The Variable and Transient Sky Seen by Fermi

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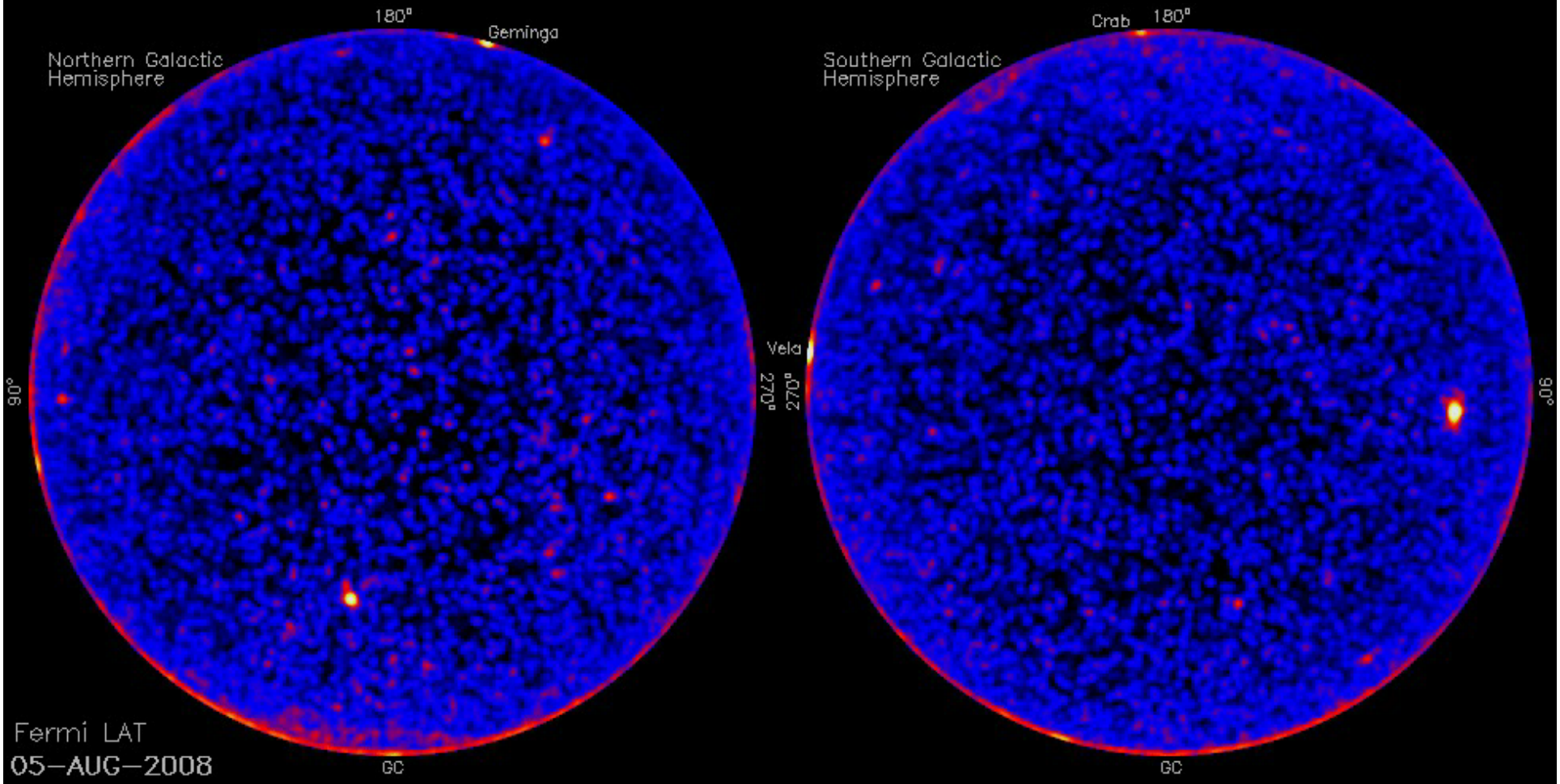
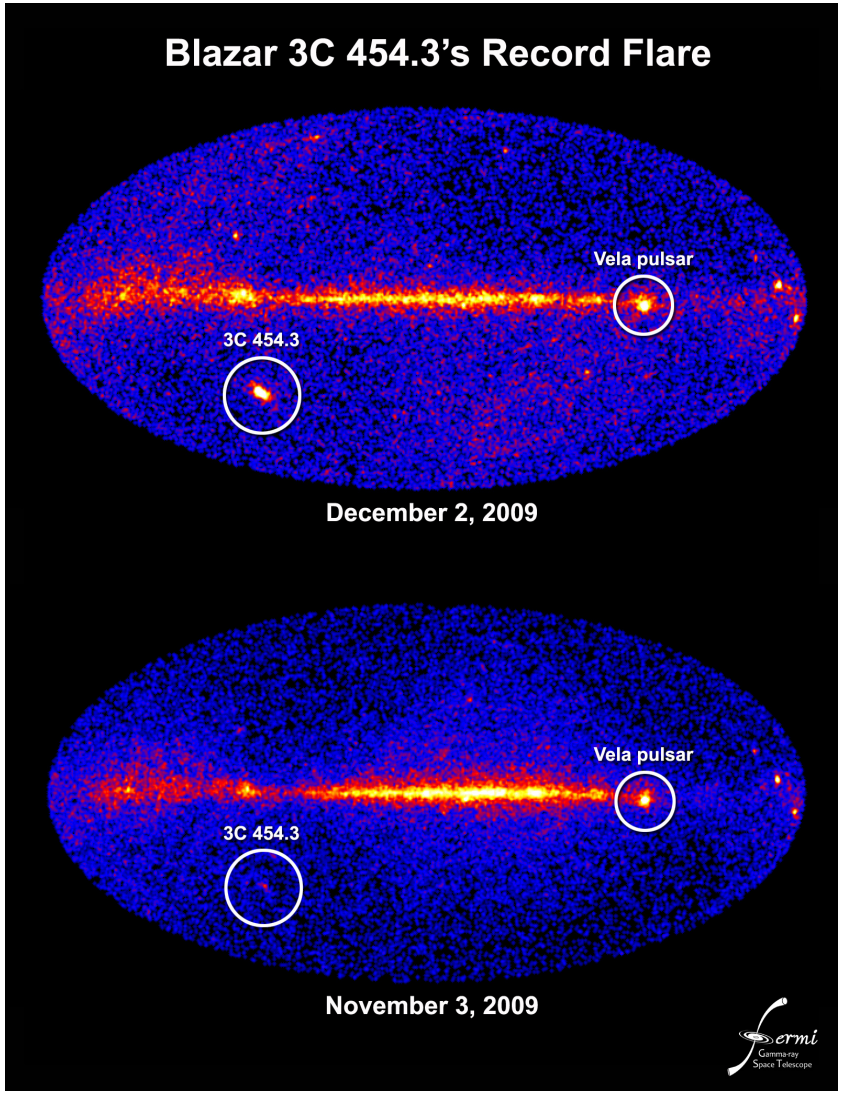
A combination of wide field of view and survey mode enabled Fermi to explore the high energy gamma-ray sky on timescales from milliseconds to years

The Variable Gamma-ray Sky

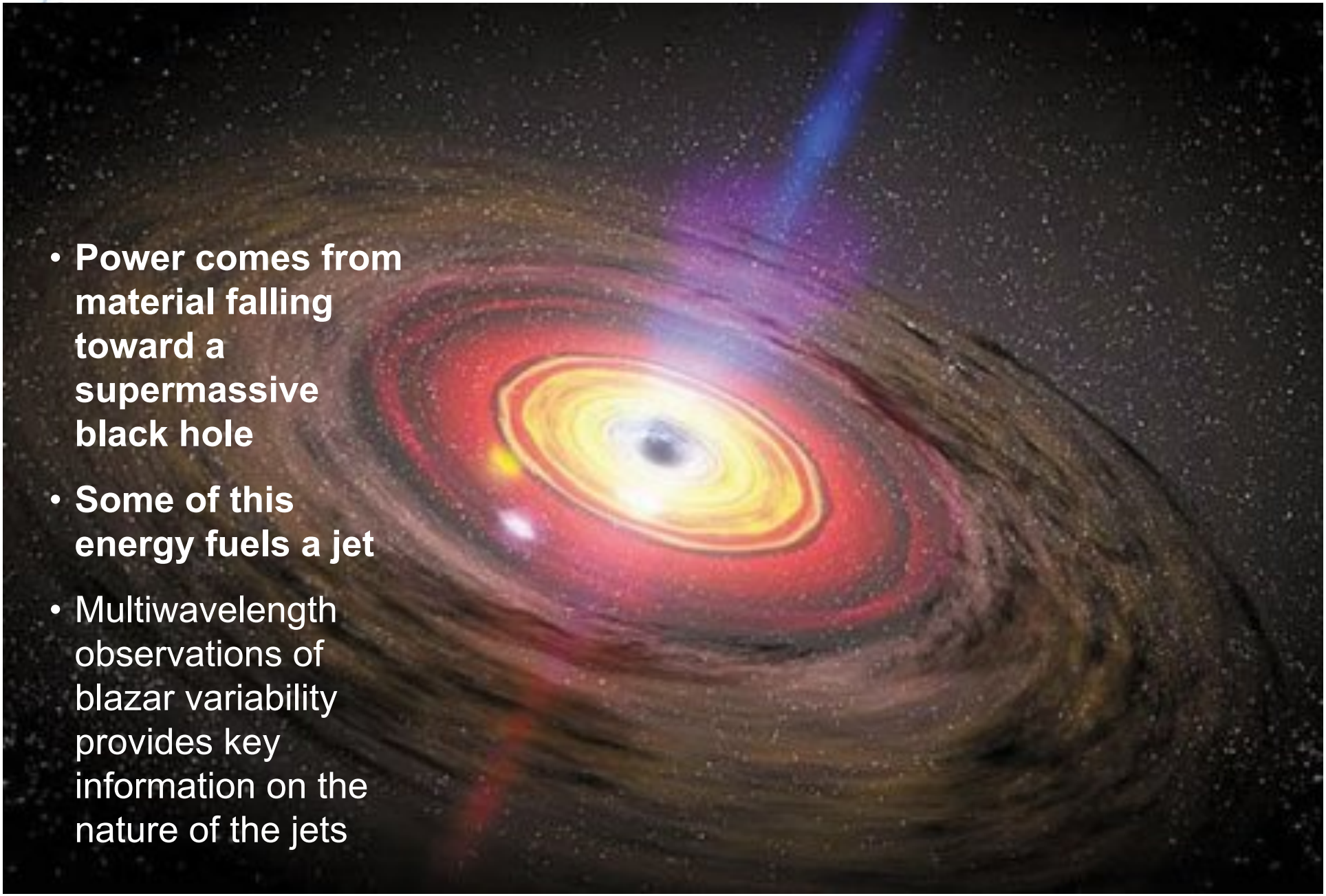


The flaring and variable sky



- **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**

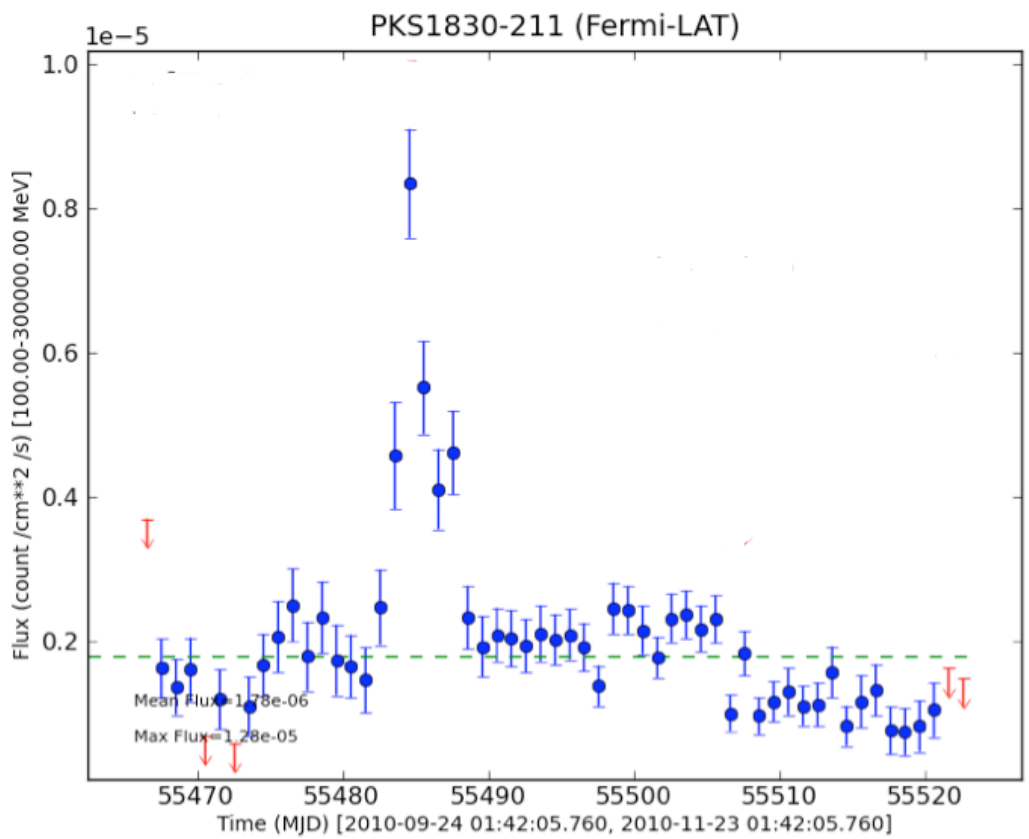
Active galaxies



- **Power comes from material falling toward a supermassive black hole**
- **Some of this energy fuels a jet**
- Multiwavelength observations of blazar variability provides key information on the nature of the jets

PKS 1830-211 - A Gravitational Lens

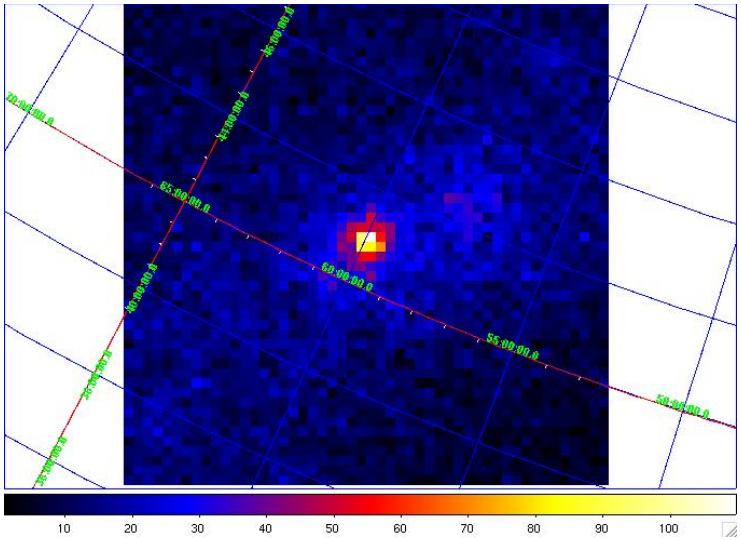
- **Radio Lens PKS 1830-211**
  - **Radio images separated by 0.98”**
  - **Should expect to see pairs of flares (one from each image) separated by ~25 days, based on previous radio observations.**

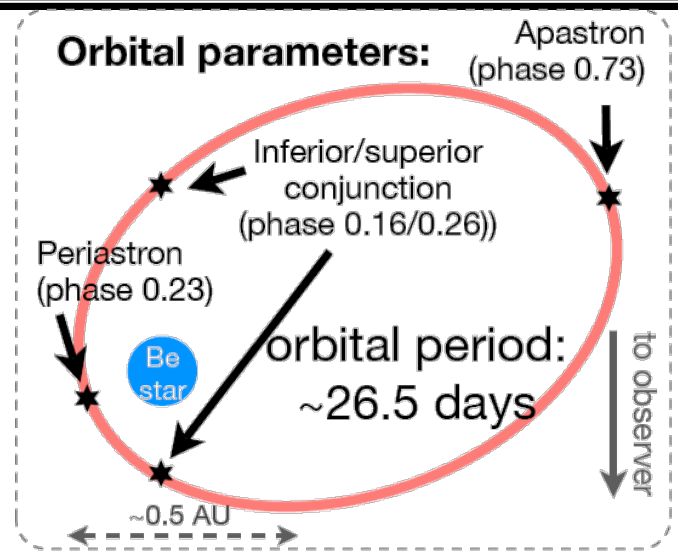


- **We didn’t see a second bright flare with Fermi-LAT**
  - **Gamma-ray source not associated with radio source?**
  - **Beaming effects in PKS 1830-211 (narrower or different beaming angle for radio and gamma-ray emission)?**
  - **Structure/micro lensing in lens galaxy?**

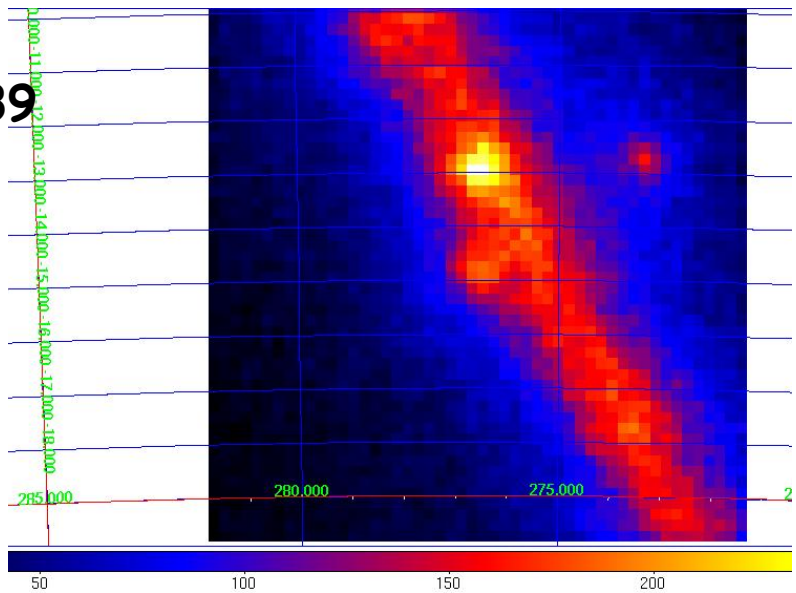
Gamma-ray binaries

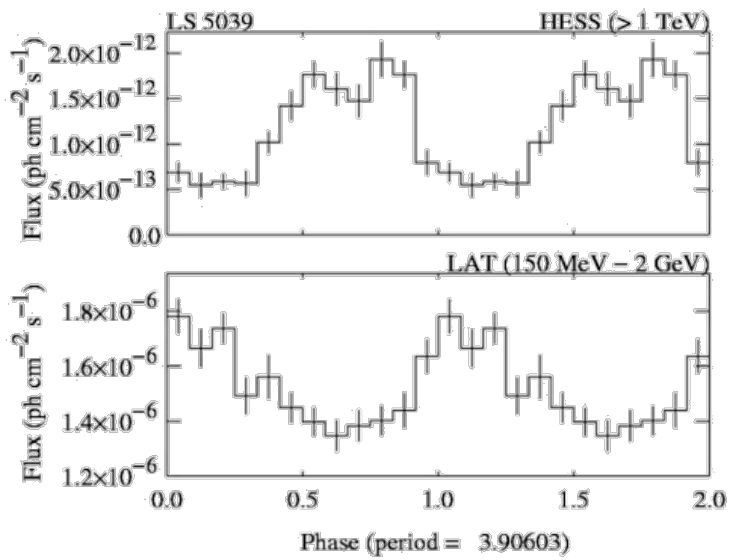
LSI +61 606



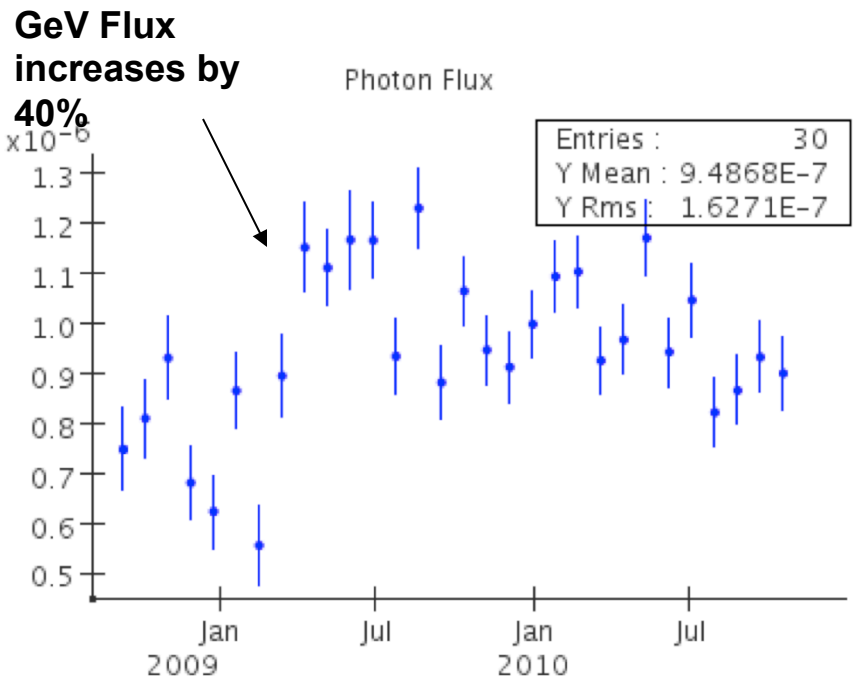


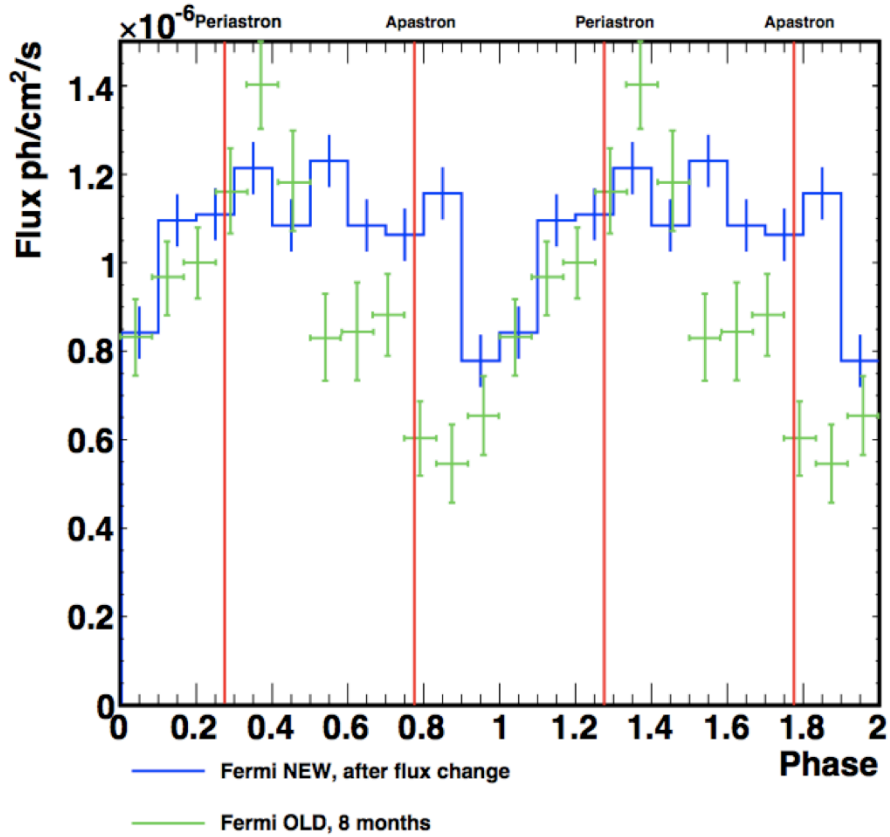
LSI 5039





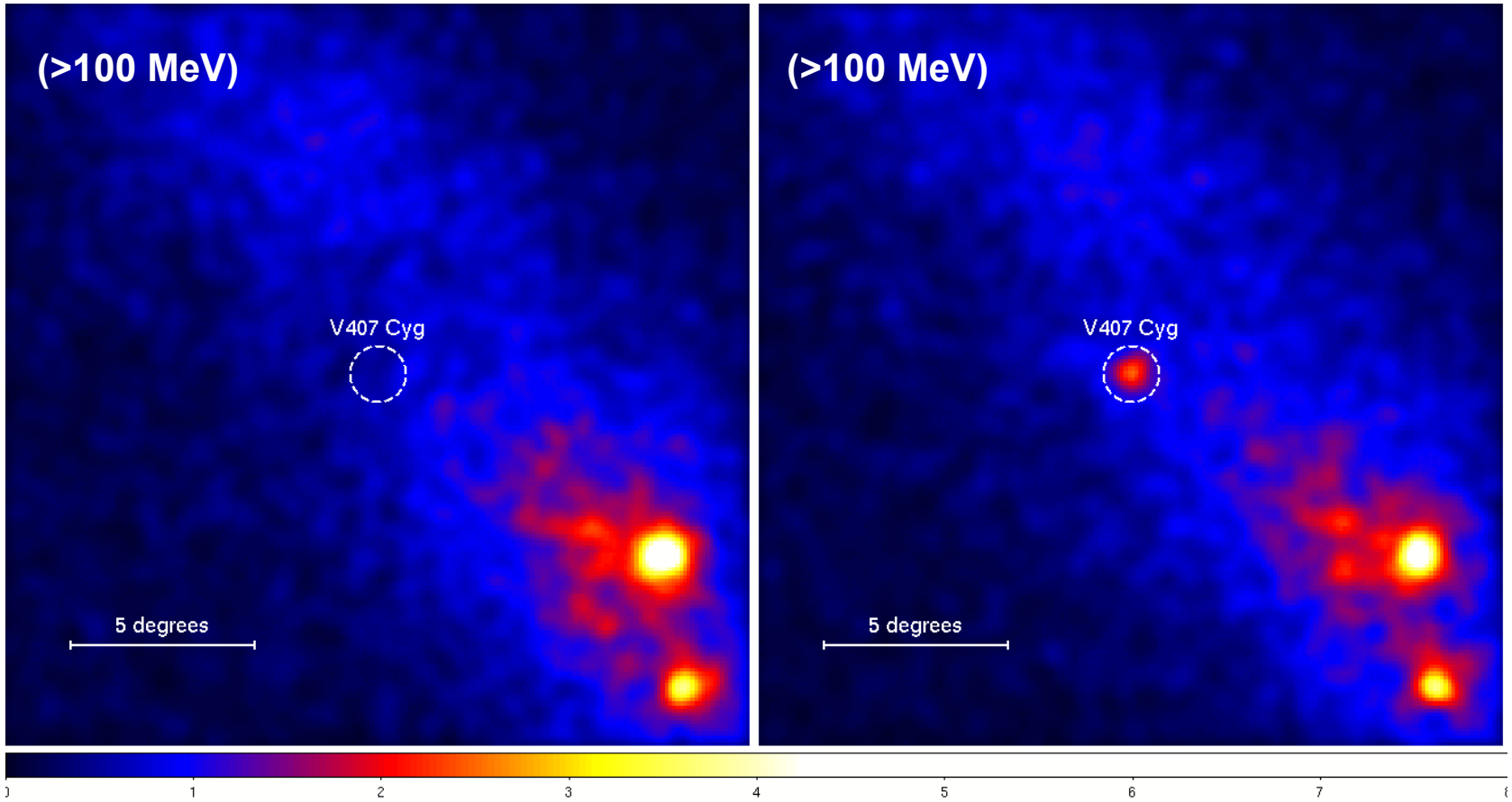
The Peculiar Behaviour of LSI +61 303





- **In March 2009, the GeV gamma-ray flux increased by ~40%, and the gamma-ray orbital modulation decreased significantly**
  - **Related to cyclical modulations of the mass-loss rate of the companion star?**

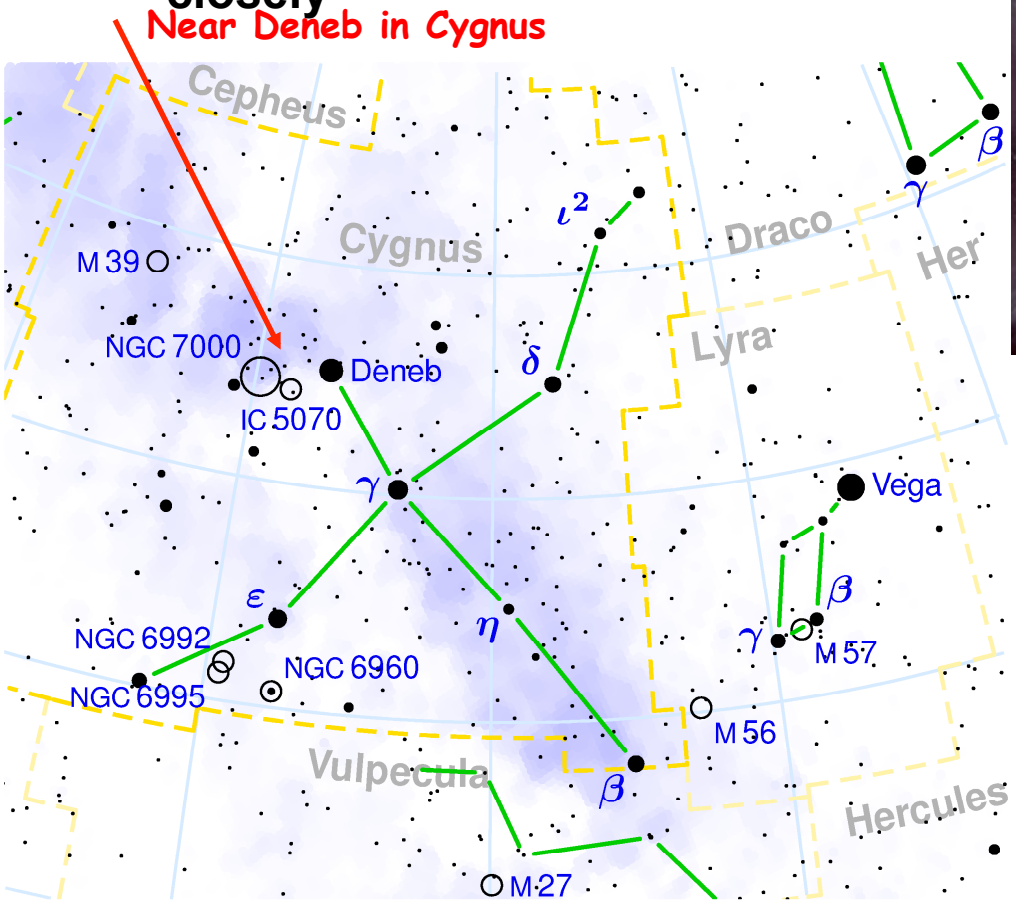
March 2010 - a Galactic plane transient



When the LAT team looked at the Swift webpage to request X-ray observations, we noticed that Swift was already looking at this location!

V407 Cygni: a variable star

Symbiotic binary:
small white dwarf star and large red giant star orbiting each other closely

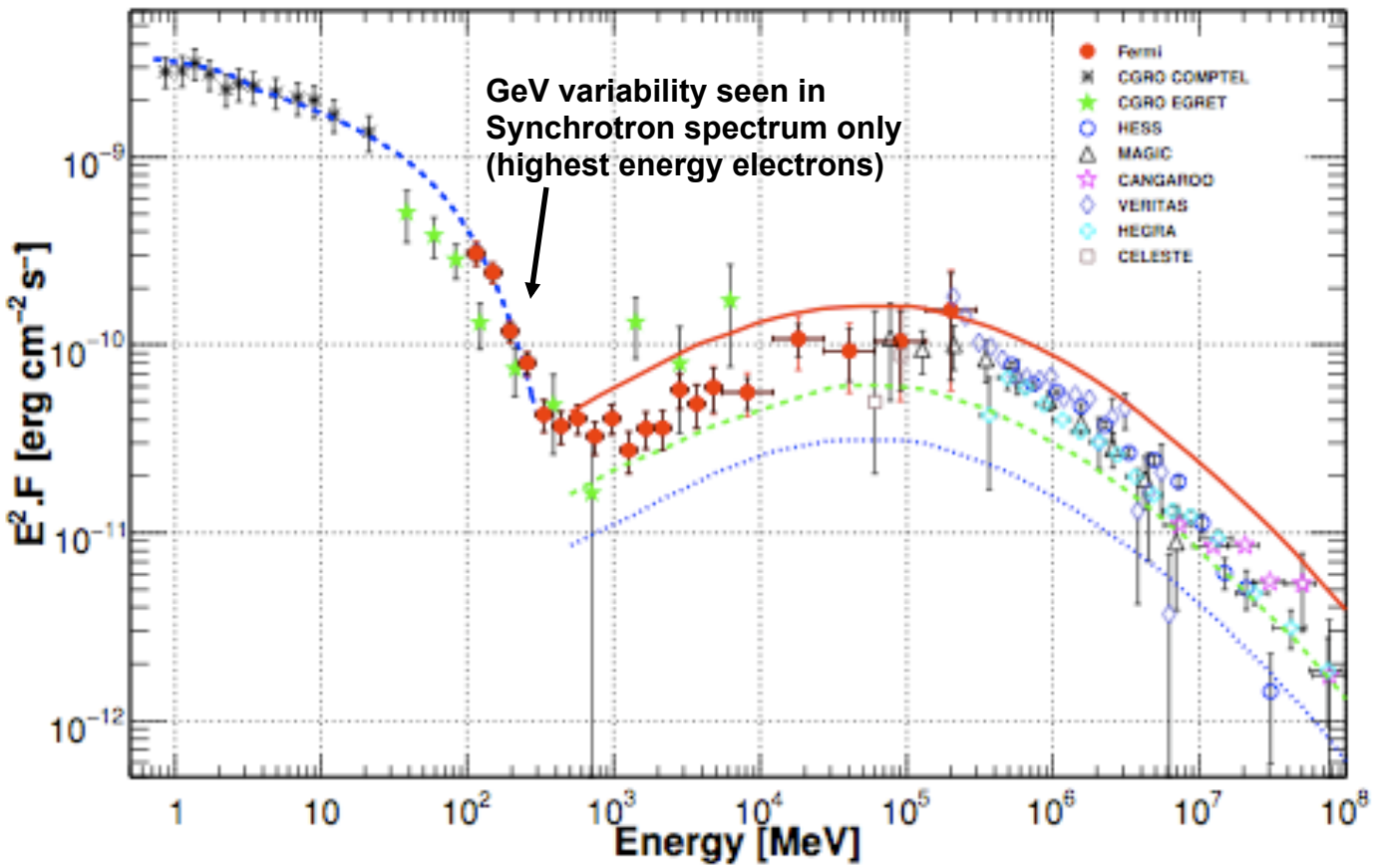


Variability can come from the binary motion, pulsations of the red giant, accretion disk of stellar material around the white dwarf - complex and fascinating systems

V407 Cyg ~ 6000 light years away

Crab Nebula - "reference source" in High Energy Astrophysics

Pulsar Subtracted Spectrum



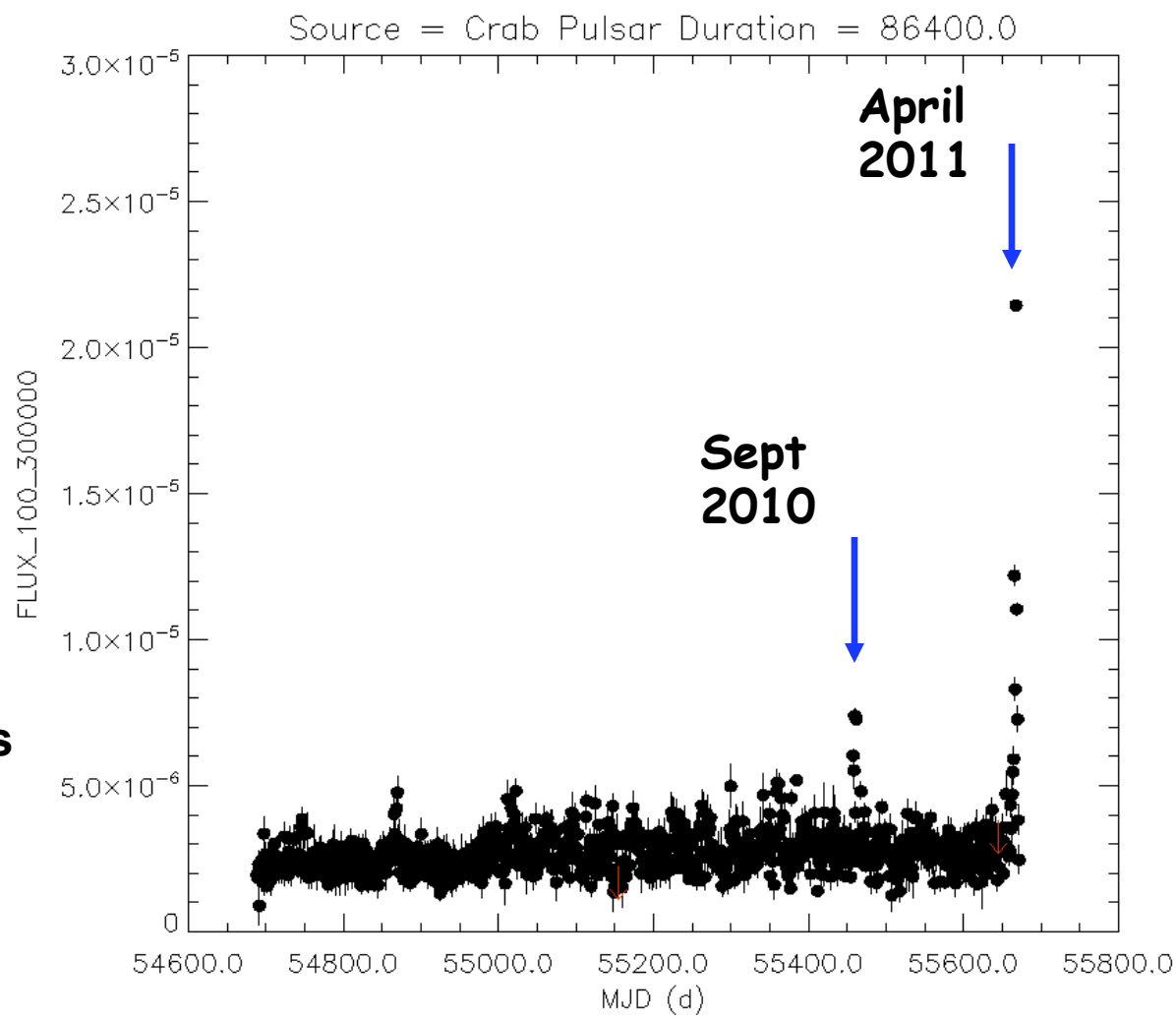
- **Broad energy coverage of LAT enables overlap with TeV observations for bright sources.**

Public Crab Gamma-Ray Lightcurve

Shockingly bright flares in Sept 2010 and April 2011.

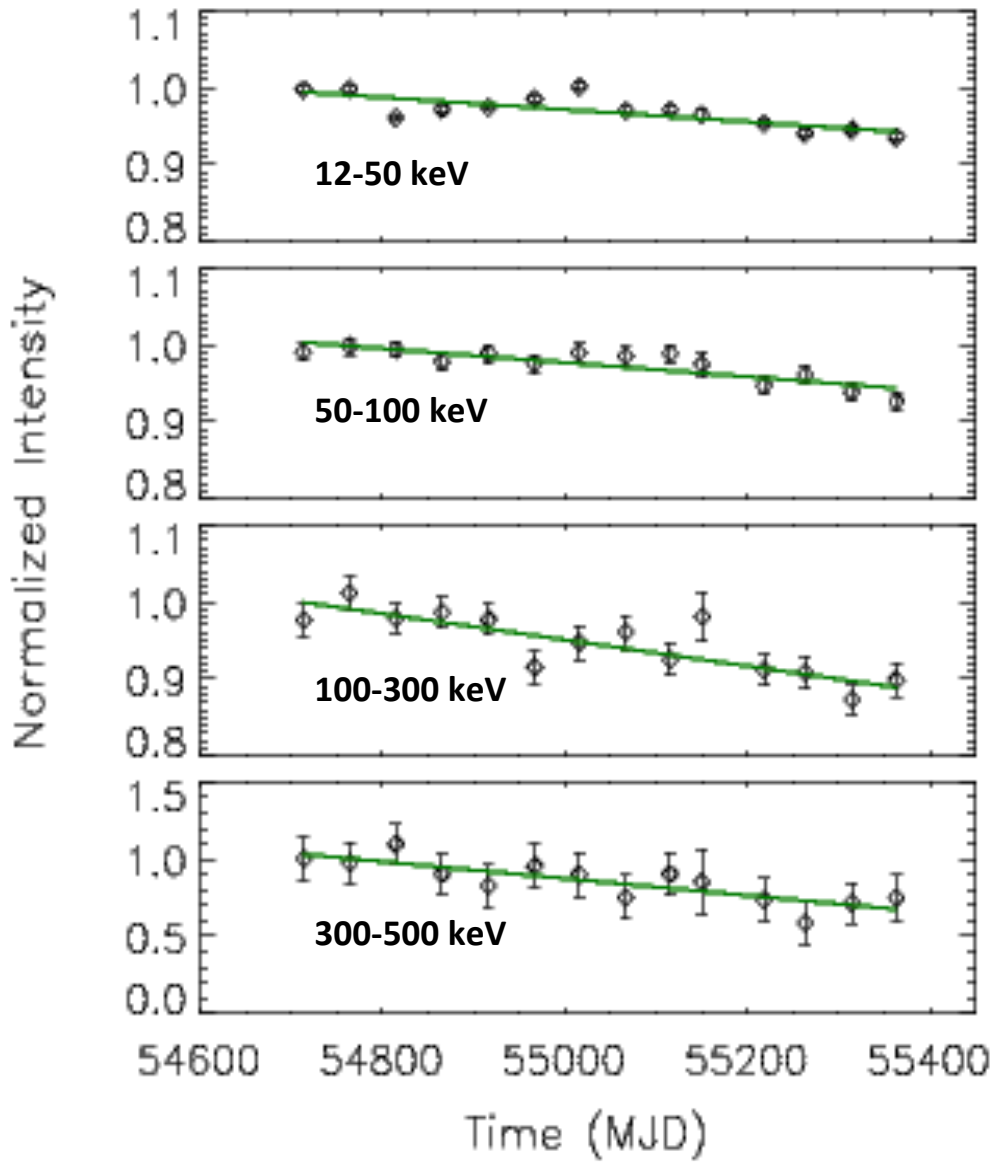
Rapid identification of flares by LAT team enabled Chandra and HST TOO observations in Sept, and sequence of Chandra observations in Sept (target visibility issues for HST)

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



Meanwhile at Soft Gamma-ray Energies….

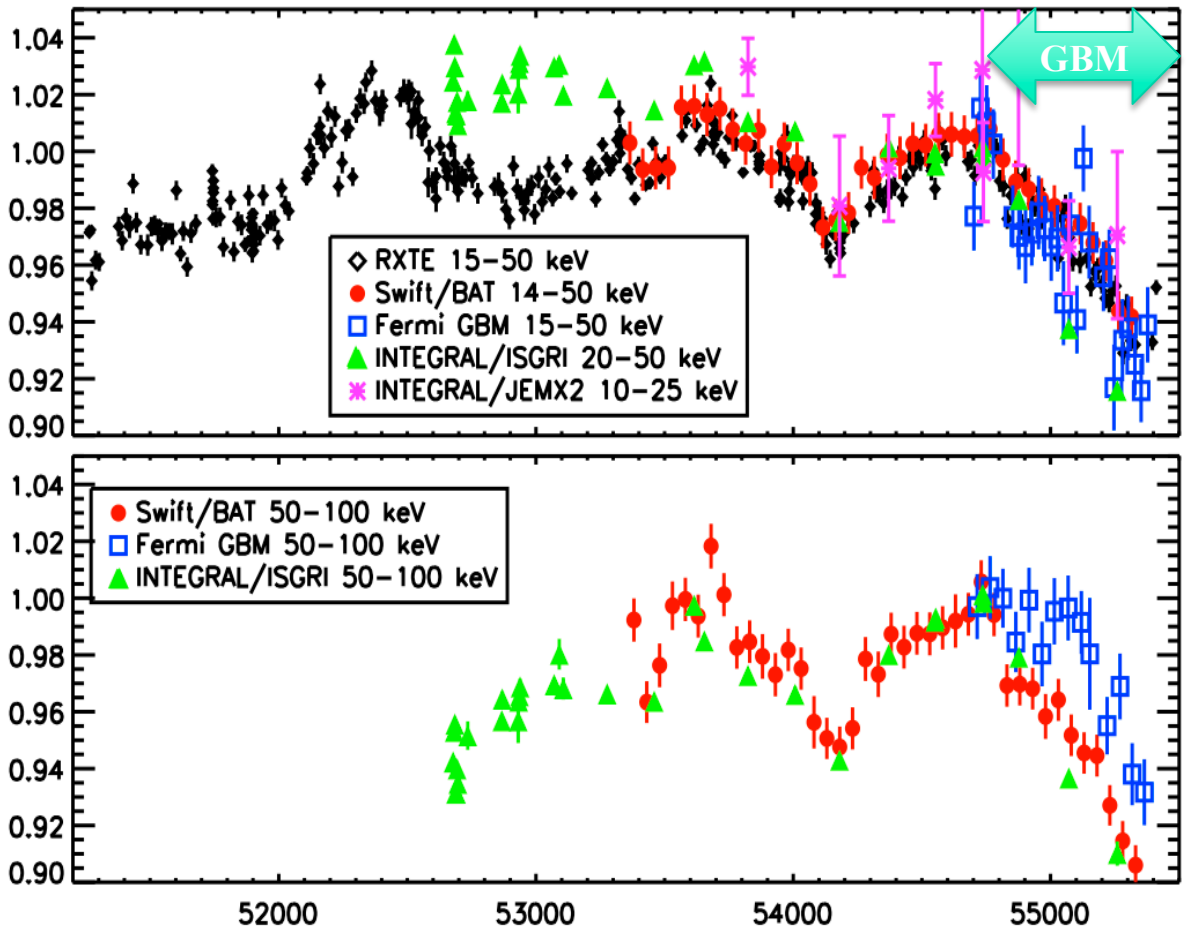
- **GBM Observations of the Crab**
  - Normalized to long-term average in each band
  - Decline in Crab flux (MJD 54690-55390)
  - No changes in GBM response or calibration



Wilson-Hodge et al 2010

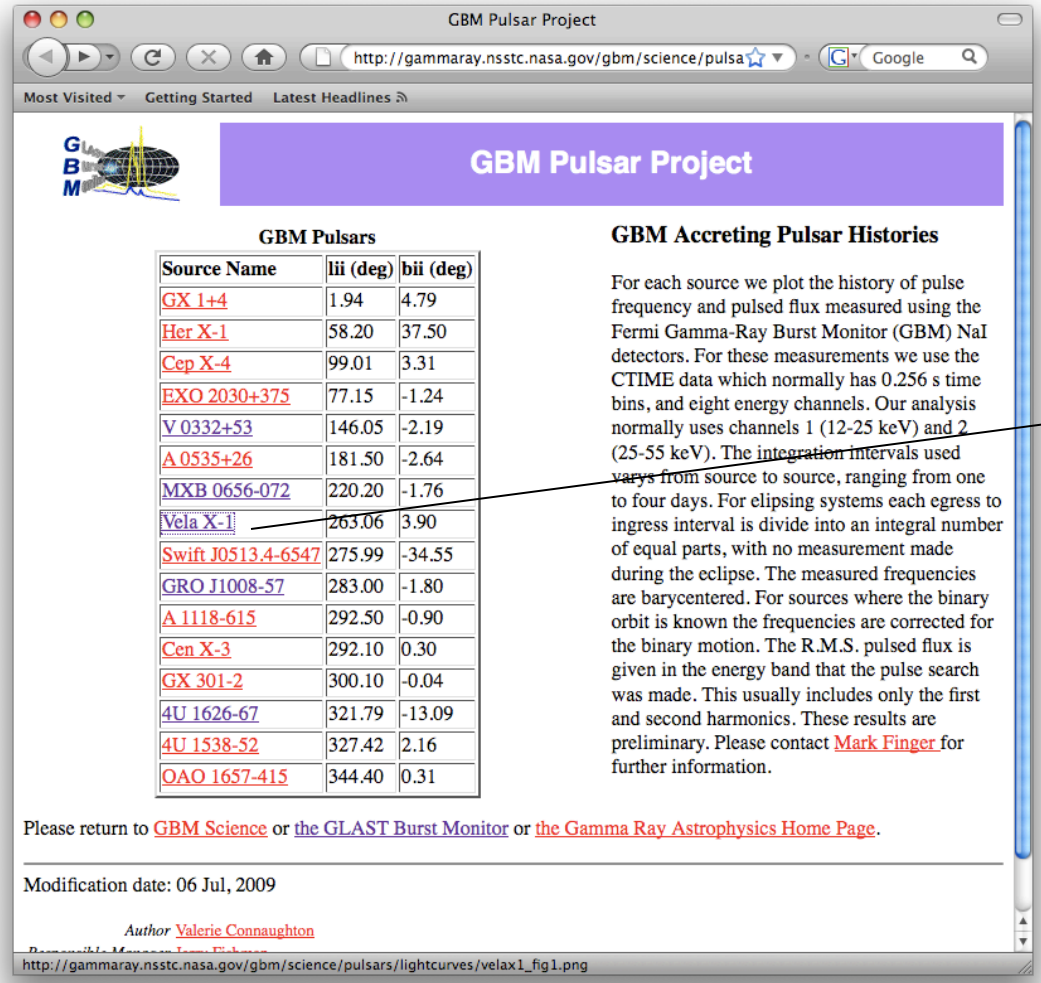
Also seen by INTEGRAL, SWIFT and RXTE

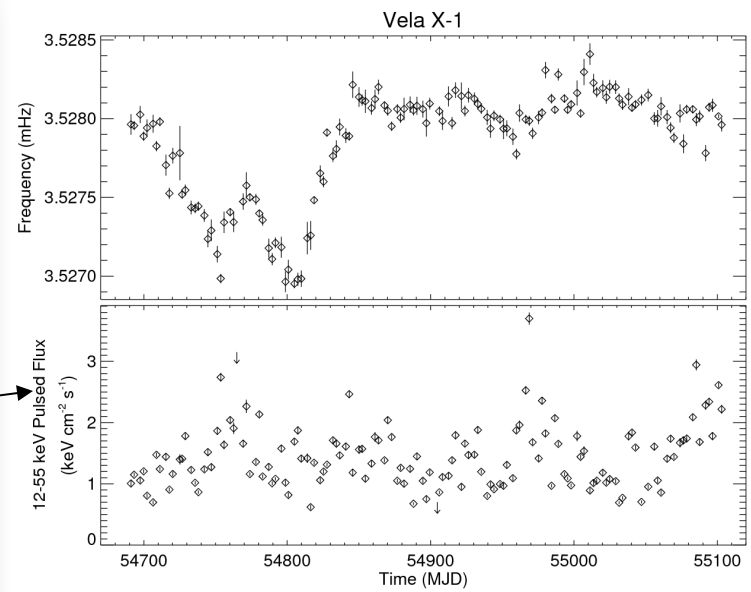
- Light curves for each instrument are normalized to its average rate from MJD 54690-54790 .



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

GBM - not just transients



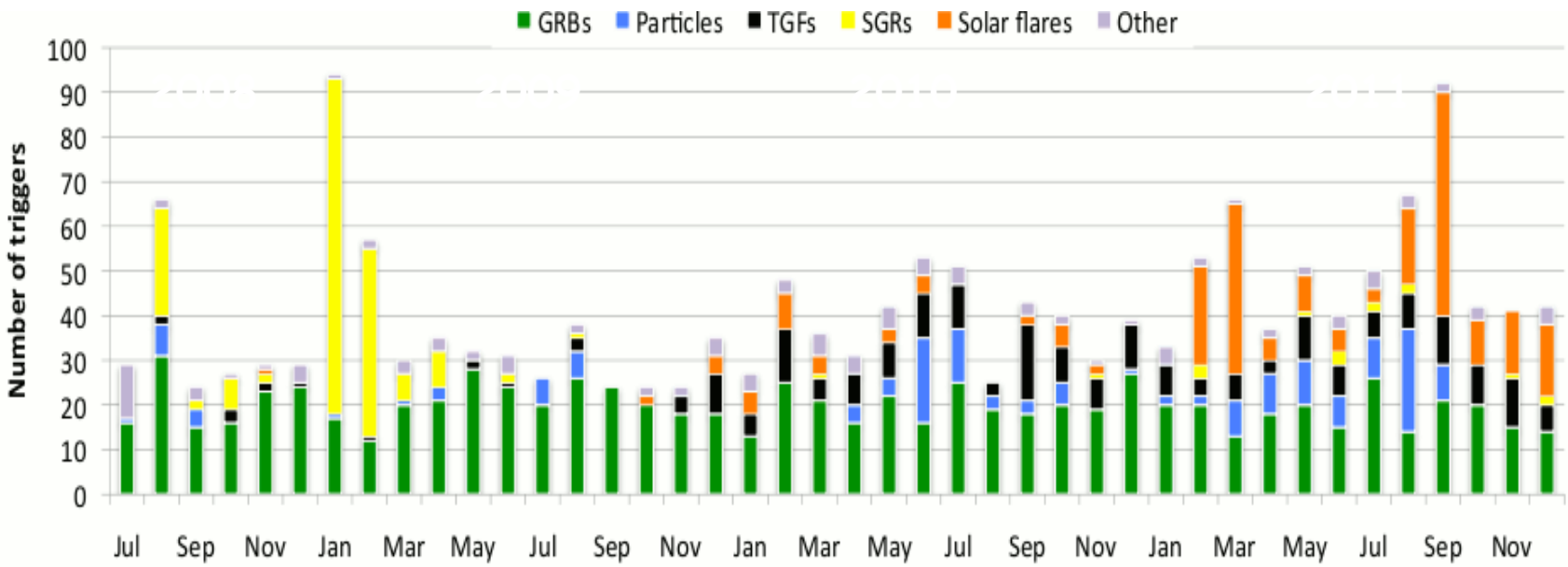


GBM team have made non-GRB high level data/ results available.

Access this from: http://fermi.gsfc.nasa.gov/ssc/data/access/

Gamma-ray Burst Monitor

GBM is the most prolific detector of Gamma-Ray Bursts and Terrestrial Gamma-ray Flashes (thunderstorms) currently in orbit



Detecting MeV transients from Earth, Sun, Galaxy and distant Universe

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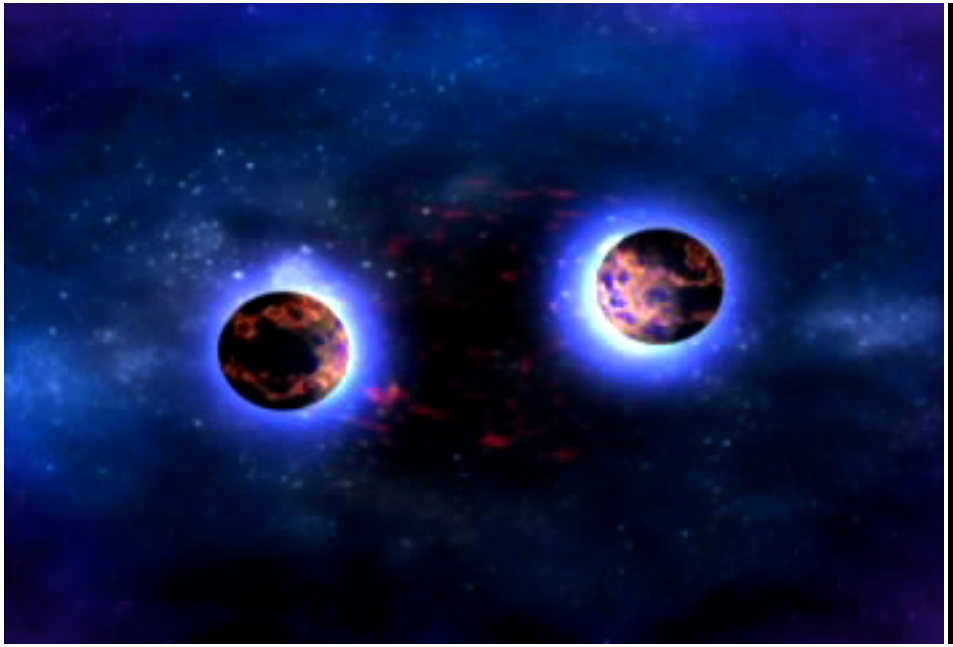
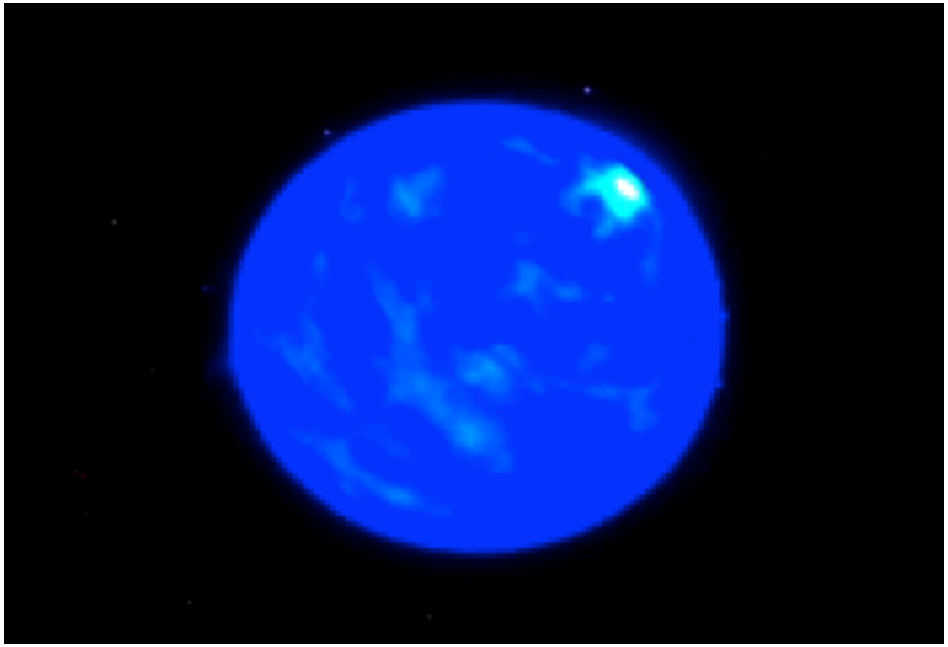
Gamma-ray bursts

Huge flux of gamma-rays lasting from 0.1-1000's seconds





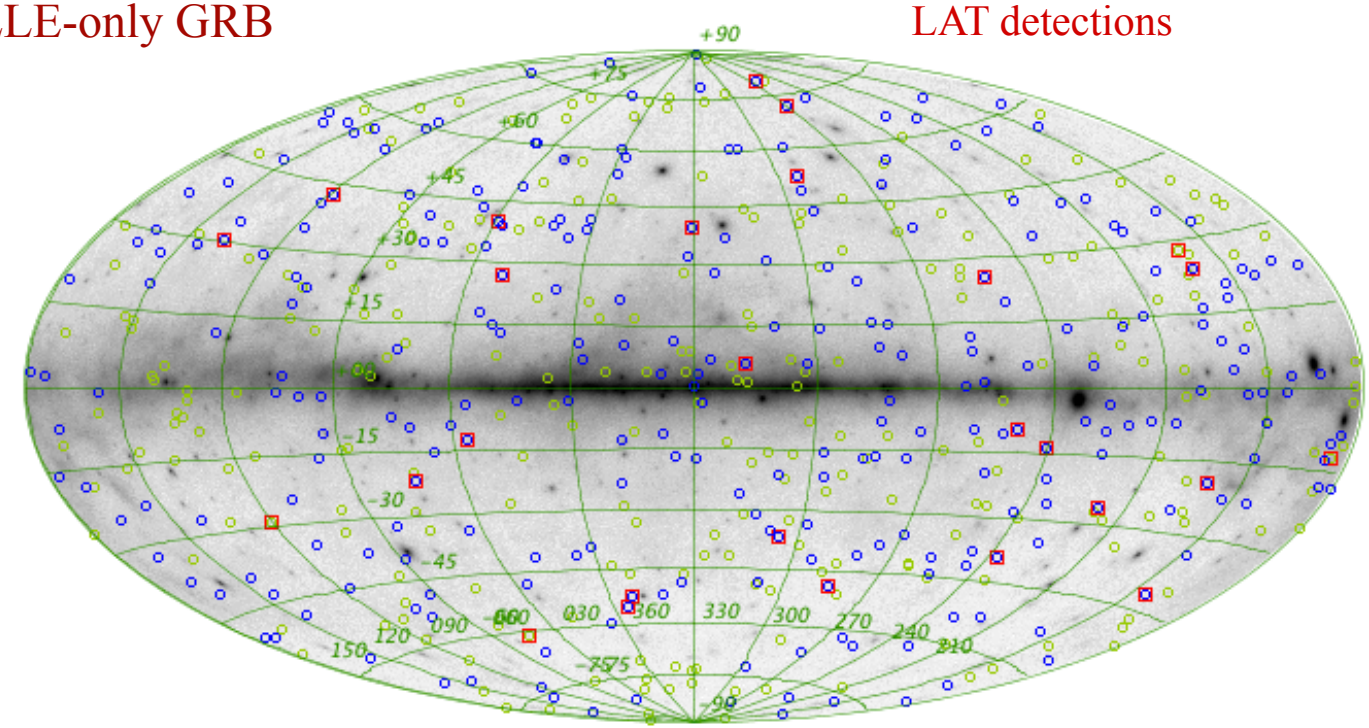
Compact Mergers: Two neutron stars, or a neutron star and a black hole, collide and merge, producing a jet.

Collapsars: A rapidly spinning stellar core collapses and produces a supernova, along with relativistic jets.

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



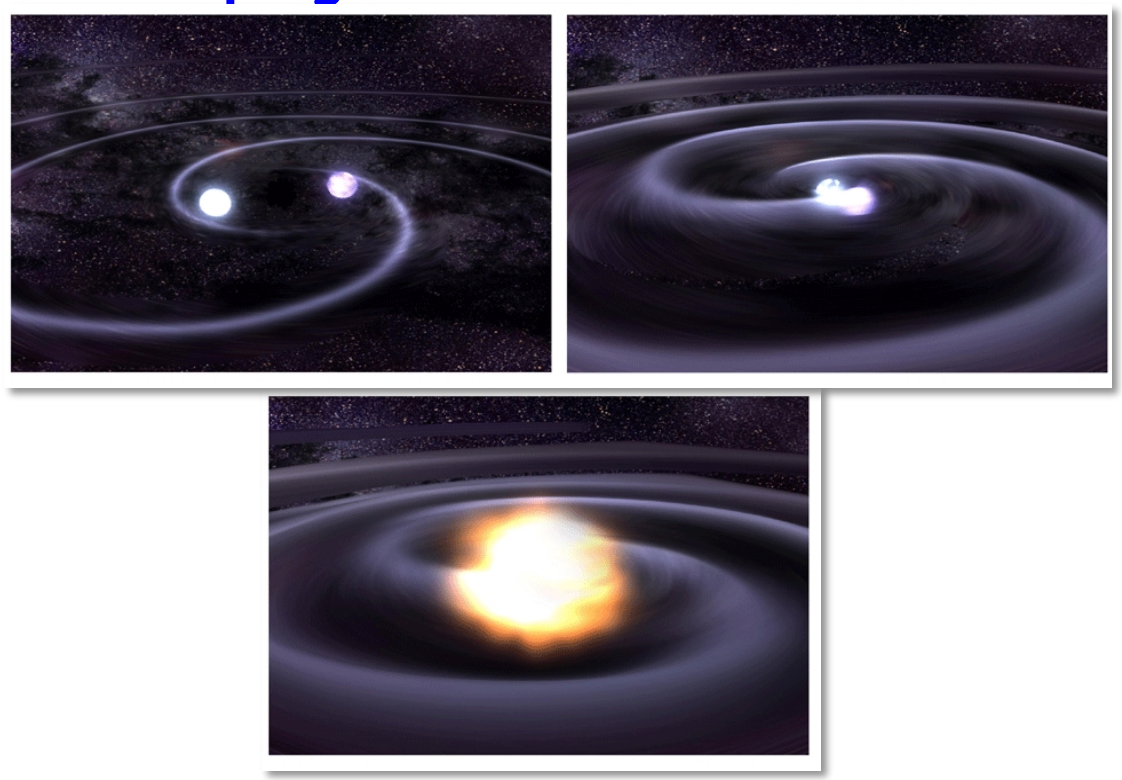
11 months Fermi LAT count map

GRBs and Gravitational Waves

***Fermi*-GBM and Advanced LIGO (>2015) should see coincident Gravitational wave/Electromagnetic emission or rule out NS-BH mergers as the progenitors of short GRB**

Large rate of short bursts in GBM is key to coincident detections

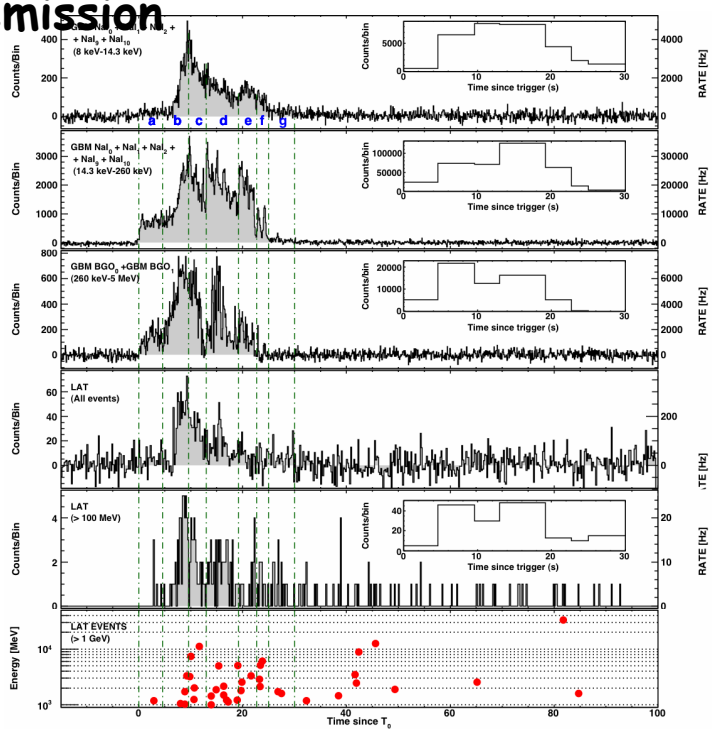
GBM Short GRBs in ALIGO horizon:
N(z<0.11, NS-NS) ~ $2^{+4}_{-1}\,yr^{-1}$
N(z<0.22, NS-BH) ~ $8^{+6}_{-3}\,yr^{-1}$



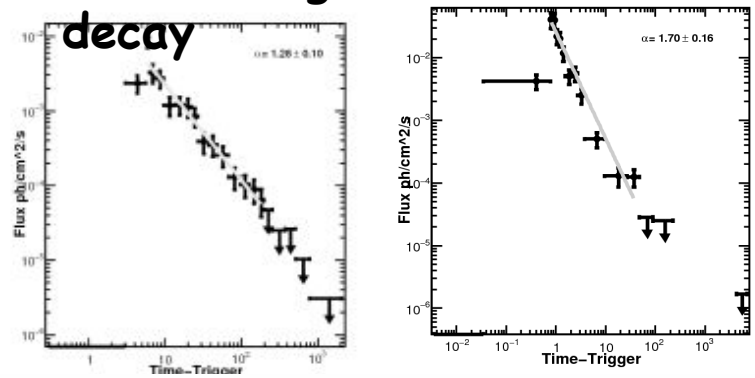
- **Both observations bring complementary information: ALIGO → inspiral characteristics ; *Fermi* → jet properties & environment**

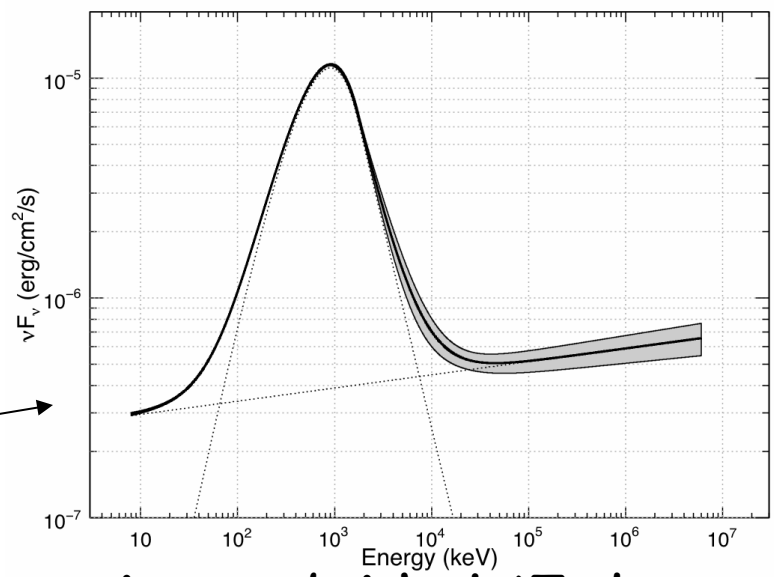
GeV GRB Properties

Delayed onset of prompt emission



GeV Afterglow with Powerlaw decay



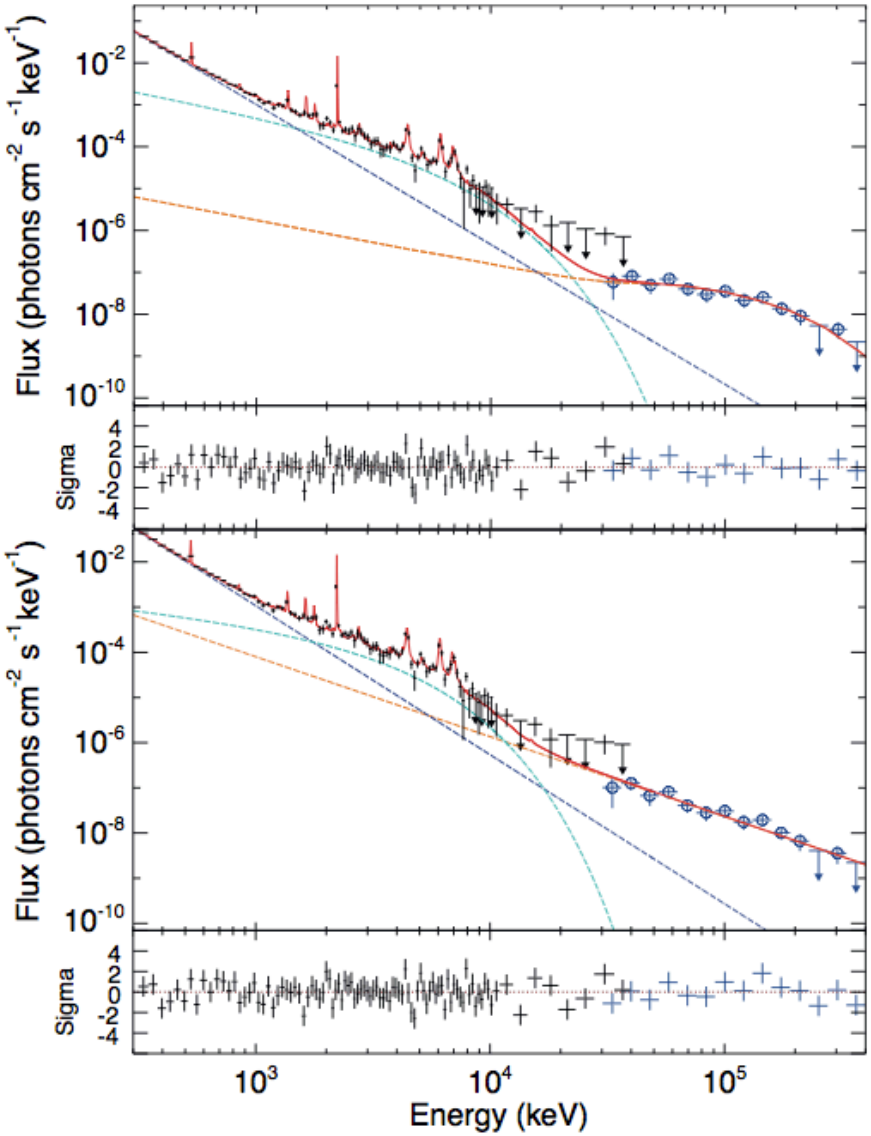


Extra Spectral Component

Remarkably, these features are seen in most bright LAT-detected GRB!

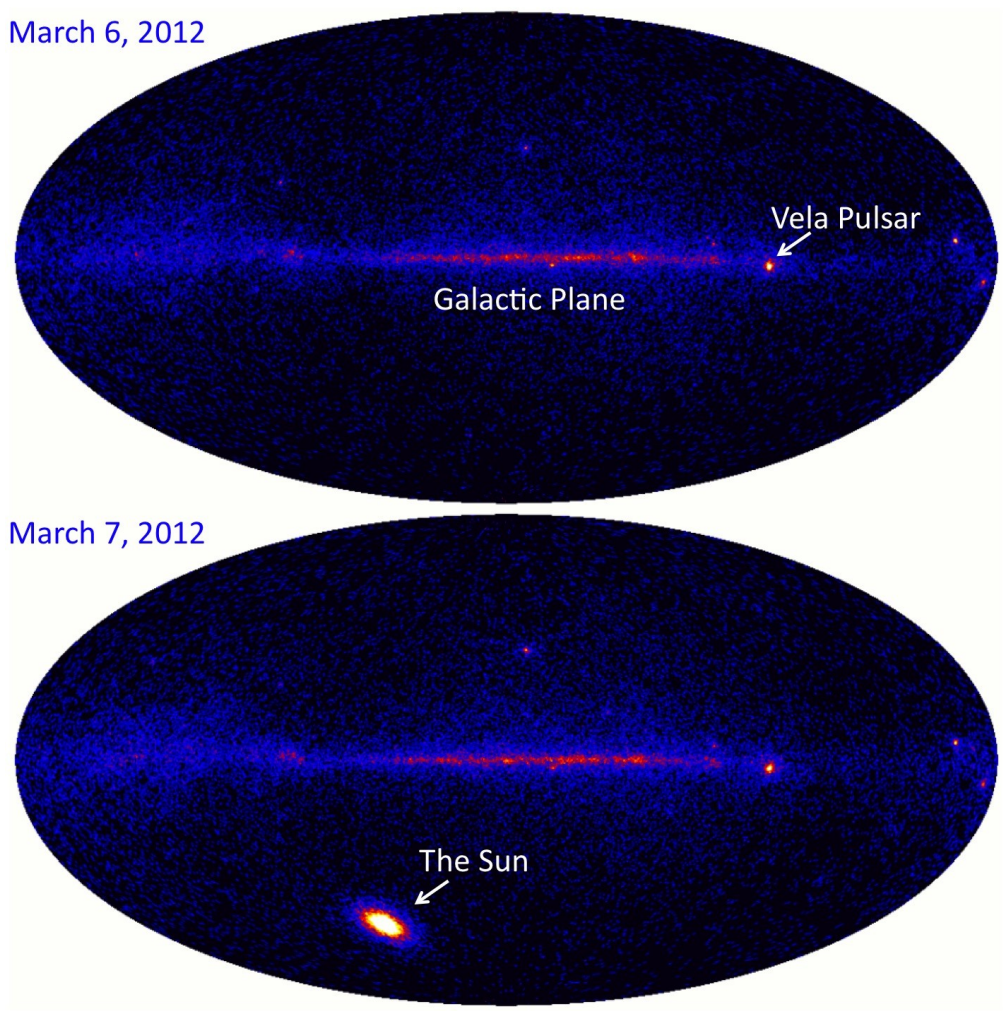
The Sun is waking up! June 12 2010

- Nuclear de-excitation lines
- 512 e+/e- annihilation line
- 2.2 Neutron capture line
- Electron spectrum described by a power law + comptonized (needs particle acceleration)
- Pion template not clearly favored over the electron emission (power law)...



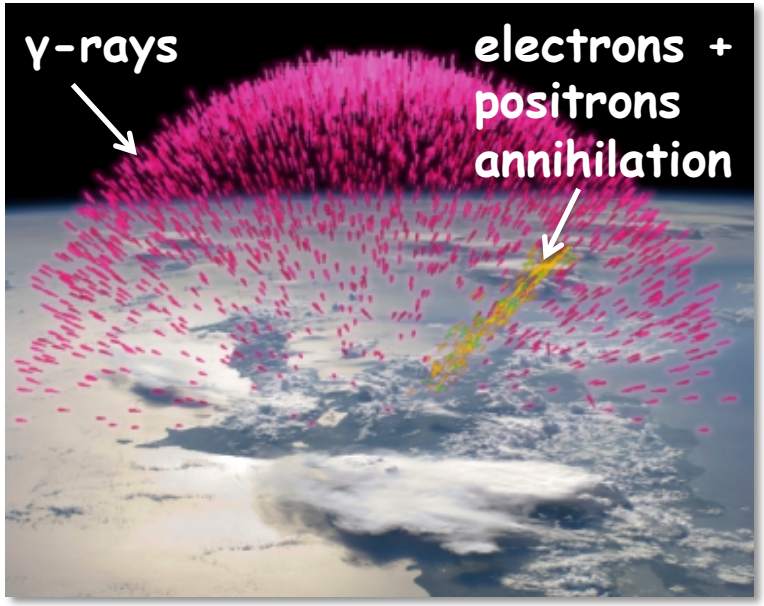
The Sun is waking up! March 2012

- **LAT sees long lasting emission**
  - Associated with one or more impulsive episode in X-rays
- **Impulsive flare events**
  - Seen in LLE data (Ackermann et al. 2012 2012ApJ...745..144A)
  - Hard X-ray pile up in ACD causes suppression of the standard LAT event rate (after classification of gamma-rays)

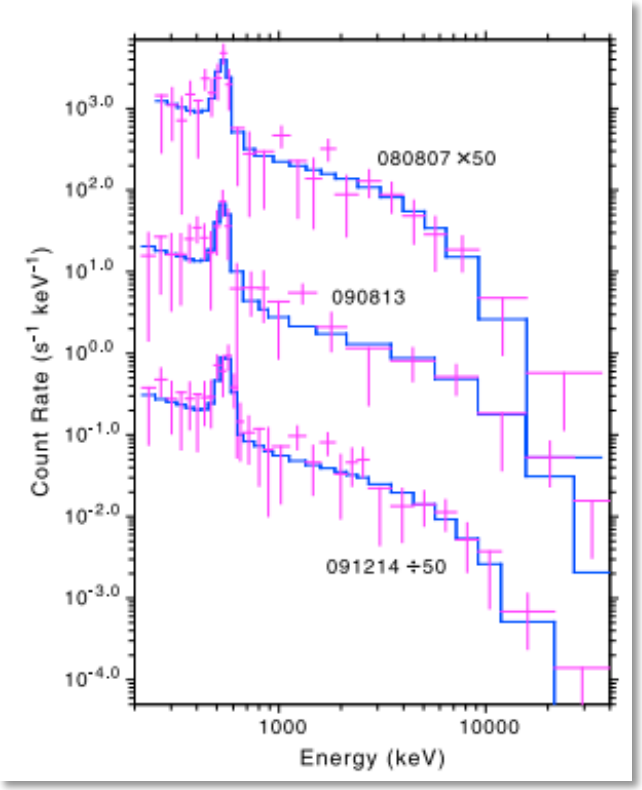


Positrons from Thunderstorms

- **Terrestrial Gamma-ray Flashes (TGFs) are short (~ms) bursts associated with lightning and thunderstorms**
  - **GBM discovered that for a subset of TGFs the observed signal is due to electrons and positrons directly hitting the detectors**



TGF Spectra



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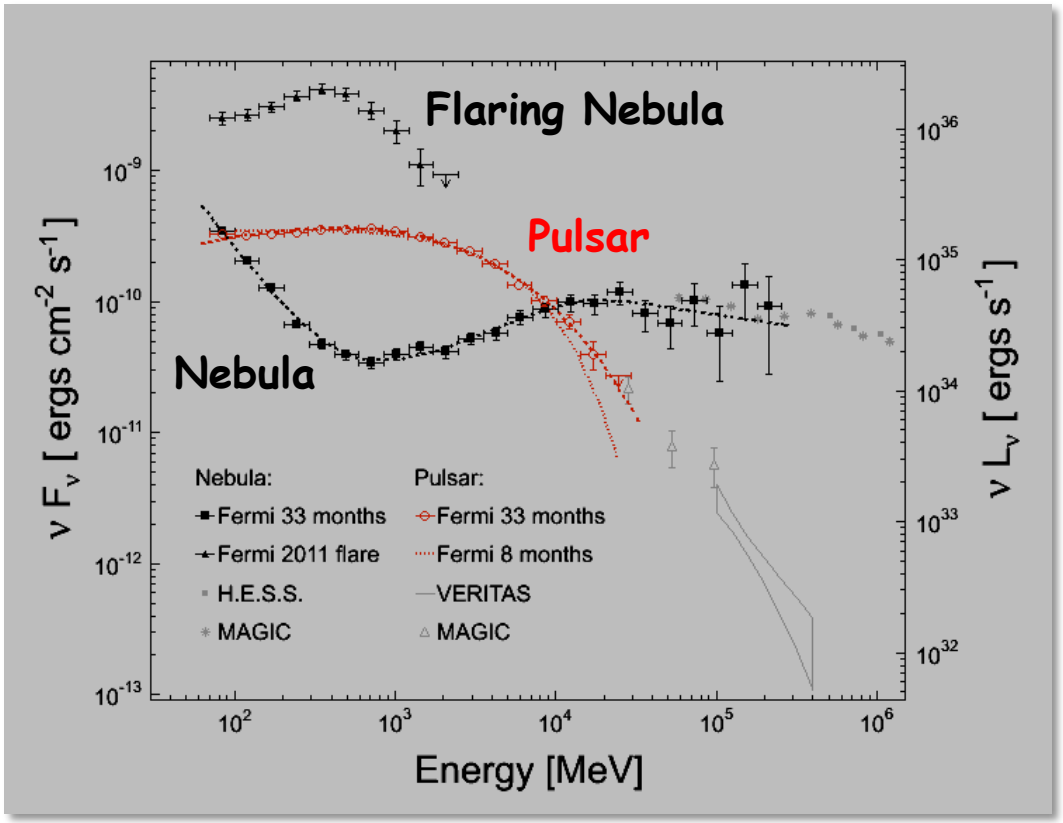
Questions?

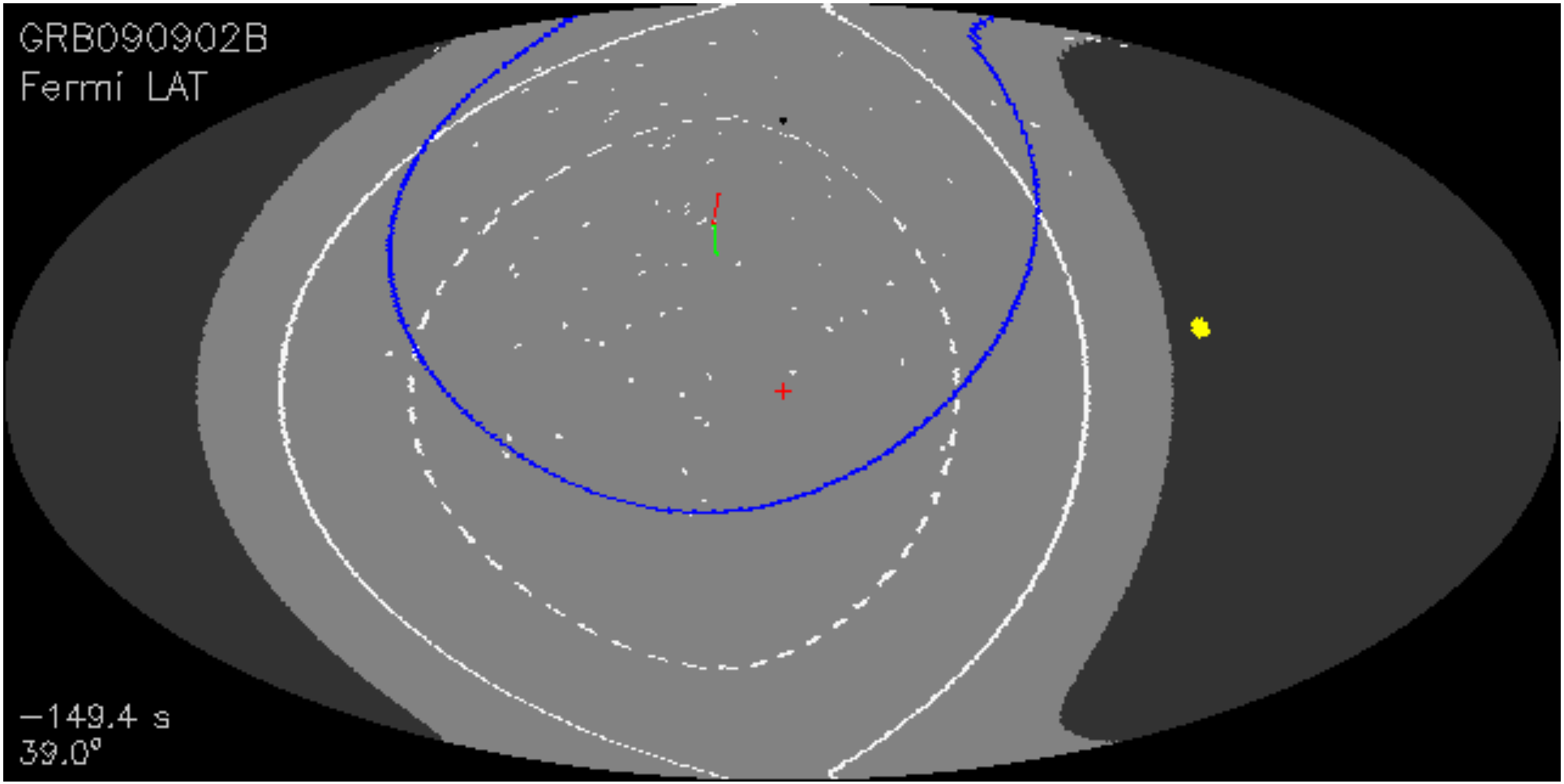
Spectral Changes Observed by LAT



- **Huge flares extending to high energies challenge shock acceleration models.**

GRB090902B - Autonomous repoint

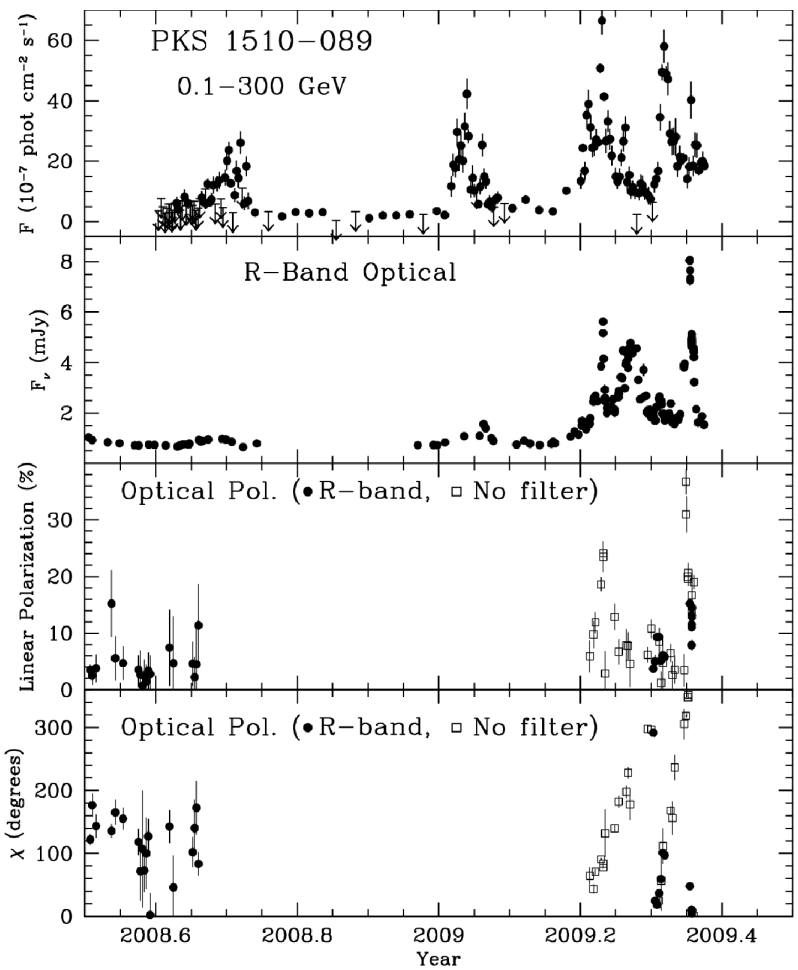
- **LAT pointing in celestial coordinates from -120 s to 2000 s**
  - **Dark region = occulted by Earth (θz>113°)**
  - **Blue line = LAT FoV (±66°), White points = LAT events**



Quasar PKS 1510-089: Repeated Outbursts

As we observe longer with Fermi, etc.: look for repeated patterns

- Discern between transient phenomena and effects caused by long-lived structure in the jet



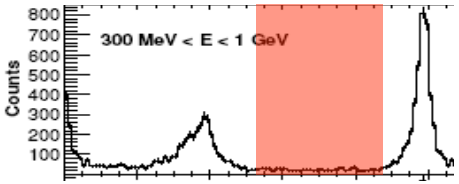
Rotation of the magnetic field direction (observed via optical polarization) occurred during γ-ray outburst in 2009 just before new superluminal knot appeared.
→As predicted by jet formation theories

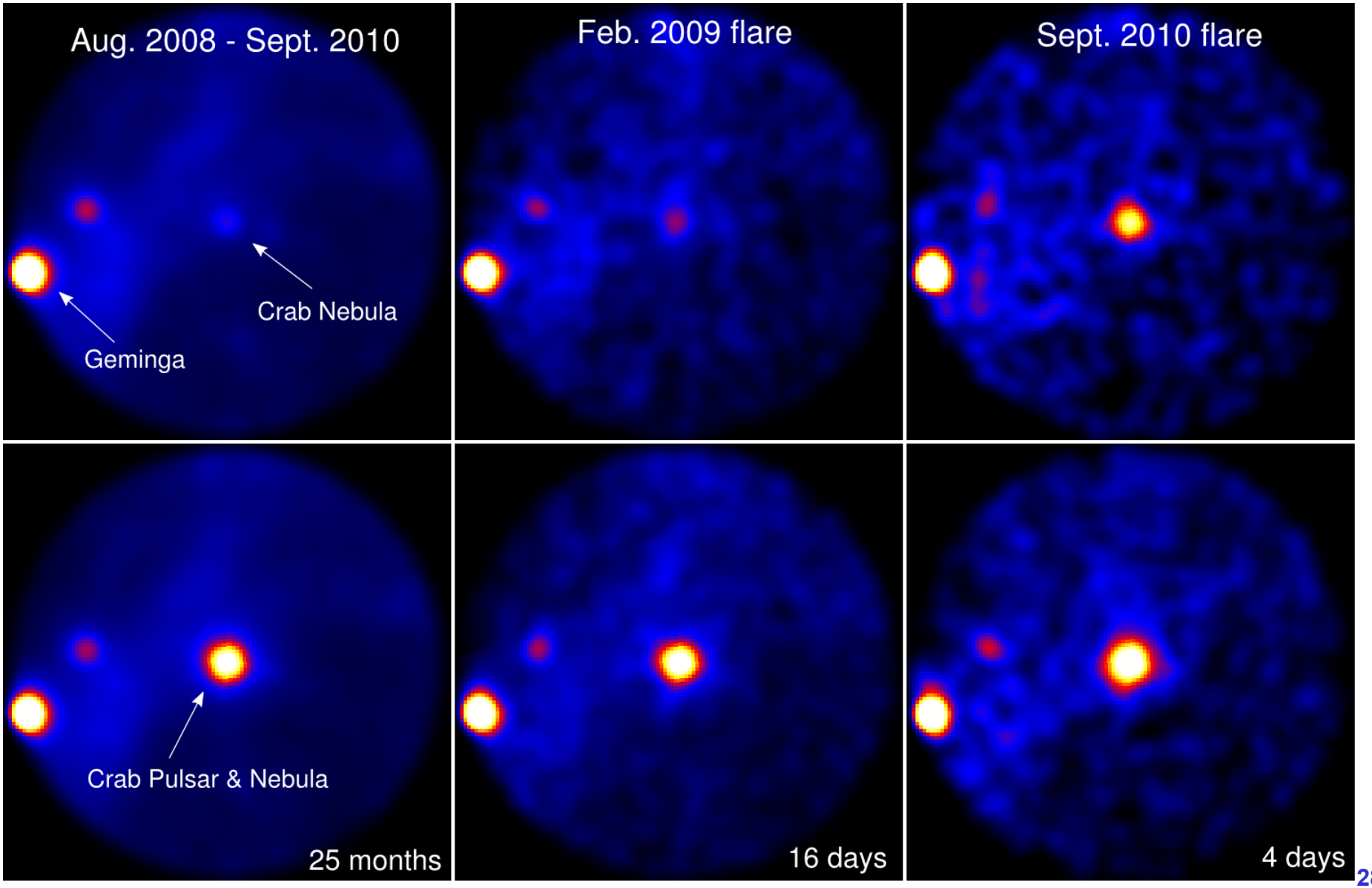
Similar behavior seen in some other blazars

- Random meanderings of magnetic field direction or predicted underlying structure of the jet?

→ Continued observations with *Fermi* et al. will answer this

Crab Nebula


300 MeV < E < 1 GeV
Counts
800
700
600
500
400
300
200
100


Aug. 2008 - Sept. 2010
Crab Nebula
Geminga
Feb. 2009 flare
Sept. 2010 flare
Crab Pulsar & Nebula
25 months
16 days
4 days

Gamma-ray, Optical, and X-ray Light Curves

- Approximate time order is optical first, next gamma, and finally X-ray
- Gamma-rays begin later in day of optical detection
- X-ray peaks ~30 d after optical and γ-ray brightening