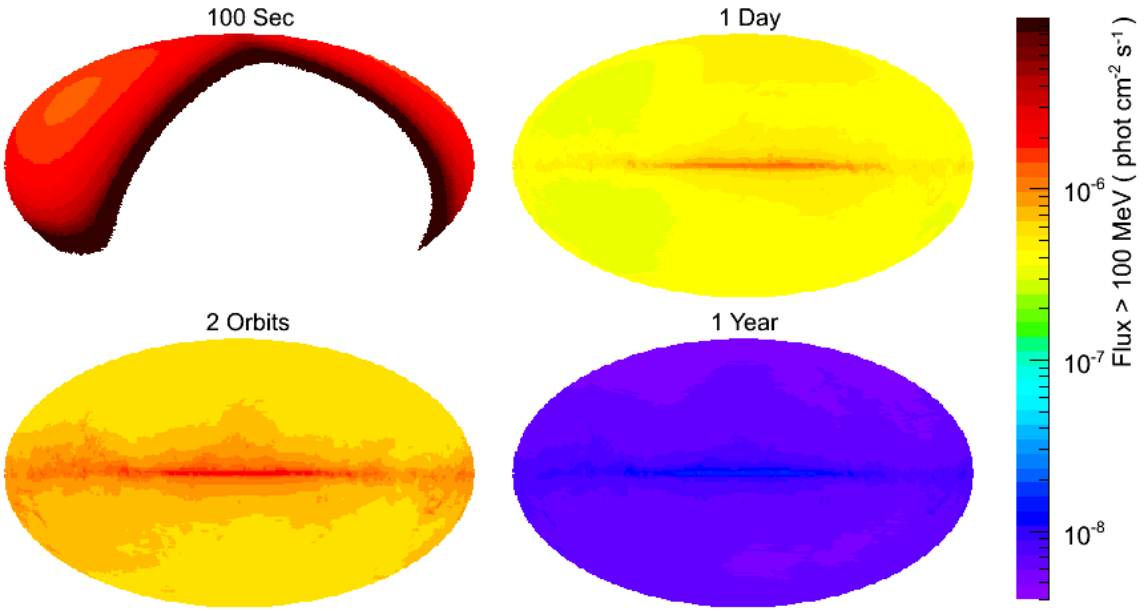
- **LAT - level 2 requirement: <72 hours from detection of gamma-ray photon to availability in public archive**
  - **Typical latency is ~8 hours**
  - **Everyone gets access to the data at the same time.**
- **GBM Data is delivered to FSSC within 24 hours for routine data taking.**
  - **GRB, Solar flares, TGFs - times, fluxes, location delivered in near real time.**

Survey mode



- **Rock north for one orbit and south for the next**
- **Cover entire sky and always keep LAT FoV away from the Earth limb**

All Sky Coverage



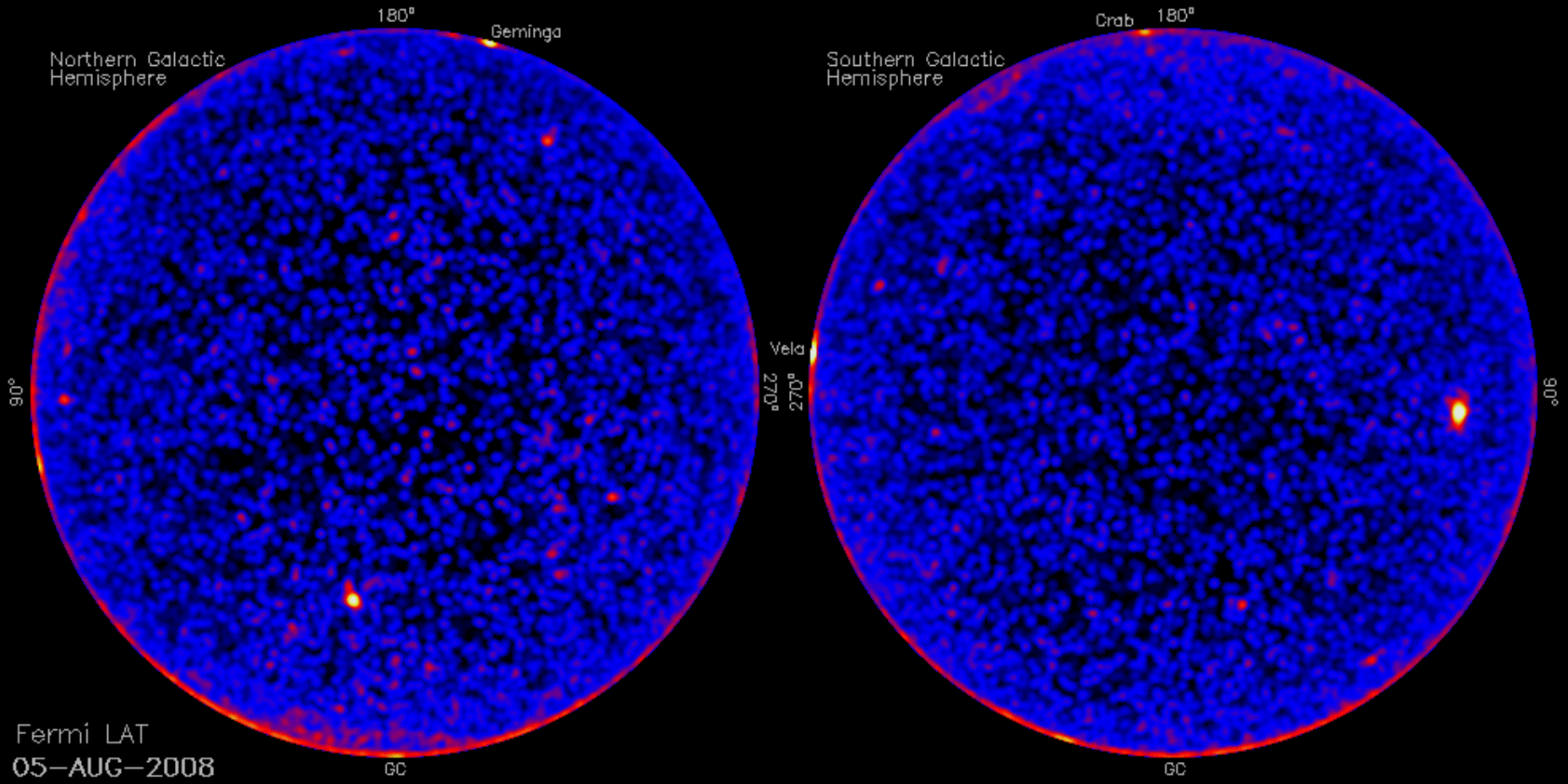
LAT sensitivity on 4 different timescales: 100 s, 1 orbit (96 mins), 1 day and 1 year

- **In survey mode, the LAT observes the entire sky every two orbits (~3 hours).**
- **Multiwavelength observations in coordination with the LAT are 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.**

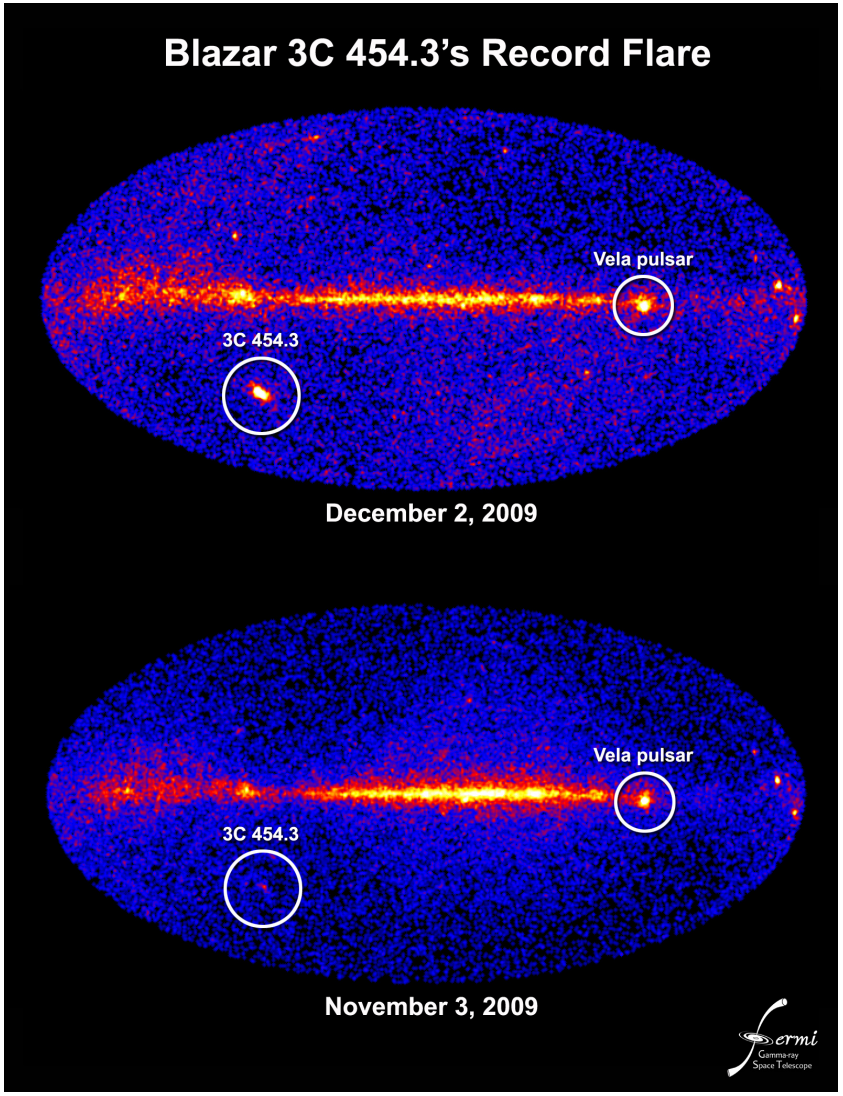
Observation modes

- Normal Survey mode (default)
  - 1 orbit rock north, 1 orbit rock south, repeat
  - Covers entire sky every two orbits (~3 hours)
  - Efficient observing, LAT boresight stays away from the Earth.
- Modified survey (improve exposure up to 2x)
  - N orbits rock north, M orbits rock south, repeat
  - Covers entire sky every N+M orbits
  - Efficient observing mode
- Target of Opportunity (improve exposure up to 4x)
  - Allows rapid initiation of pointed mode observations
  - Boresight traces earth limb while target is occulted.
  - Least efficient observing mode (Significant occultation of LAT FoV by Earth)
- Pointed mode (improve exposure up to 4x)
  - Planned pointed mode observation
  - Perform small segment of sky survey while target is occulted.
  - Inefficient observing mode (some occultation)

The Variable Gamma-ray Sky



The flaring and variable sky



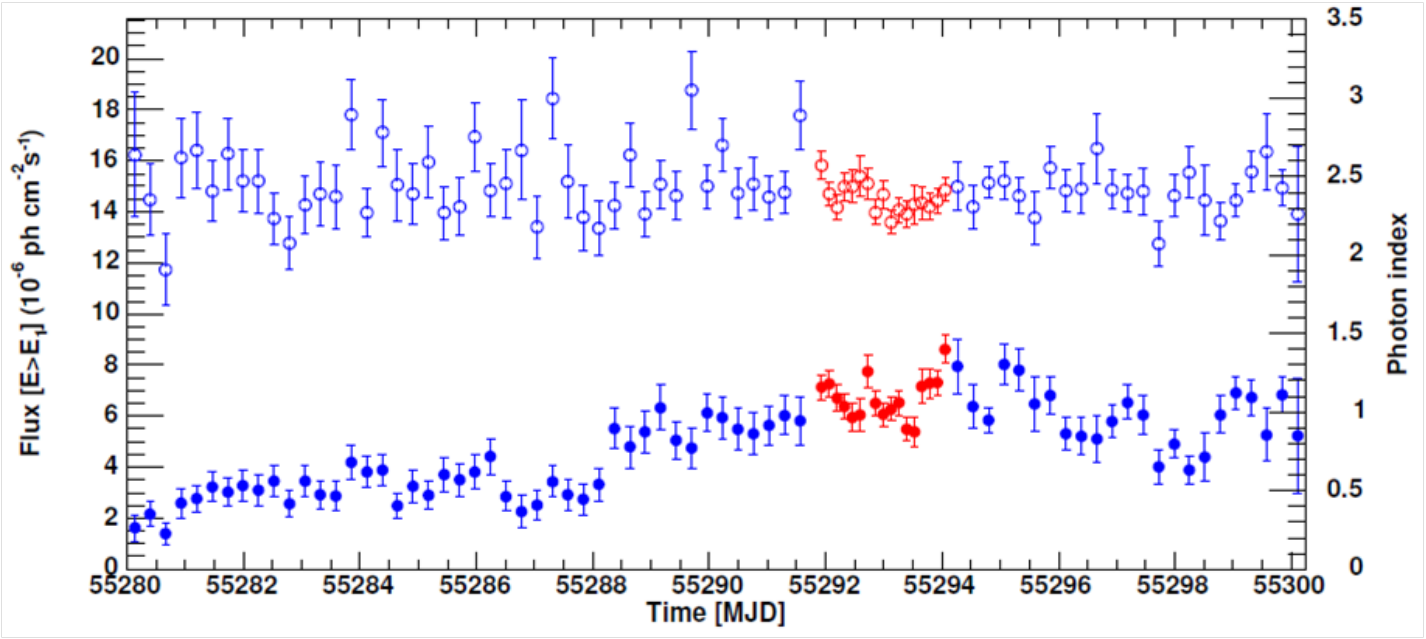
- **Automated search for flaring sources on 6 hour, 1 day and 1 week timescales.**
  - **LAT scientists perform follow-up analyses, produce ATels, and propose ToOs**
- **>100 Astronomers telegrams**
  - **Discovery of new gamma-ray blazars**
  - **Flares from known gamma-ray blazars**
  - **Galactic plane transients**

Observations summary

- Almost exclusively in nominal data taking in survey mode
  - 50 deg rocking angle from May 27 2009 onwards
- ARRs (~2/month)
  - Duration reduced to 2.5 hours (from 5 hours)
- 3 Target of Opportunity Observations
  - 3C 454.3
  - Crab Nebula flare (2010-266-15:50:50 through 270-19:48:52)
  - Cygnus X-3
  - Crab Nebula (April 2011)
- 1 modified survey mode observation
  - Two orbits south, 1 orbit north to enhance coverage during PSR B1259 periastron.
- LAT Calibrations
  - ~<12 hours/year

Pointed mode observations - 3C 454.3

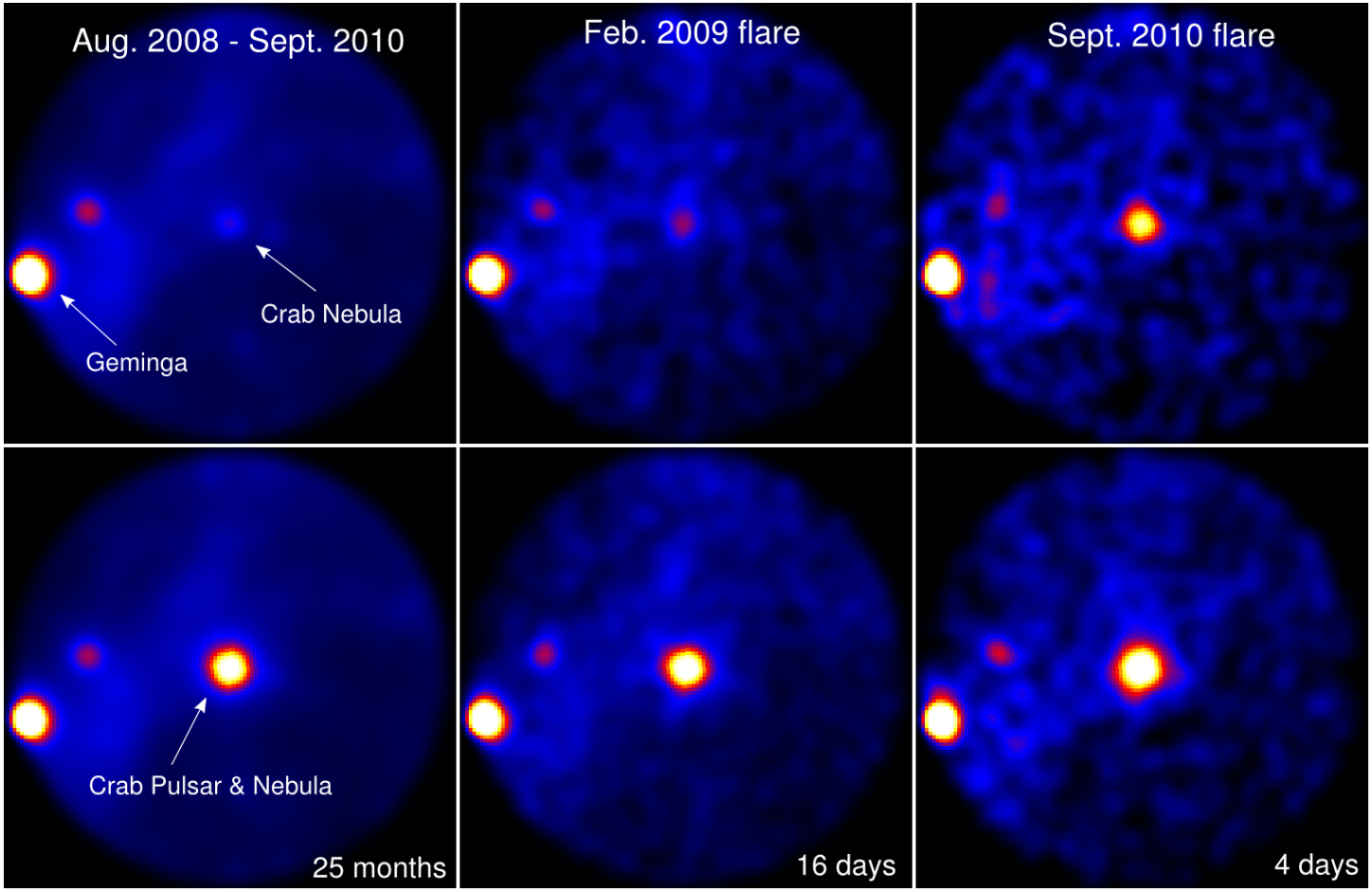
2.5 day TOO on 3C454.3 (the red points are from the TOO interval)



Allows production of lightcurves on <3 hour timescales (for very bright sources)

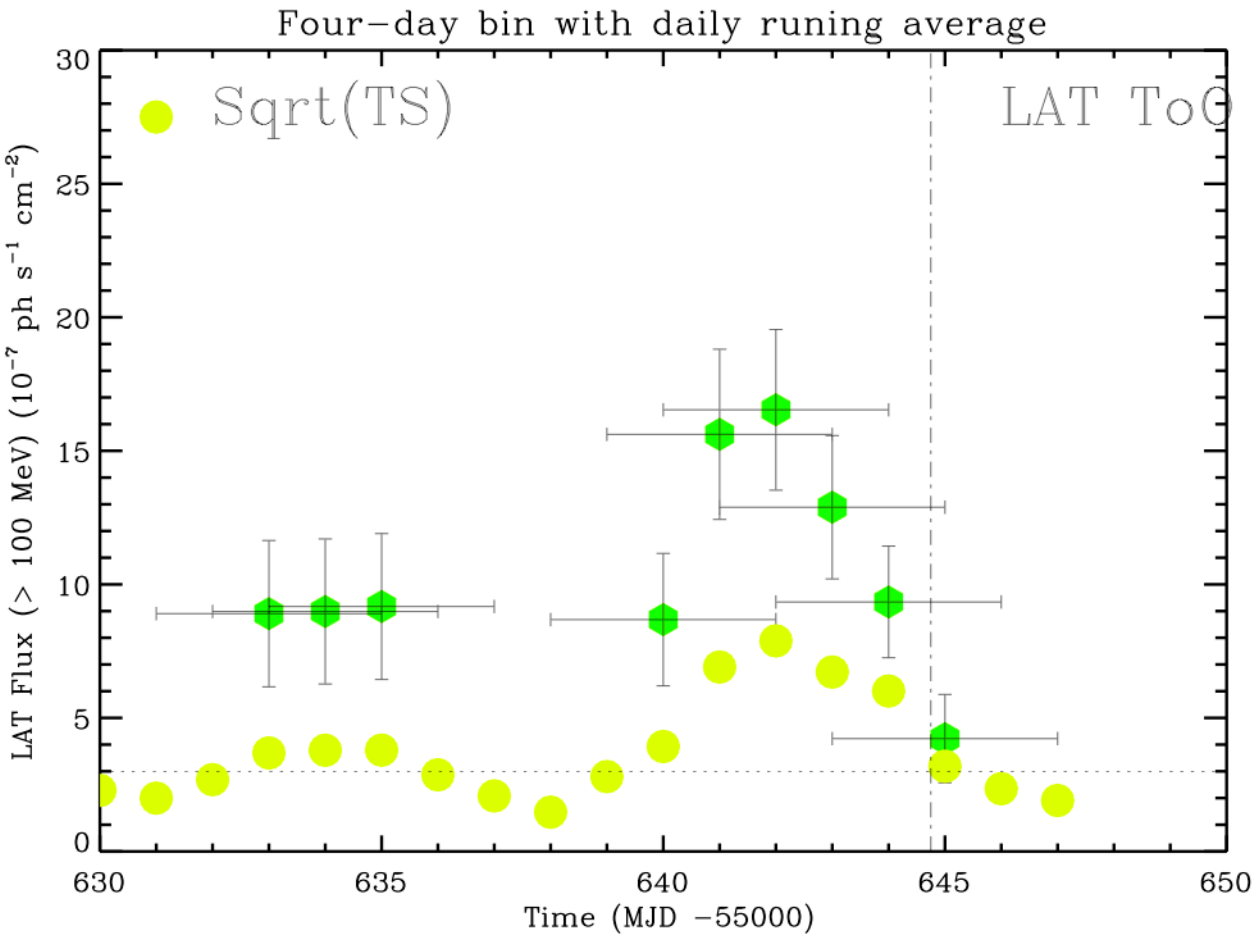
- **Unfortunately, the rapid flux increase flattened just as we started the TOO.**

Pointed mode observations - Crab Flares



- **Unfortunately the second flare was much shorter (4 day vs 16 days) than the first one. The TOO observations commenced after the end of the flare.**

Pointed mode observations - Cygnus X-3



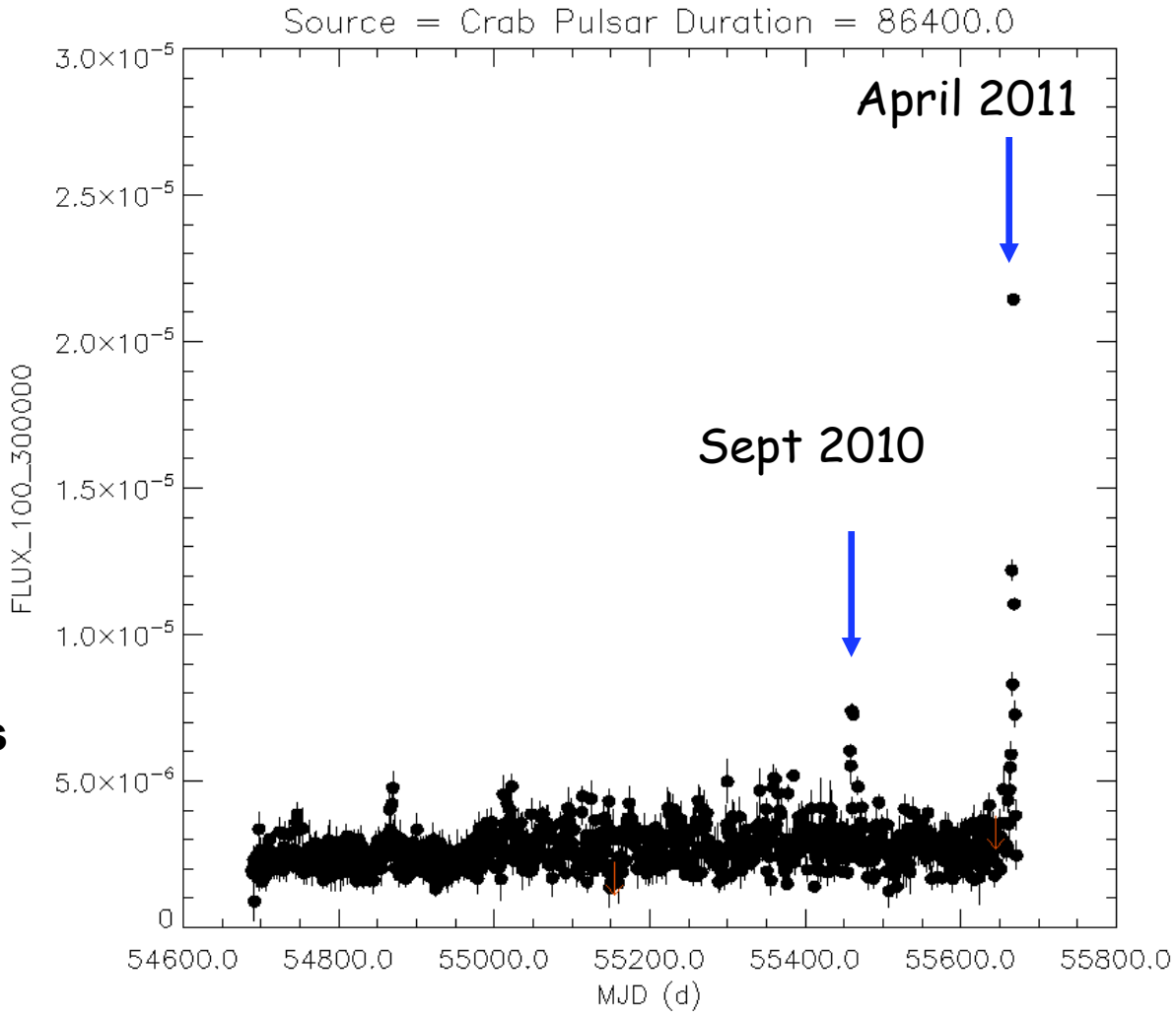
- **Gamma-ray flare was short, and stopped just before the TOO commenced.**

Public Crab Gamma-Ray Lightcurve

Shockingly bright flares in Sept 2010 and April 2011.

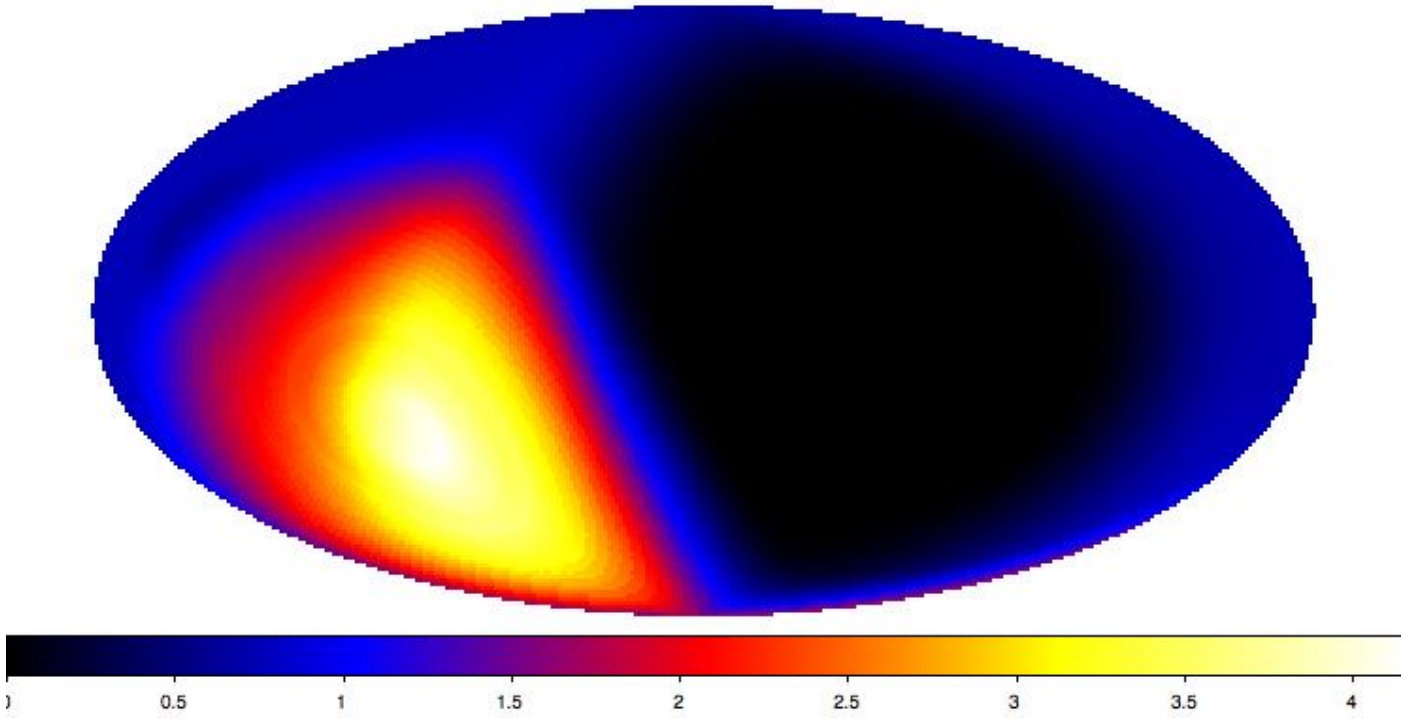
Rapid identification of flares by LAT team enabled Chandra and HST TOO observations in Sept, and sequence of Chandra observations in April (target visibility issues for HST)

Rapid (hourscale) variability of PeV electrons poses severe challenges for acceleration mechanisms



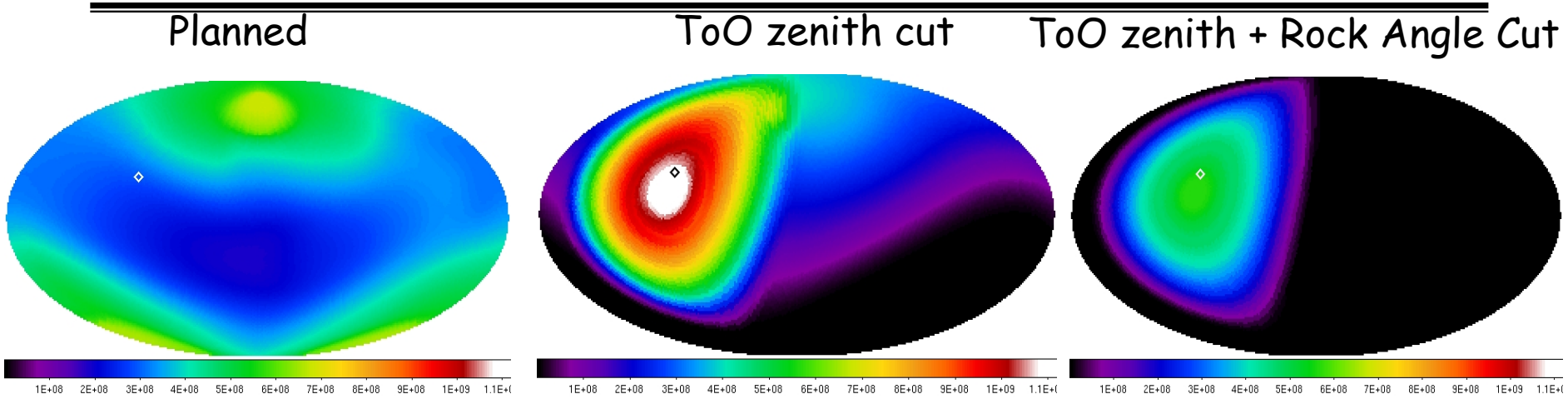
A Successful TOO!

Impact on rest of sky



- **Factor of ~4 exposure at 3C454.3, however large region with no exposure (including M87 which, was flaring at the time)**

Crab ToO Exposure



Exposure (cm^2 s) in celestial coordinates for the planned timeline and the timeline as executed for the 360 ks ToO

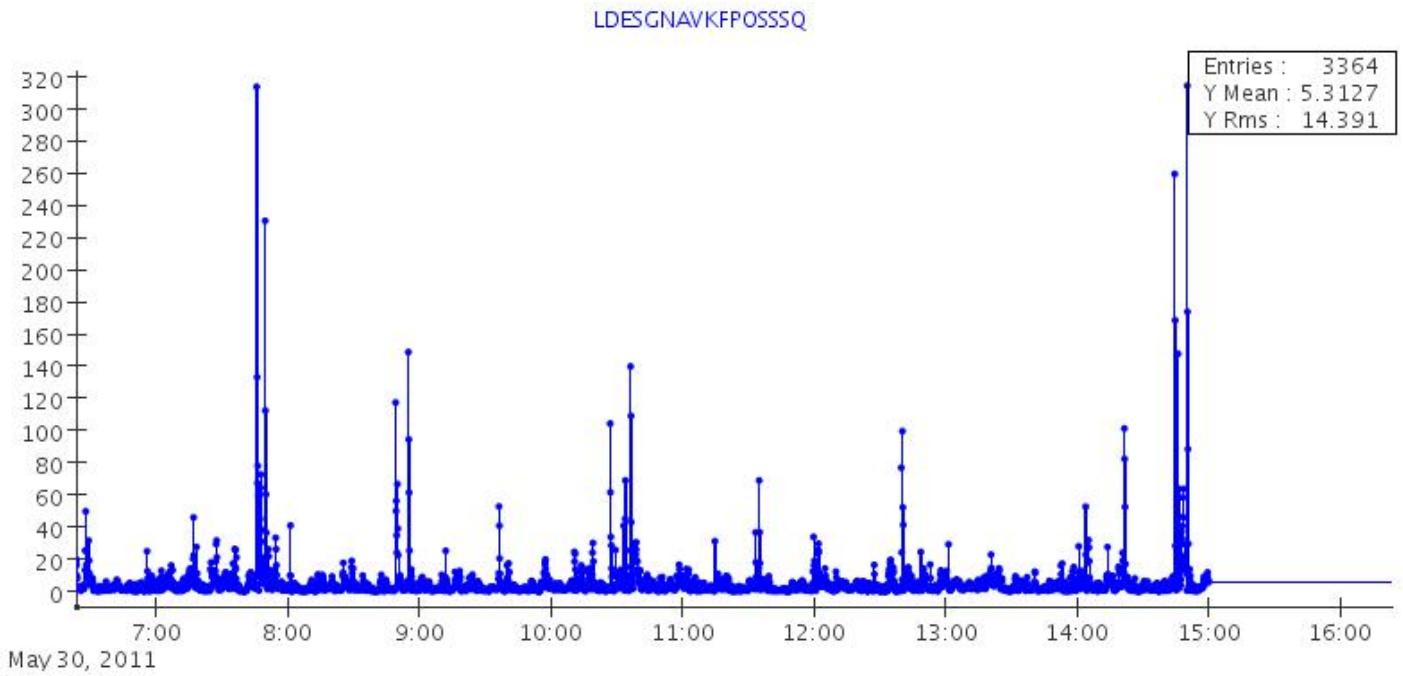
- **Target location offset 10 deg. towards the orbit equator**
- **Planned exposure did not favor direction of Crab**
- **ToO provided estimated 3.9x exposure for regional zenith exclusion (2.2x if rocking angle cut of 52 deg is also applied)**
- **A substantial fraction of the sky received no exposure during the ToO**
- **Ended early**
  - **Operational complications**
  - **Crab nebula stopped flaring in gamma-rays**

Where are we pointing (1)

- 3 star trackers (2 active, 1 spare)
  - Acquires, tracks and identifies up to 6 bright stars in its FoV
- Also have set of 4 gyroscopes that measure angular rates of the spacecraft
  - Used to propagate attitude solution during star tracker outages (and between updates)
- Propagated solution from the gyros is corrected by attitude measurements from the star trackers (similar to orbit location)
  - Solution is robust to outliers and outages in star tracker measurements
  - Track the residuals between star tracker measurements and propagated solution (always tiny compared with LAT psf)
- Attitude solution reported at 5 Hz

How do we know where we are?

- **GPS**
  - **Propagate orbit model, refine orbit solution using GPS location data, data lying close to predicted location given higher weight (Kalman filter)**
    - **Filtered solution robust against outliers or GPS outages**
    - **Filtered solution more accurate than any individual GPS meas.**
  - **Orbit location (from filter) reported at 1 Hz**



Spacecraft files (aka FT2 files)

- **These combine the orbit position and attitude information from the spacecraft.**
  - **Entries spaced every 30 s**

Absolute timing and orbit location

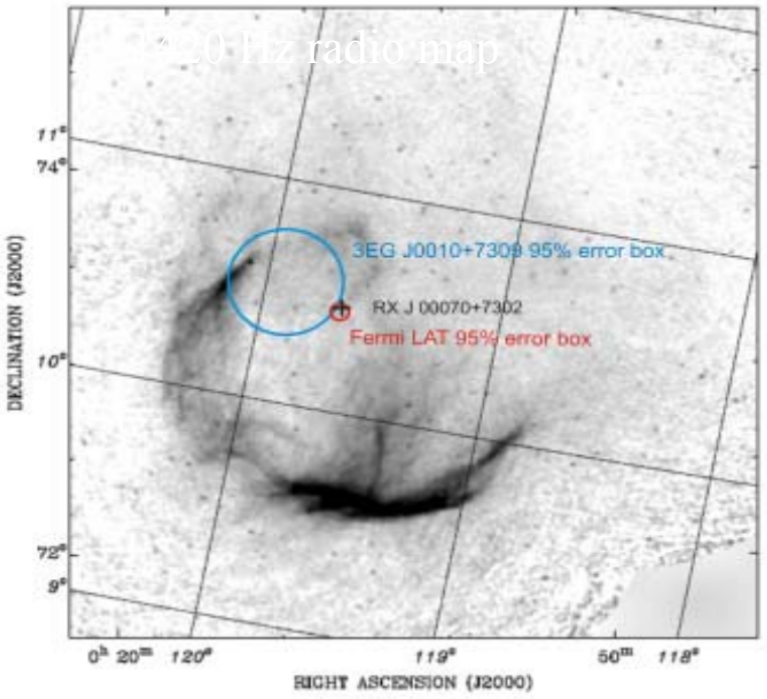
- GPS also provides an absolute timestamp
  - Used to calibrate an onboard oscillator.

- Absolute timestamps are accurate to <300 ns (verified in ground test, and on orbit).
- Orbit position determination good to ~<20 m

- Both of these are important when considering very short timescales
  - Millisecond pulsars!

New Pulsar in CTA 1

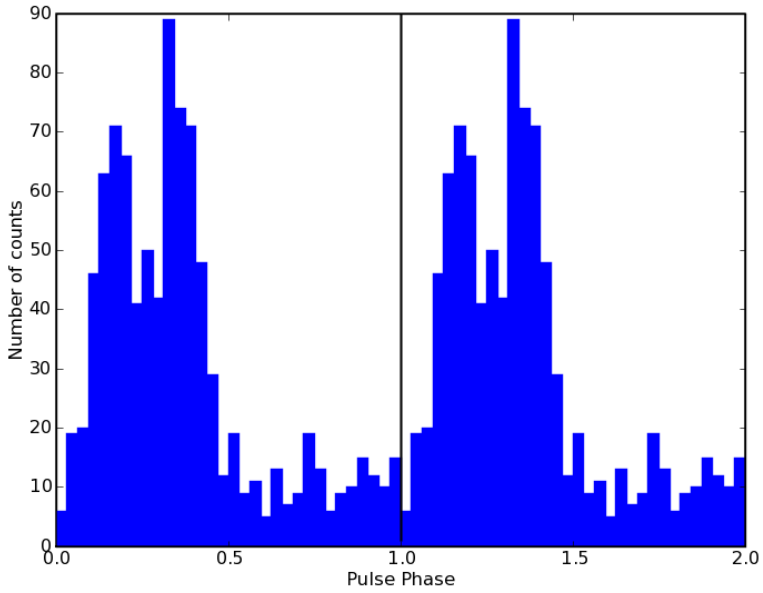
Science Express October 16
Abdo et al., 2008, Science



LAT 95% error radius = 0.038 deg (in 1 month!)
EGRET 95% error radius = 0.24 deg

P ~ 316 ms
Pdot ~ 3.6 x 10^{-13}
Flux (>100MeV) = 3.8 ± 0.2 x 10^{-7} ph cm-2 s-1

Pulse undetected in radio/X-ray

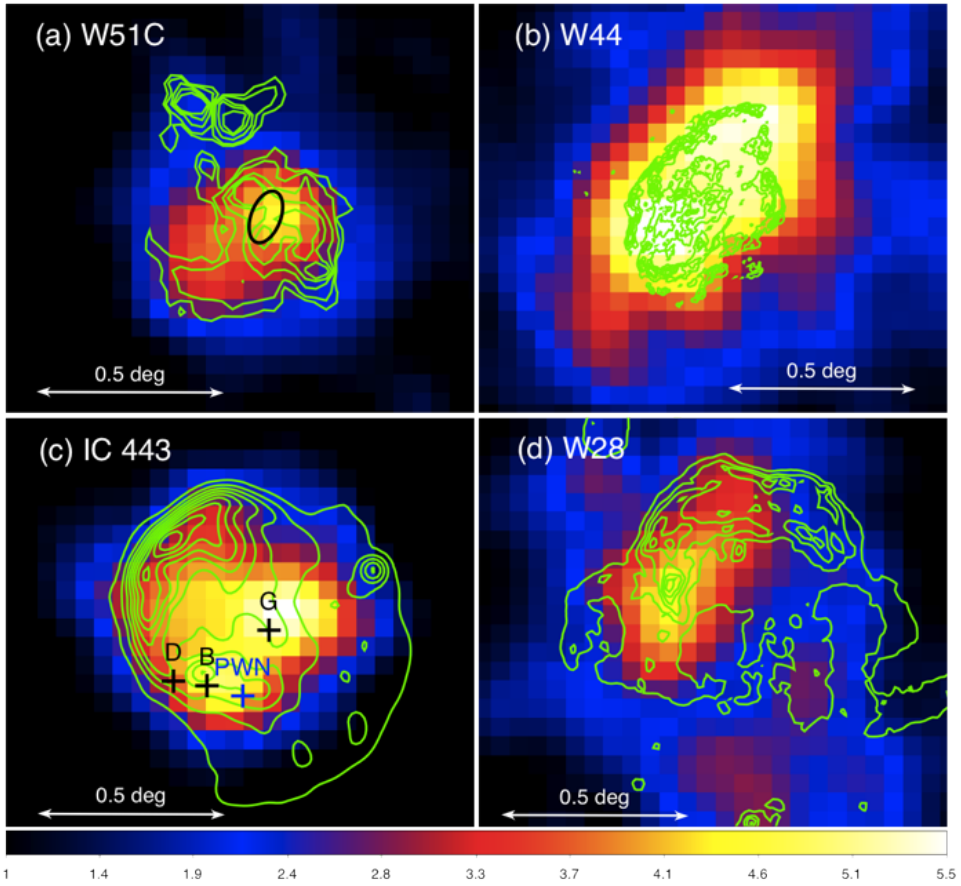


Unidentified EGRET sources - many are pulsars!

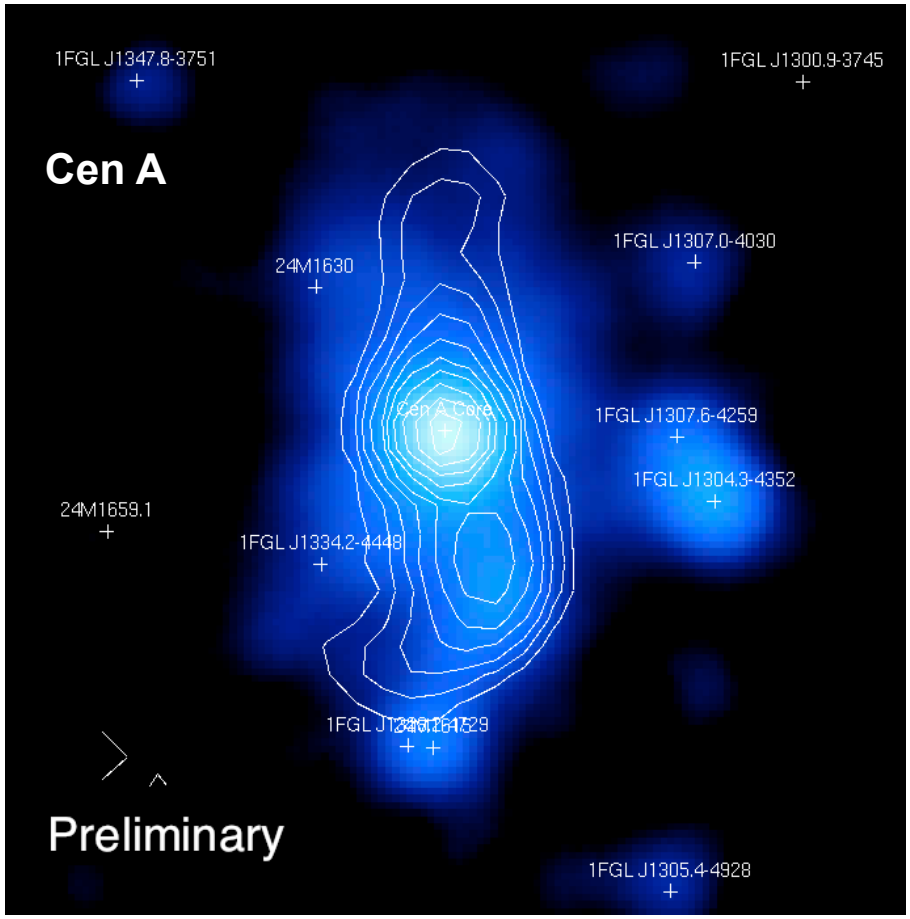
Extended Sources

- **LAT is resolving the MeV-GeV gamma-ray emission from extended sources.**

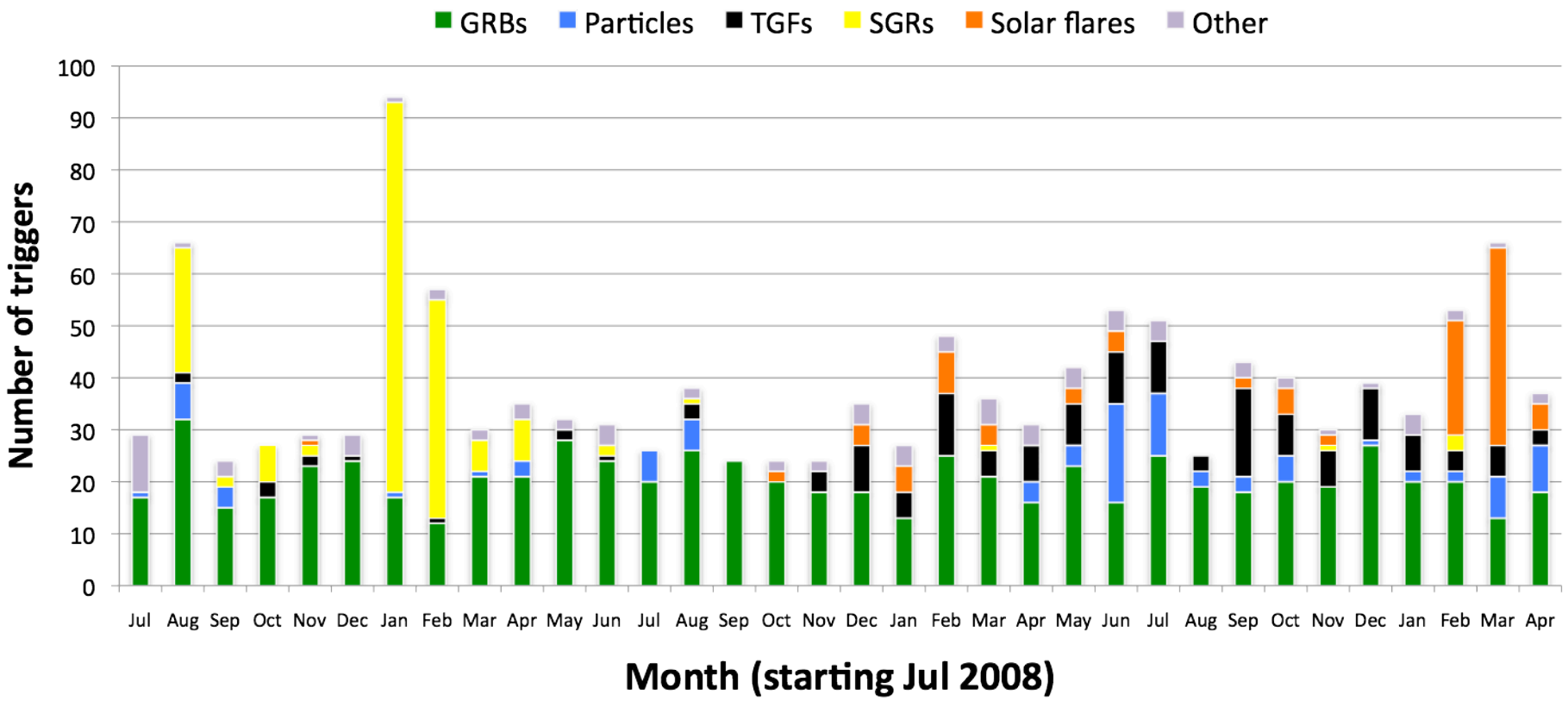
Uchiyama et al, 2011



Perkins et al, 2011



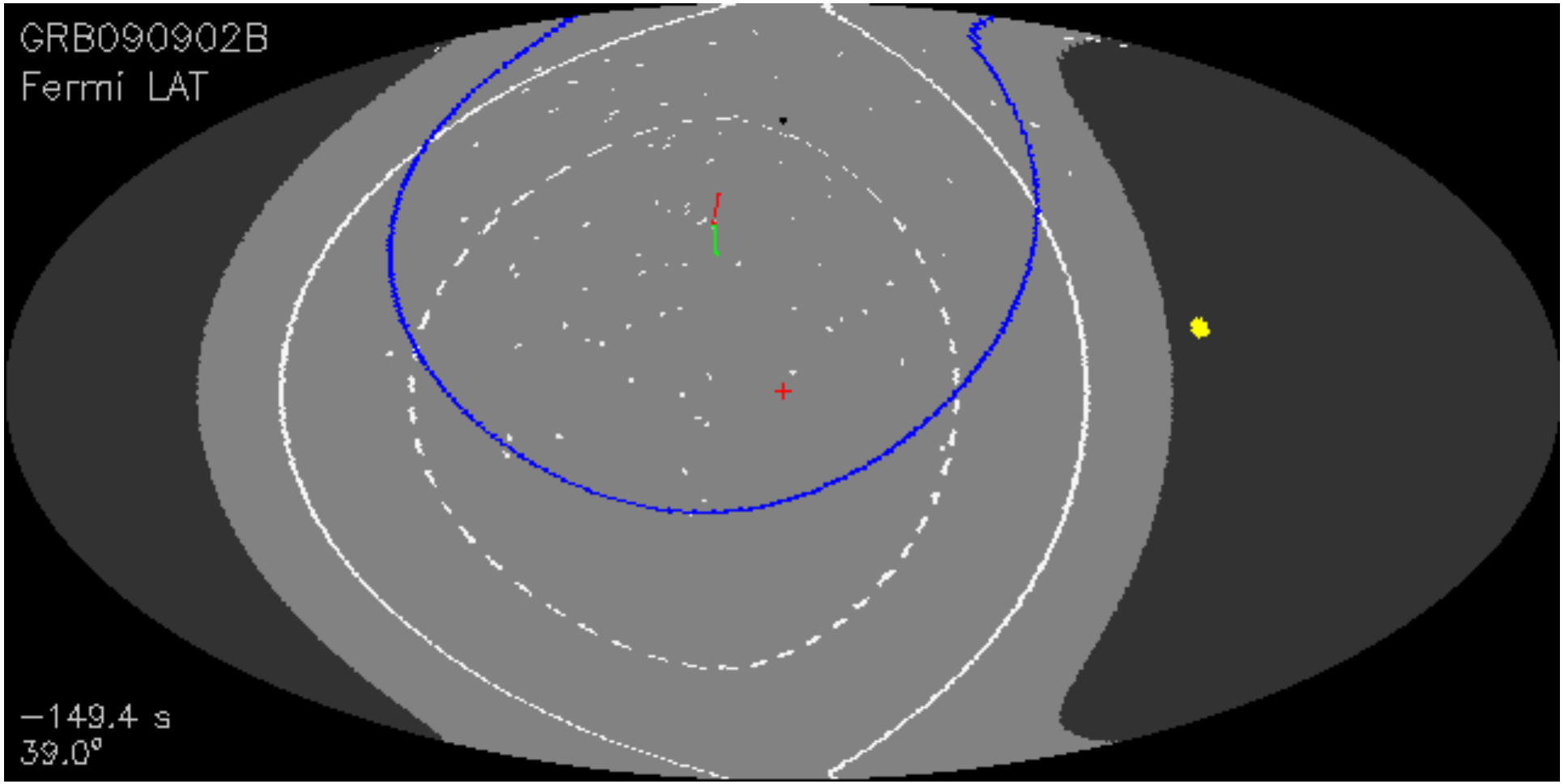
GBM Triggers/Month



- **Nov 9, 2009 - add new TGF trigger**
  - **TGF trigger rate increased by factor of ~10 to 1 per 3.7 days**
- **Feb/March 2011, solar activity**

GRB090902B - Autonomous repoint

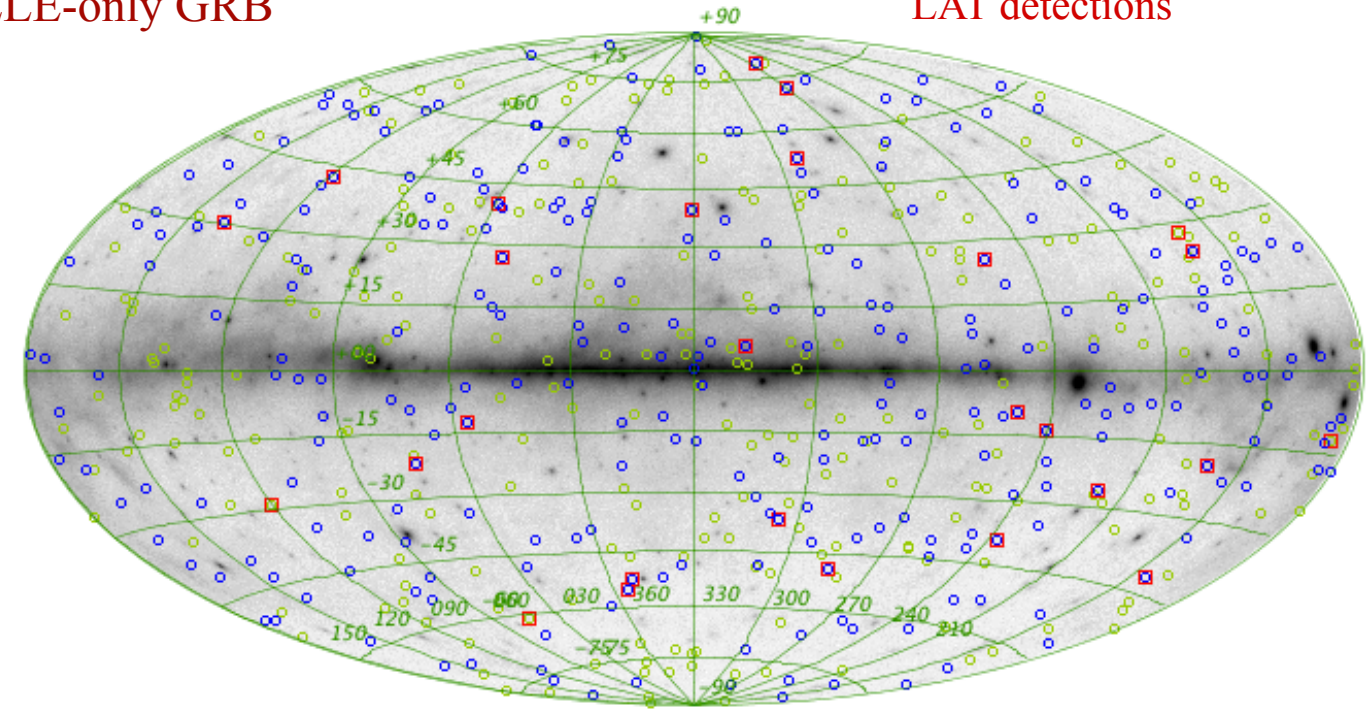
- LAT pointing in celestial coordinates from -120 s to 2000 s
  - Dark region = occulted by Earth (θz>113°)
  - Blue line = LAT FoV (±66°), White points = LAT events



Fermi detections as of 2011-01-20

530 GBM GRB (since Aug 2008)
27 LAT GRB
20 (>100 MeV, TS > 16)
7 LAT LLE-only GRB

Circles:
In Field-of-view of LAT (<70°): 275
Out of the FOV
Squares:
LAT detections



11 months Fermi LAT count map

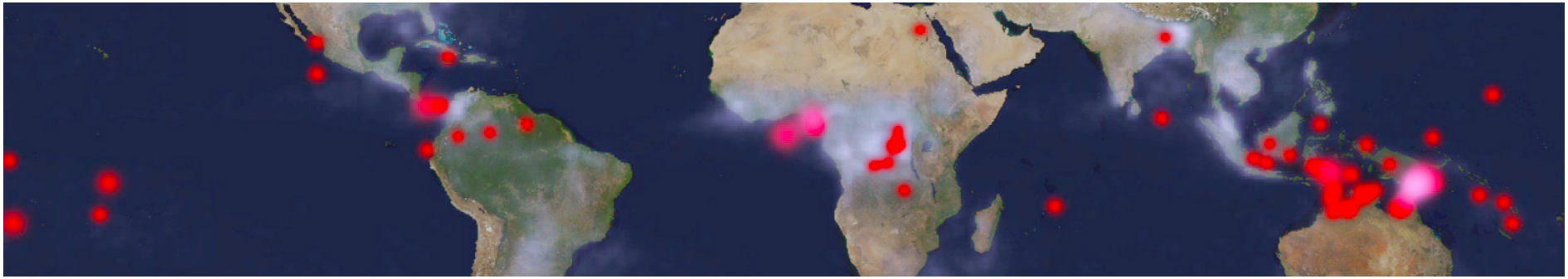
PRELIMINARY

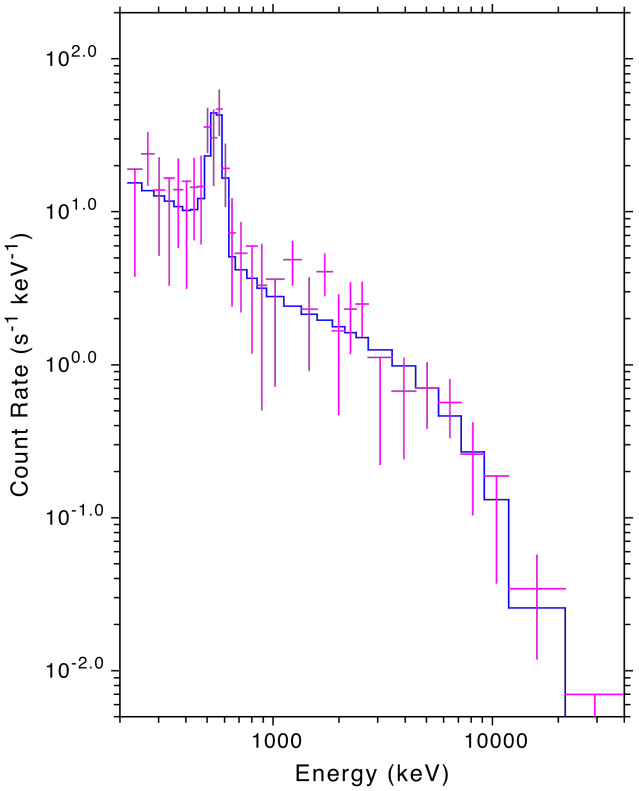
Terrestrial Gamma-ray Flashes

Rapid flashes of gamma-rays produced by highly energetic particles produced in thunderstorms.

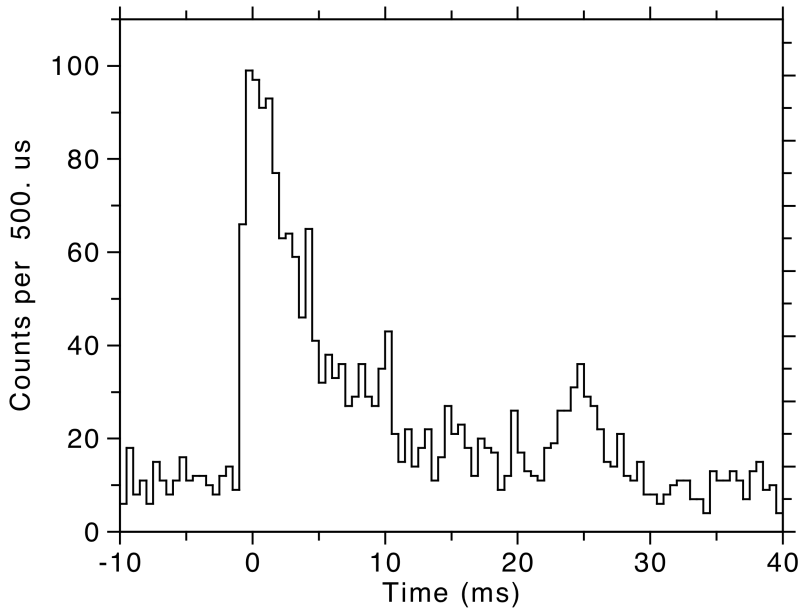
Terrestrial Gamma-ray flashes

Briggs et al, GRL, 2011





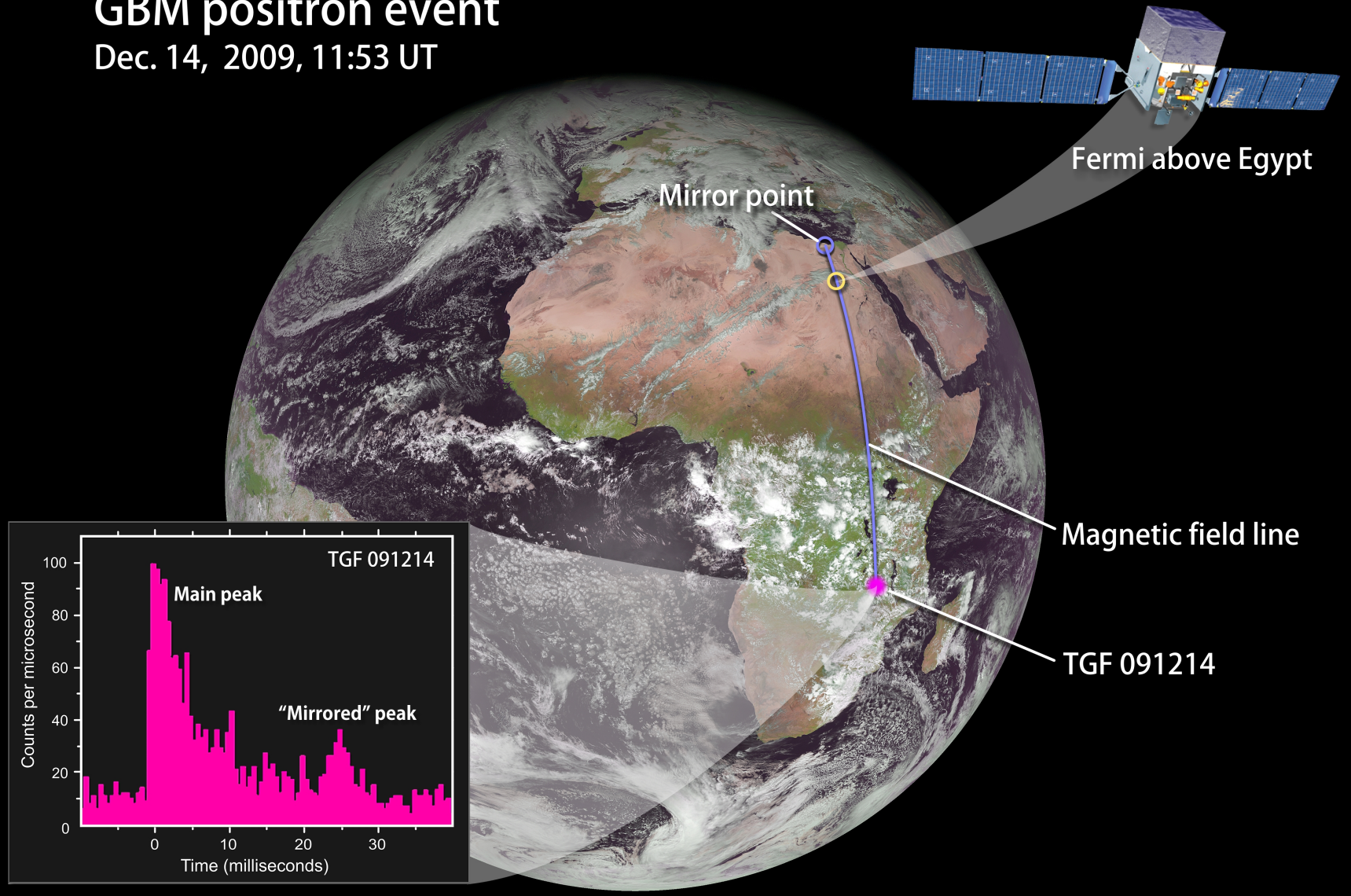
TGFs are concentrated in the tropics near thunderstorms



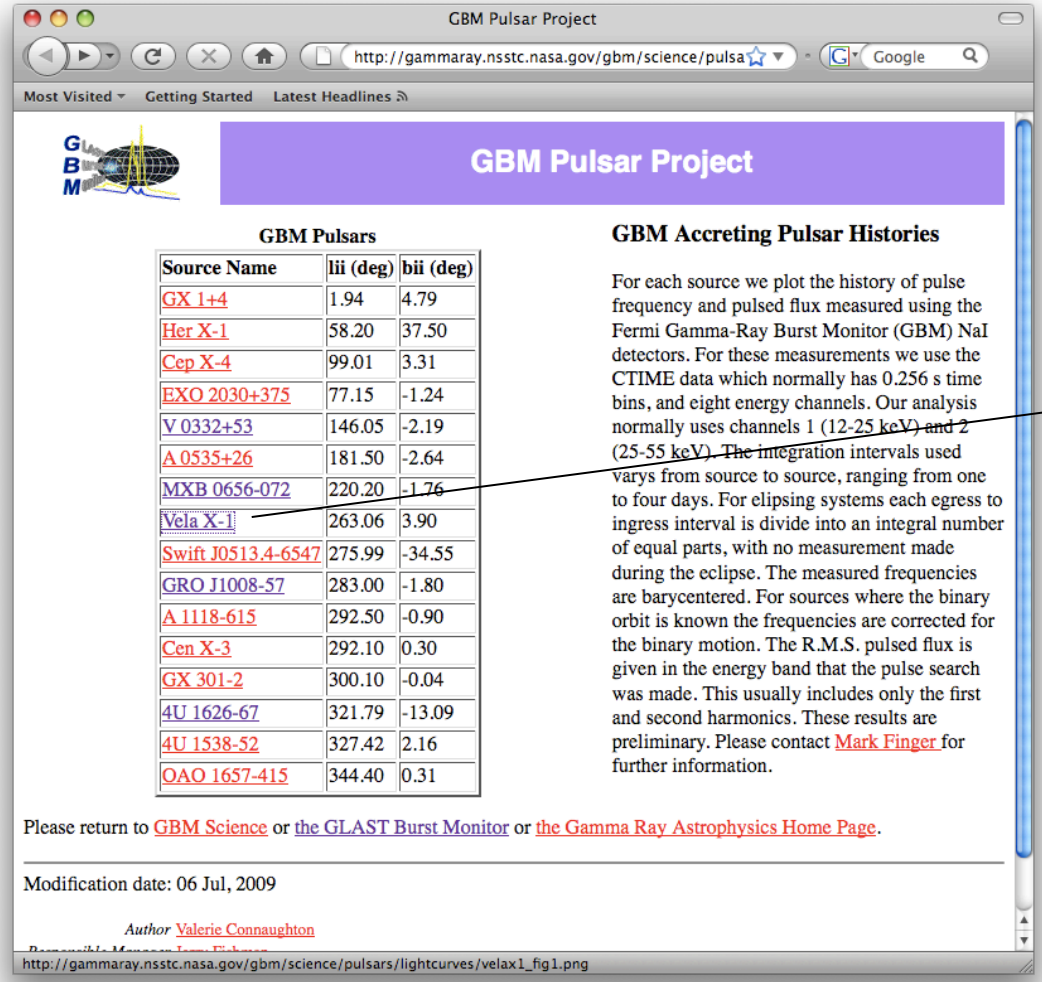
Antimatter from Thunderstorms!

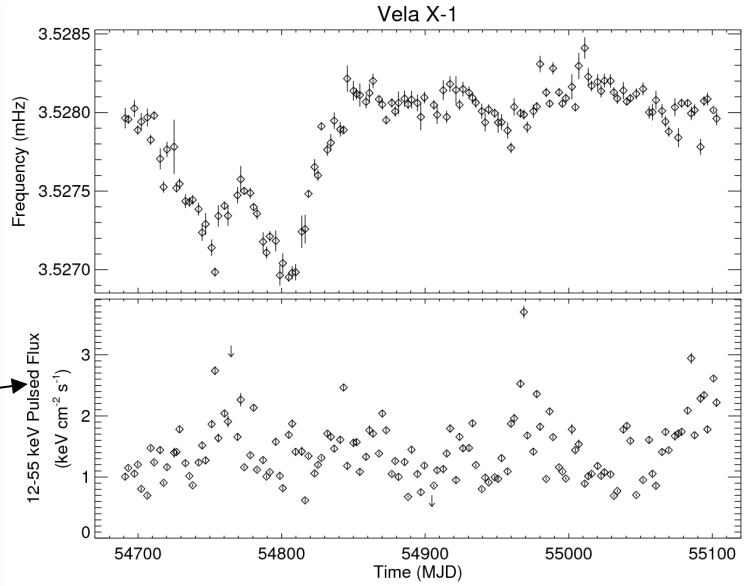
GBM positron event

Dec. 14, 2009, 11:53 UT



GBM - not just transients

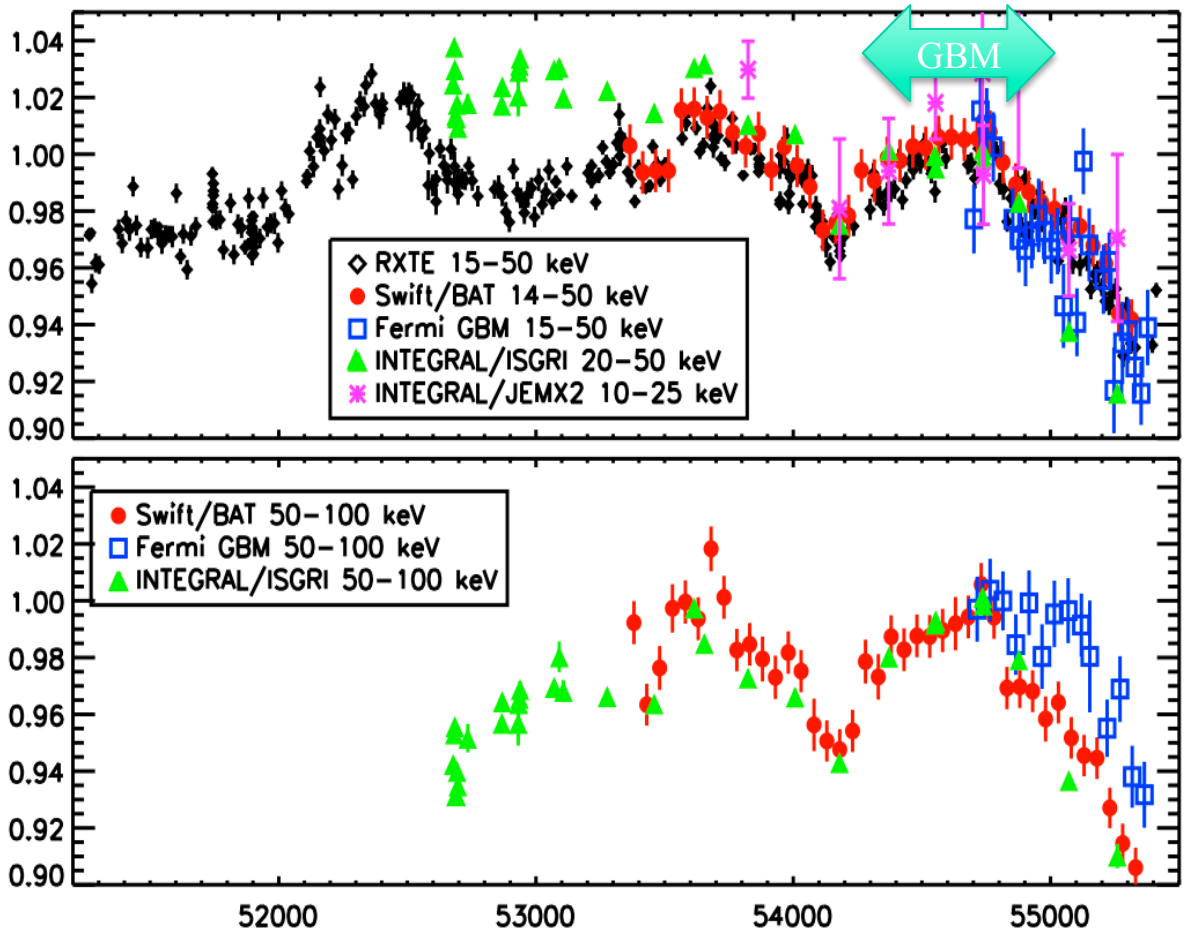




GBM team have made non-GRB high level data/ results available.

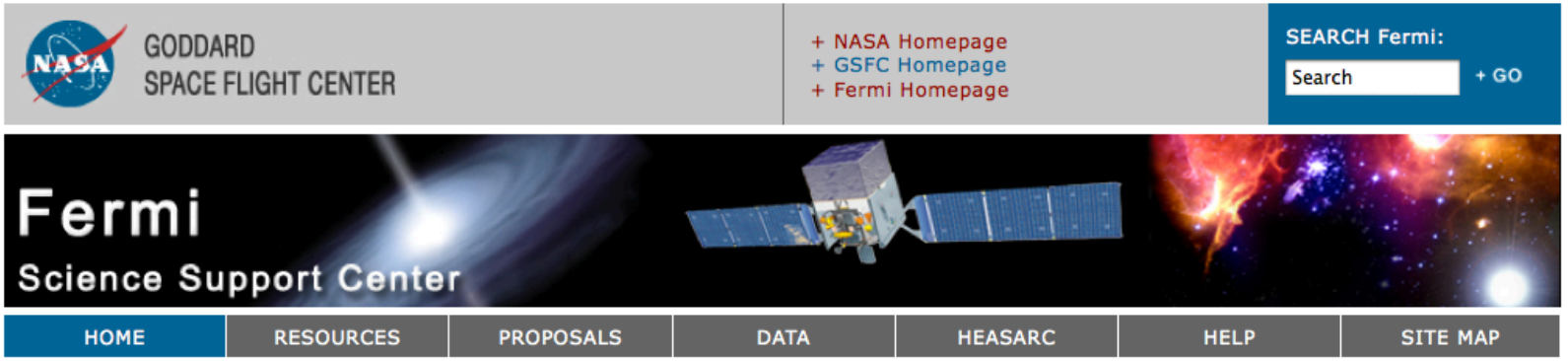
Soft gamma-ray observations of the Crab

- **GBM team noticed that the Crab flux appeared to be decreasing, and compared with other instruments.**
- **Light curves for each instrument are normalized to its average rate from MJD 54690-54790.**

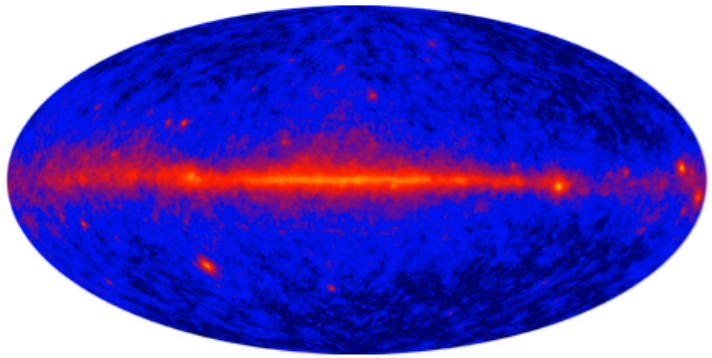


Instruments on four separate spacecraft show decline in Crab flux since August 2008.

Fermi Science Support Center



The Fermi Science Support Center (FSSC) runs the guest investigator program, creates and maintains the mission time line, provides analysis tools for the scientific community, and archives and serves the Fermi data. This web site is the portal to Fermi for all guest investigators.



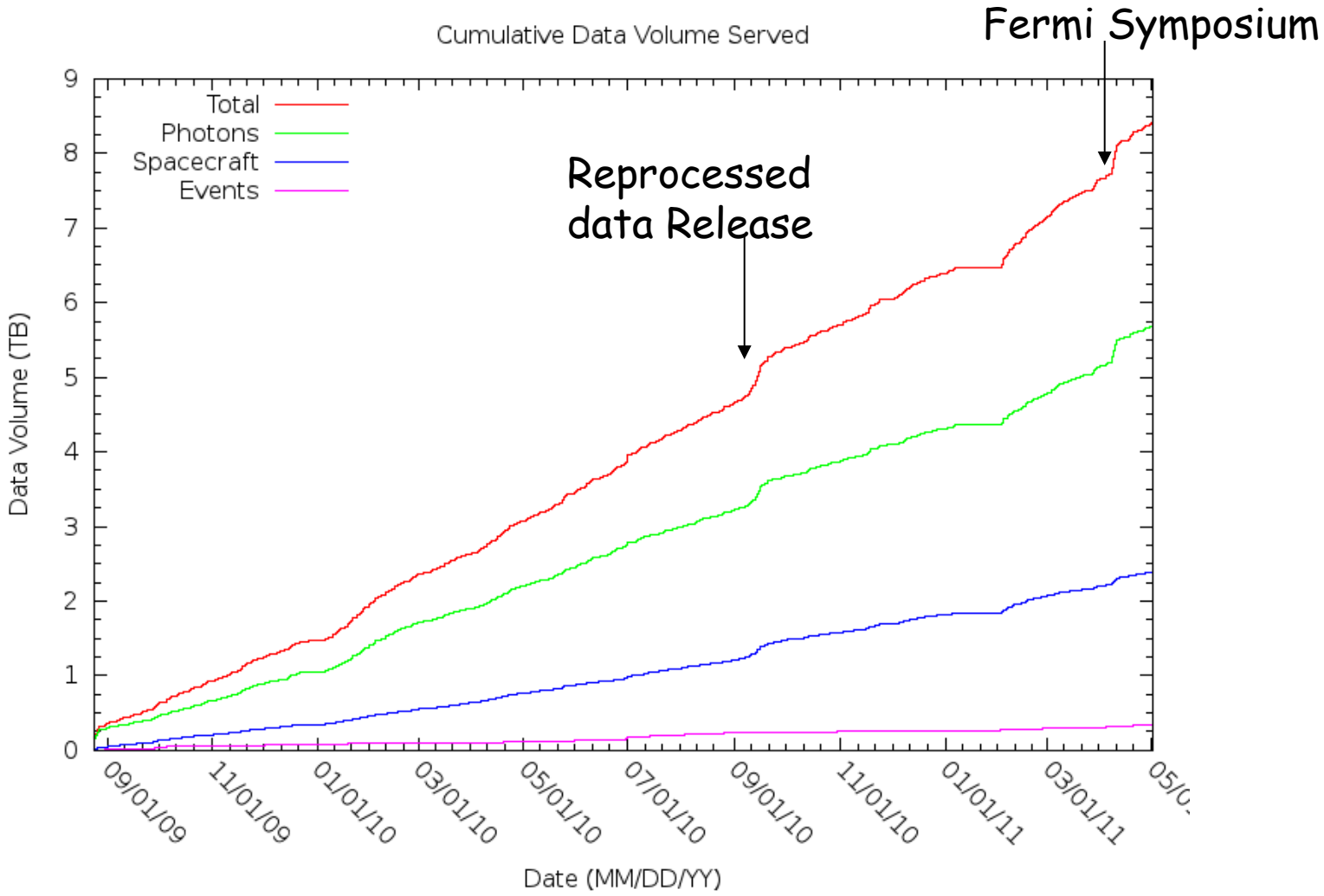
This all-sky view from Fermi reveals bright emission in the plane of the Milky Way (center), bright pulsars and super-massive black holes.
Credit: NASA/DOE/International LAT Team

News

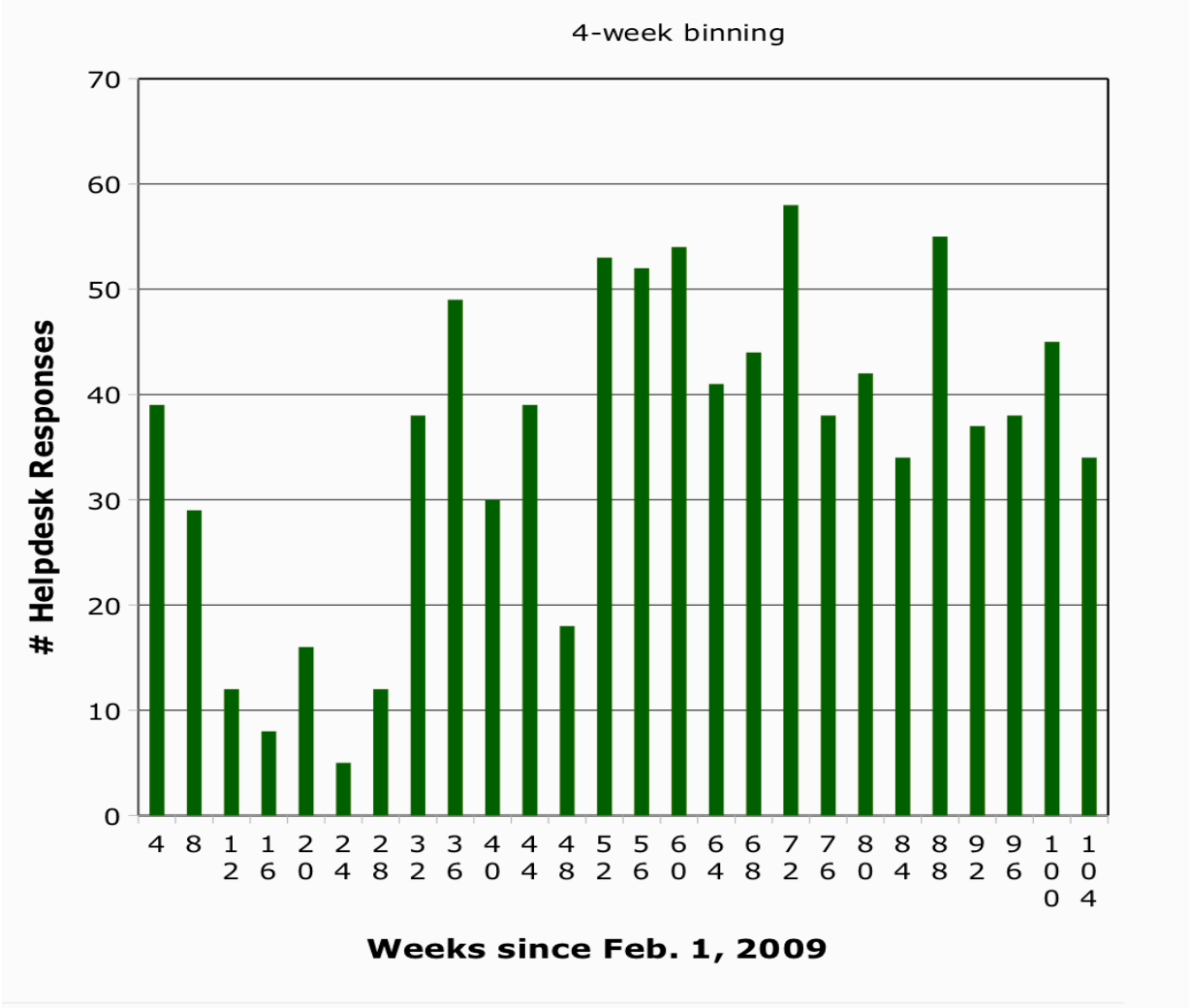
April 13, 2010
Multiwavelength Coordination is Important
The recent ToO on 3C 454.3 serves as a reminder of the need for community input on multiwavelength coordination with Fermi. In evaluating the impact of a ToO, we review scheduled or ongoing multiwavelength observations that have been reported to the FSSC. To ensure your planned observations are taken into consideration, please provide details via our multiwavelength reporting page.
+ Learn More

Public data and extensive support for science Analysis Tools
http://fermi.gsfc.nasa.gov/ssc/
FSSC Supports Guest Investigator Analysis

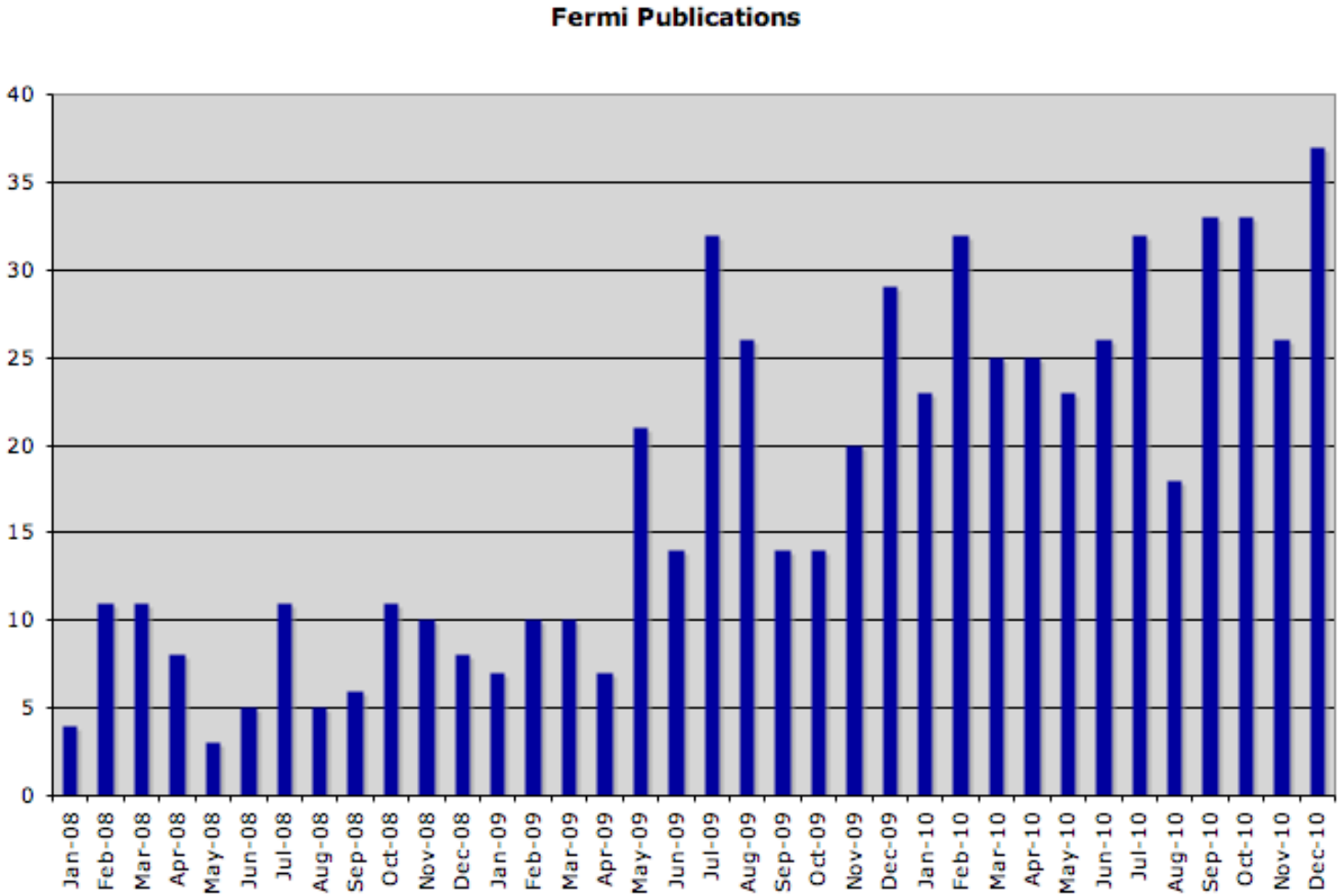
Data Downloads from Science Support Center



Queries to FSSC Helpdesk



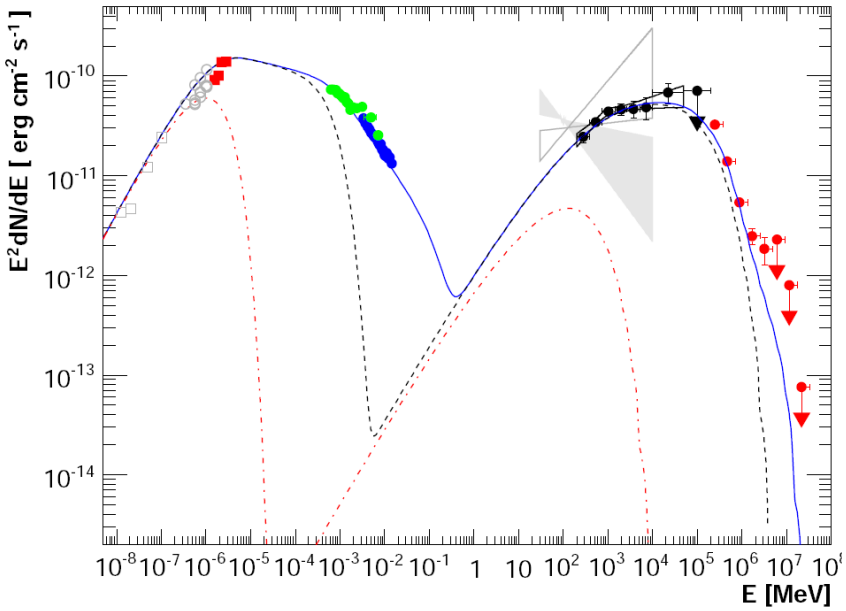
Published Refereed Papers



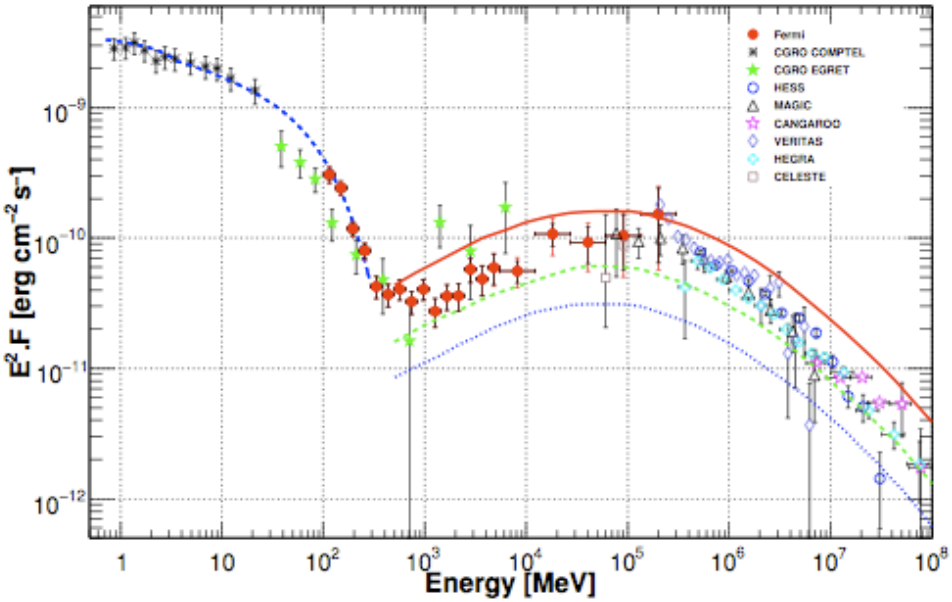
Questions?

LAT Energy Reach: science benefits

PKS 2155-304



High energy Crab Nebula Spectrum



- **Finally closed the unexplored energy range between 10 and 100 GeV**
- **Allow joint fits between LAT (MeV-GeV) and IACTs (GeV-TeV)**
- **Several examples of papers using data beyond 300 GeV: Abdo et al (arXiv: 1011.5260), Neronov et al (arXiv:1004.3767 and arXiv:1011.0210)**