

## Fermi-LAT Observations of Galactic Transients

*Elizabeth Hays  
(NASA/GSFC)  
on behalf of the Fermi-LAT  
Collaboration*



# 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)**

~390 Scientific Members (including 96  
Affiliated Scientists, plus 68 Postdocs  
and 105 Students)

**Managed at SLAC**

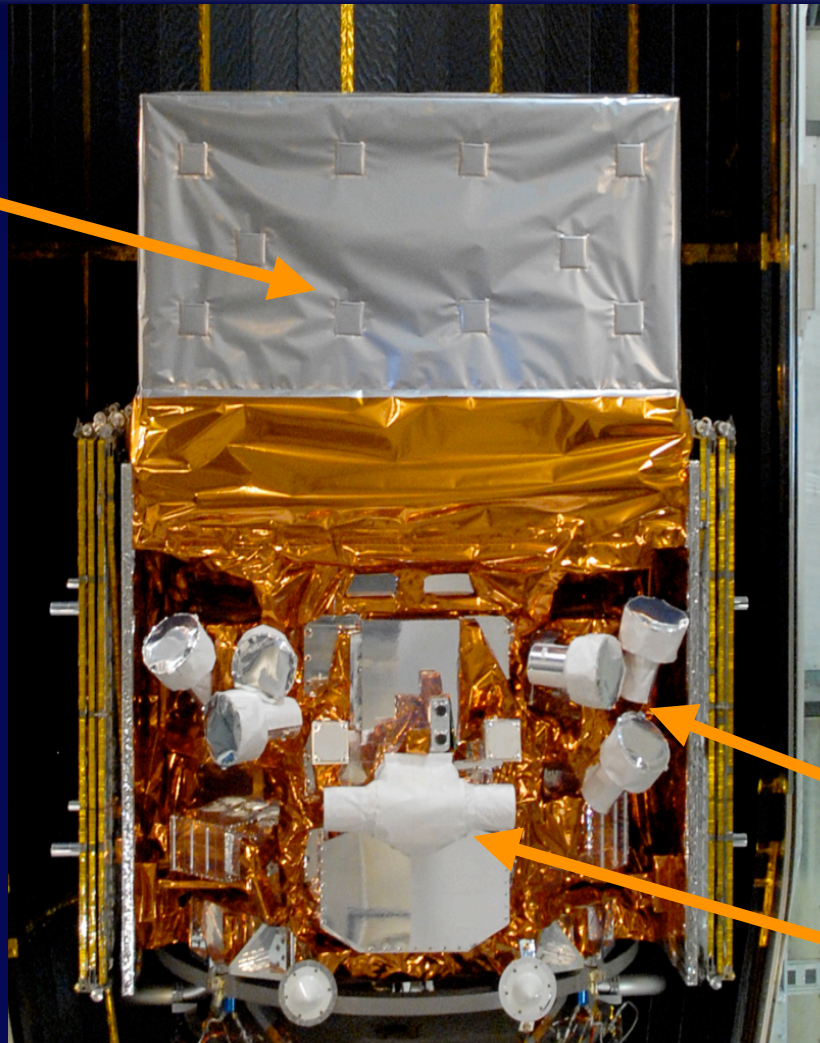




# The Fermi Observatory

## Large Area Telescope (LAT)

- ♦ Large field of view ( $>2.4$  sr)
- ♦ Entire sky every 3 hrs (every 2 orbits)
- ♦ Broad energy range (20 MeV -  $>300$  GeV)



## Gamma-ray Burst Monitor (GBM)

- ♦ Views entire unocculted sky
- ♦ **NaI:** 8 keV - 1 MeV
- ♦ **BGO:** 150 keV - 40 MeV



# Large Area Telescope (LAT)

Large Field of View  $>2.4$  sr  
Broad Energy Range 20 MeV -  $>300$  GeV

## ACD

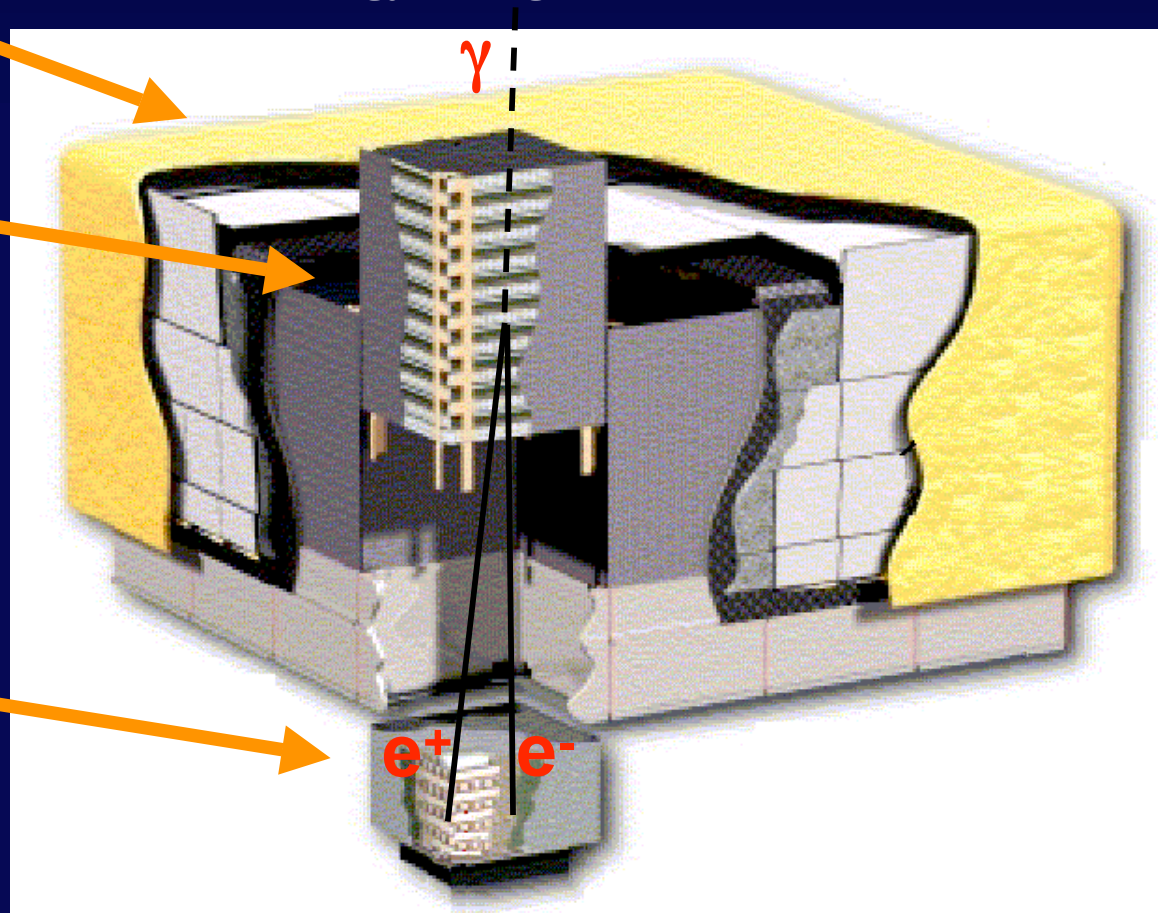
scintillator  
89 tiles

## Tracker

Si strip detectors  
Tungsten foil  
converters  
pitch = 228  $\mu\text{m}$   
 $8.8 \times 10^5$  channels  
18 planes

## Calorimeter

CsI crystals  
hodoscopic array  
 $6.1 \times 10^3$  channels  
8 layers



4x4 detector array





# LAT Sensitivity with Time

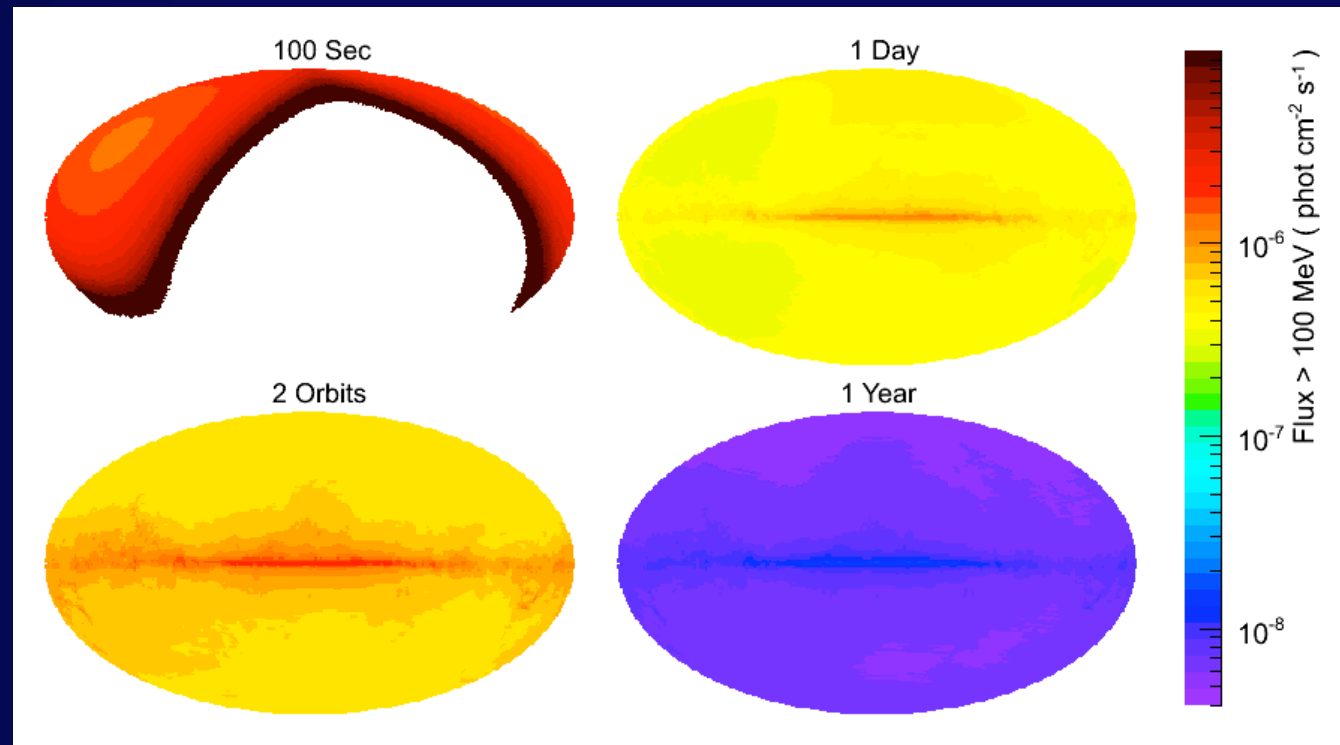
**Transient Science:** Flares, bursts, multiwavelength campaigns, unidentified transients

**Accumulated Science:** New source types, populations, long-term monitoring, spatially extended and diffuse studies

**Deepest and most uniform survey of the sky at these energies**

All-sky in ~3 hrs  
(2 orbits)

Minor asymmetry  
due to passages  
through South  
Atlantic Anomaly

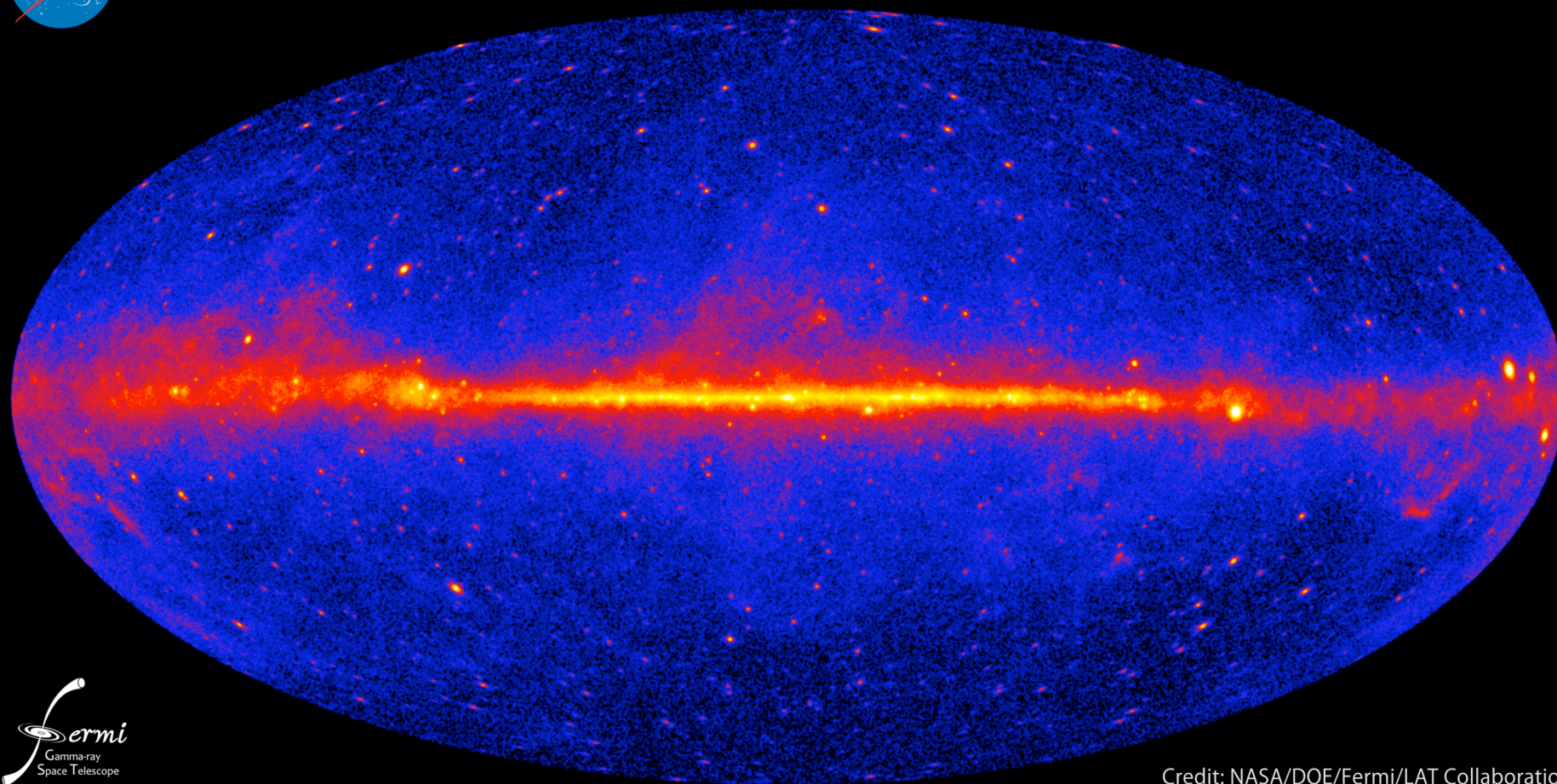




# The Steady Sky



## Fermi two-year all-sky map



Credit: NASA/DOE/Fermi/LAT Collaboration

**>1 GeV**

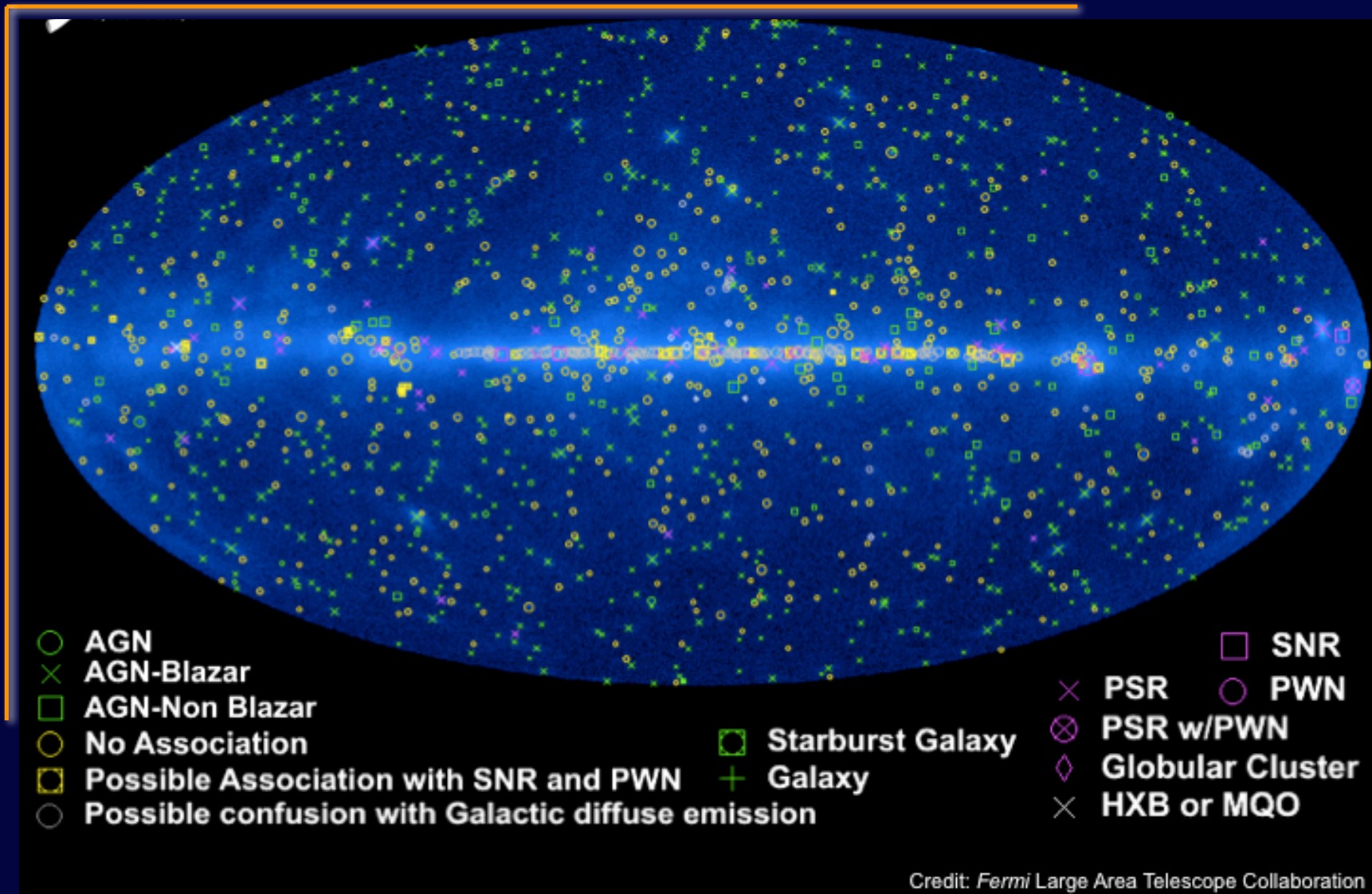
November 30, 2010

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# 1FGL Catalog



Credit: *Fermi* Large Area Telescope Collaboration

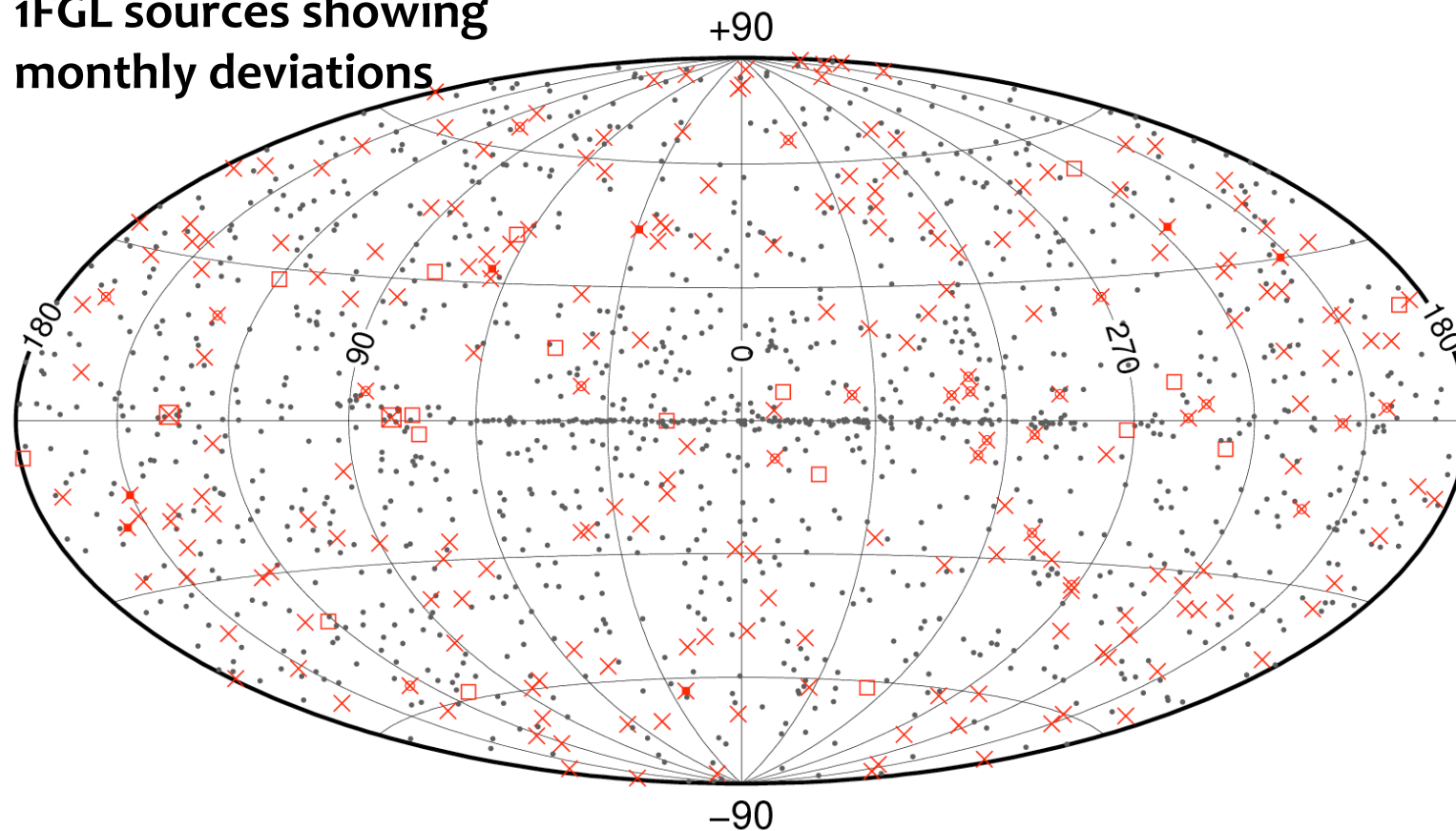
November 30, 2010

Based on 11 months of data

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# The Variable Sky

1FGL sources showing  
monthly deviations



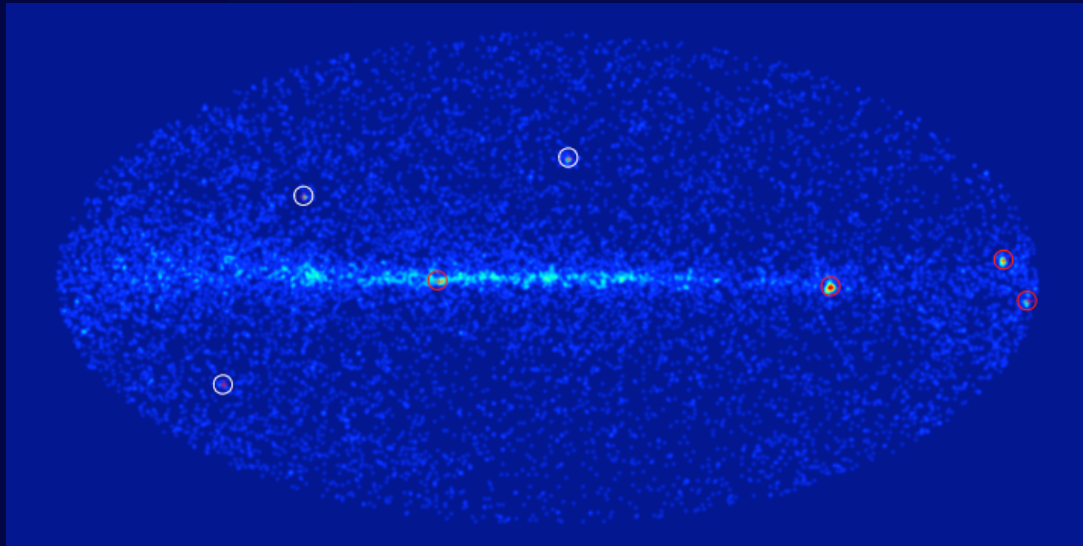
- |                    |   |
|--------------------|---|
| □ No association   | ▣ Possible association with nearby SNR or PWN |
| × AGN – blazar     | * Starburst Gal                               |
| × AGN – unknown    | + Galaxy                                      |
| × AGN – non blazar | ◇ PWN   |
|                    | ○ SNR   |
|                    | ☆ Pulsar                                      |
|                    | ☆ Pulsar w/PWN                                |
|                    | △ Globular cluster                            |
|                    | ⊠ XRB or MQO                                  |





# LAT Automated Science Processing

All-sky search runs every 6 hours, 1 day, 1 week



LAT counts map  
 $E > 100$  MeV, 6 hours

LAT flare advocates monitor data daily and trigger multiwavelength follow-up. Also check for interesting transients reported in other wavebands.

- >100 Astronomer's Telegrams
- Public lightcurves through FSSC at <http://fermi.gsfc.nasa.gov/ssc>
- Weekly and Special Reports <http://fermisky.blogspot.com>

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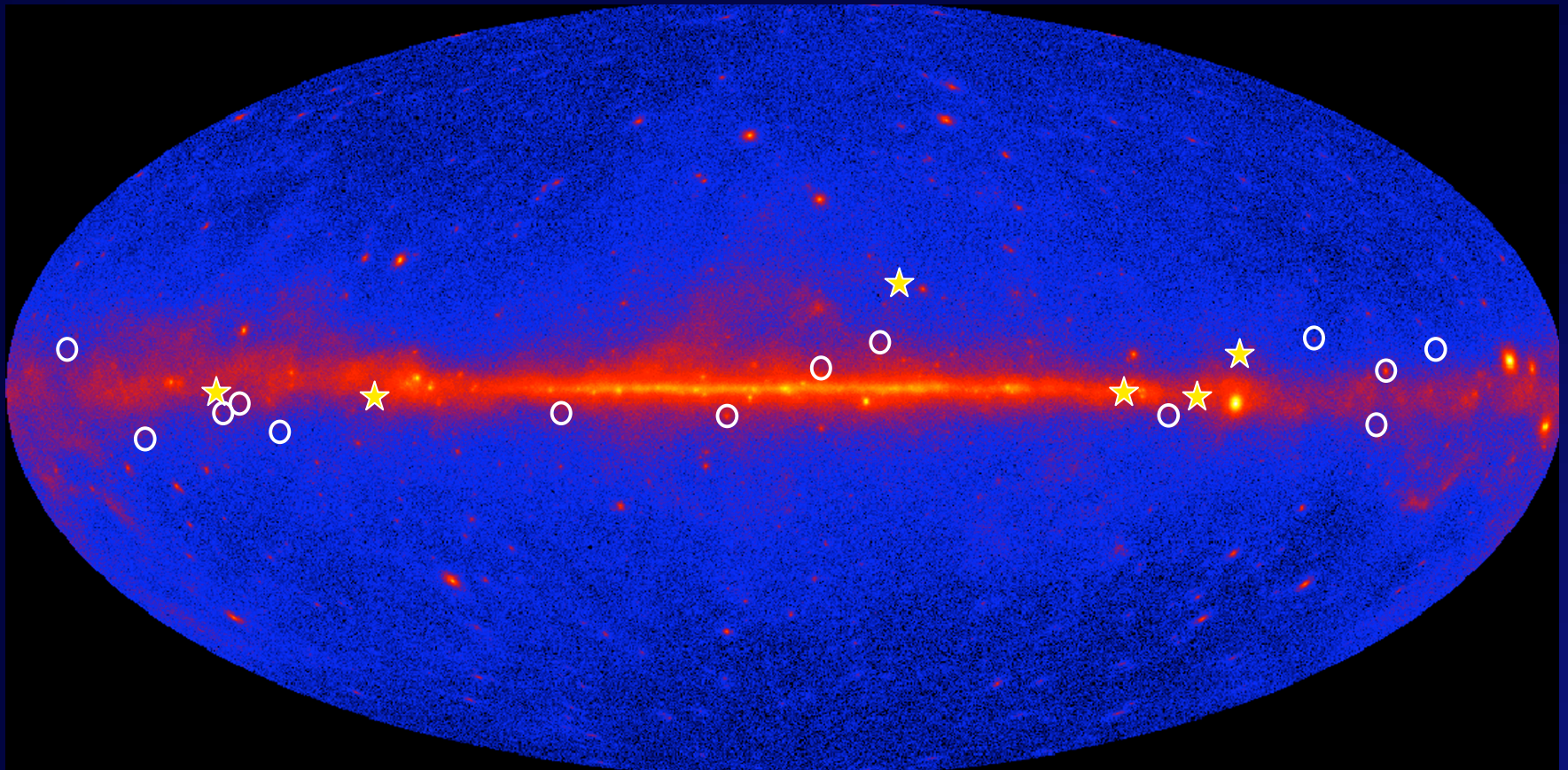


# Flaring Galactic Sources in the LAT

- ✦ Search for new transients near the Galactic plane
- ✦ Cygnus X-3
- ✦ Nova of V407 Cygni
- ✦ Crab Nebula



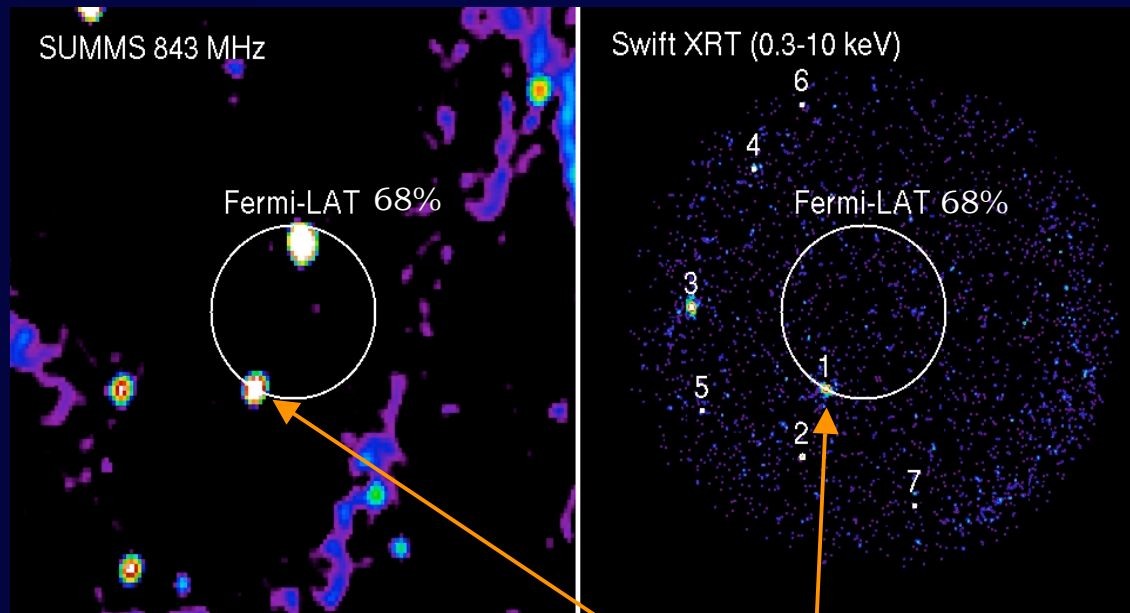
# LAT Unassociated Transient Detections



- ★ Unassociated transients from daily search
- Low latitude blazars from First LAT Catalog



# Counterpart Search - Fermi J0910-5041



## **Fermi J0910-5041** (ATEL #1788)

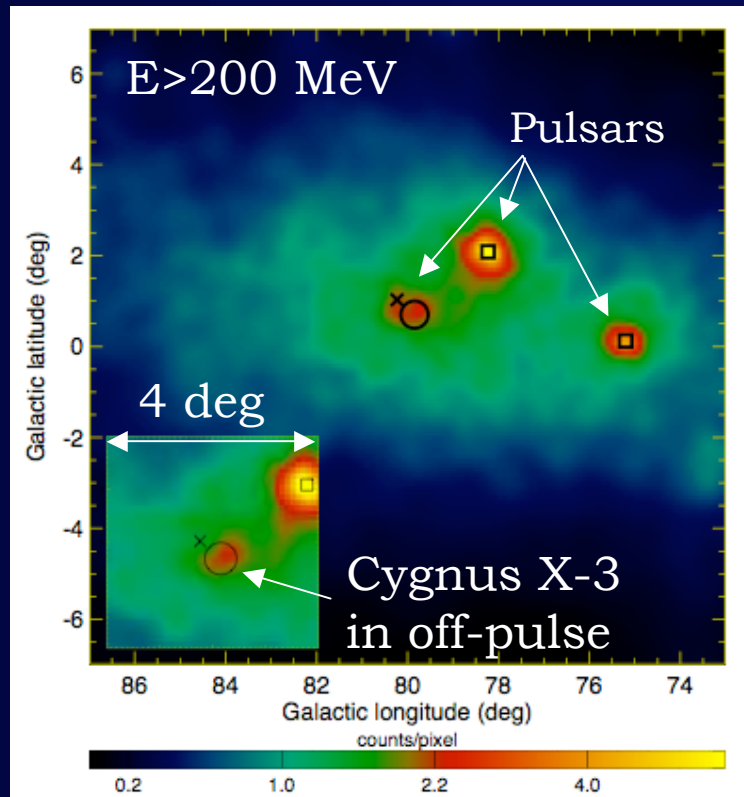
- October 15, 2008
- ~10x above average gamma-ray flux for 2 days
- Swift XRT ToO within 1 day
- 1 of 2 high confidence LAT transients without a firm counterpart

LAT 95% error circle contains Swift XRT source (Landi et al. ATEL #1822) coincident with flat-spectrum radio source from SUMMS and AT20G (Sadler ATEL #1843)

# Cygnus X-3

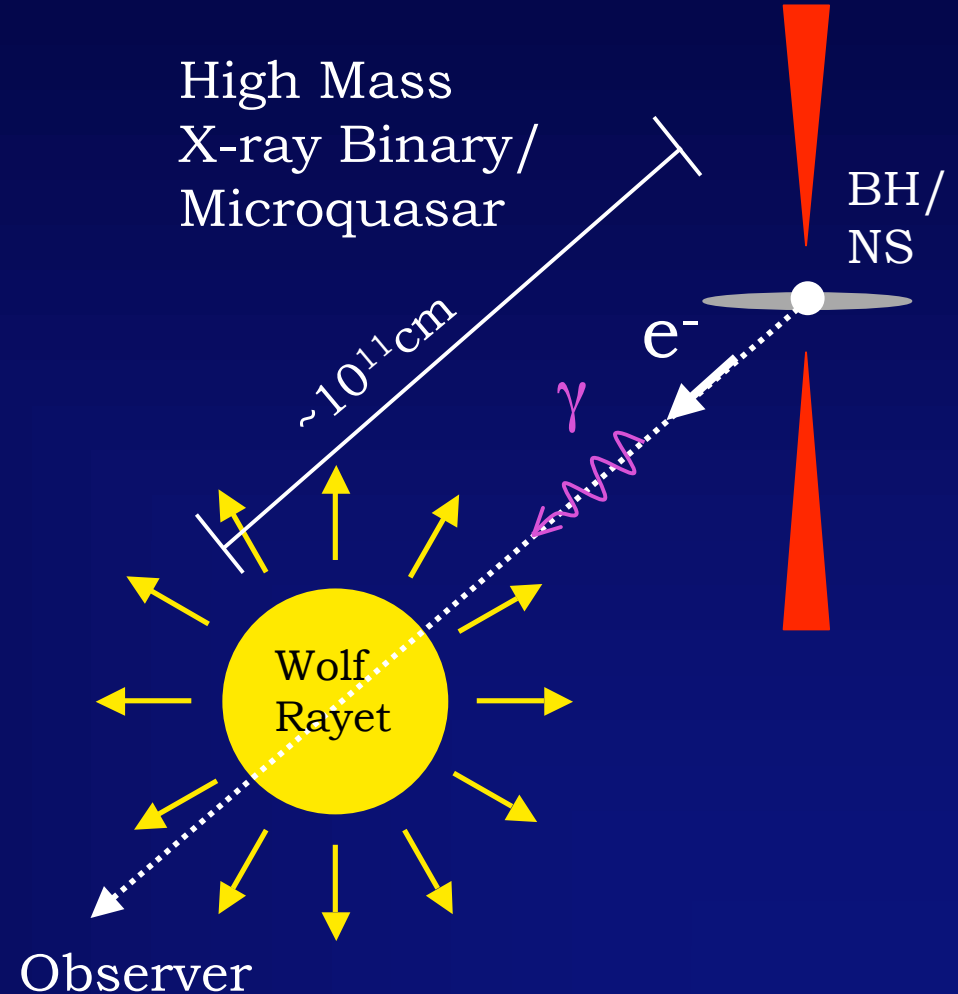
## First secure gamma-ray detection of Cygnus X-3

- high significance source and binary modulation



Science 326, 1512 (2009)

November 30, 2010

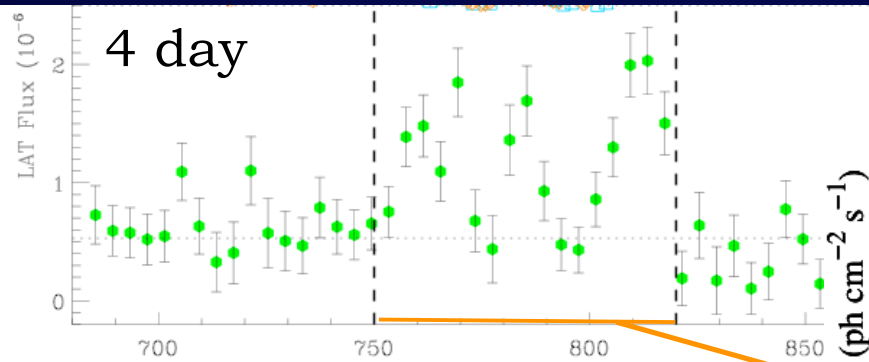


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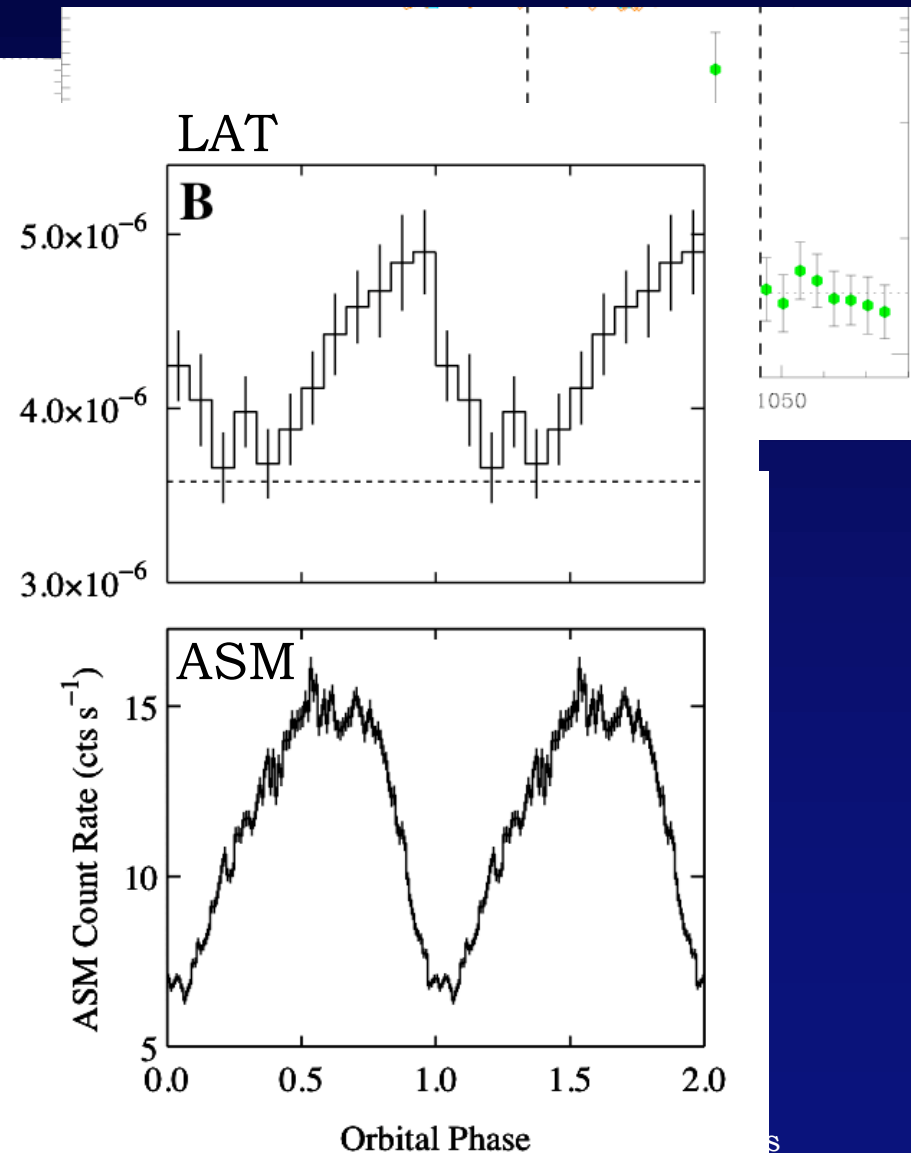


# Gamma-ray Flares and Modulation

Aug. 4 2008 to Sept. 2 2009

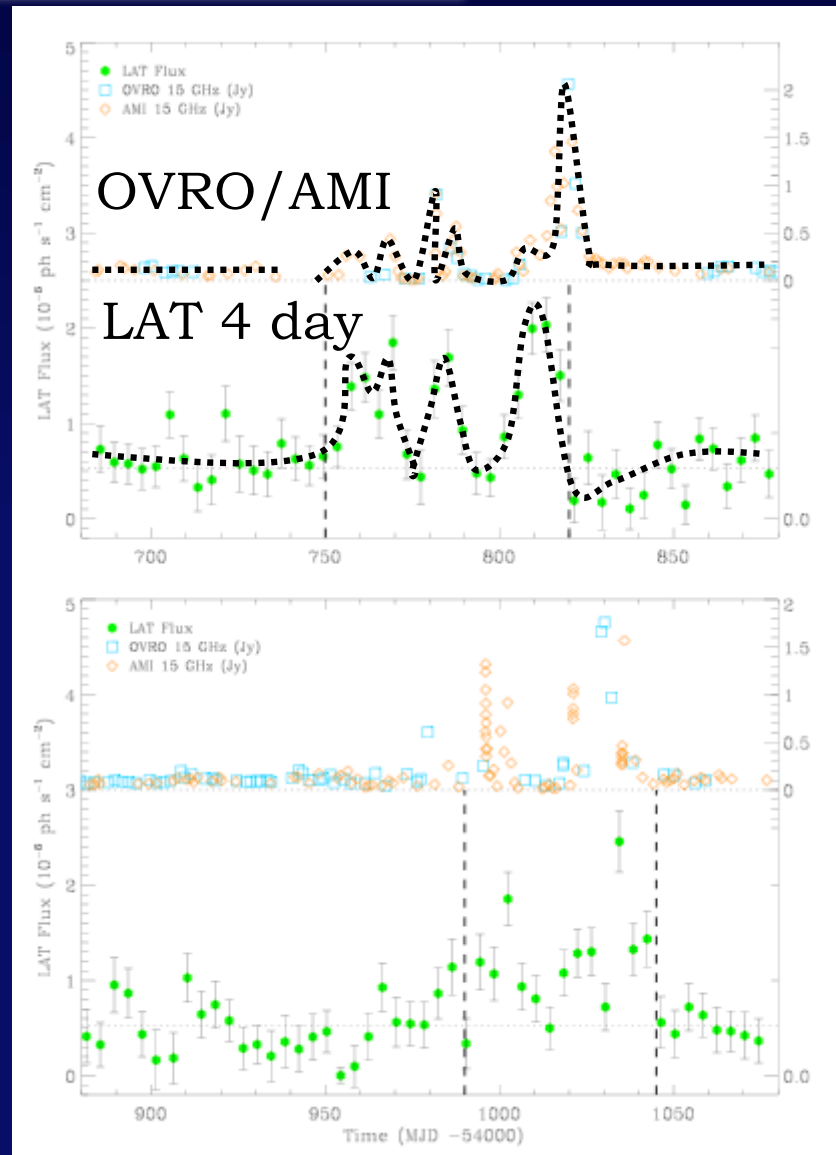


- ✦ LAT active periods correspond to soft X-ray state
- ✦ Gamma rays modulated at 4.8 hour binary period
- ✦ LAT detected a third flare from 2010 May 19-26 during transition to the soft state (Corbel et al. ATEL #2646)



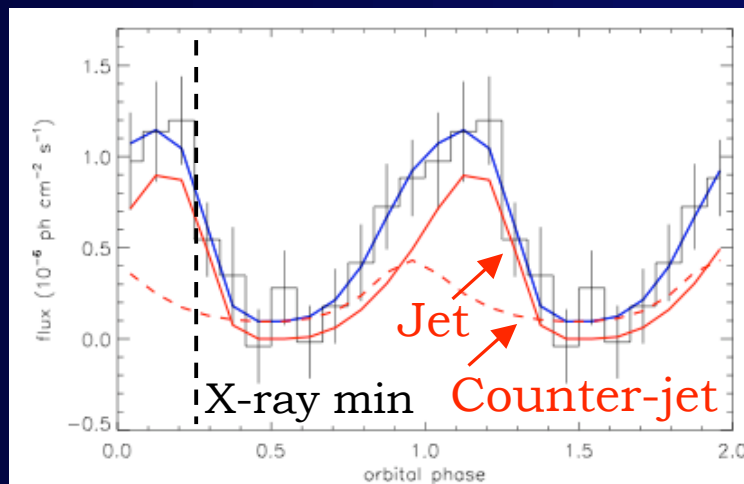
# Connection to Jet Activity

- ✦ LAT active periods correspond to radio flares
  - ✦ Possible radio lag is not well constrained by correlation analysis
- ✦ Expect high energy electrons somewhere along the jet to scatter the stellar radiation field (UV) via inverse Compton
  - ✦ Superior conjunction favored for gamma-ray production

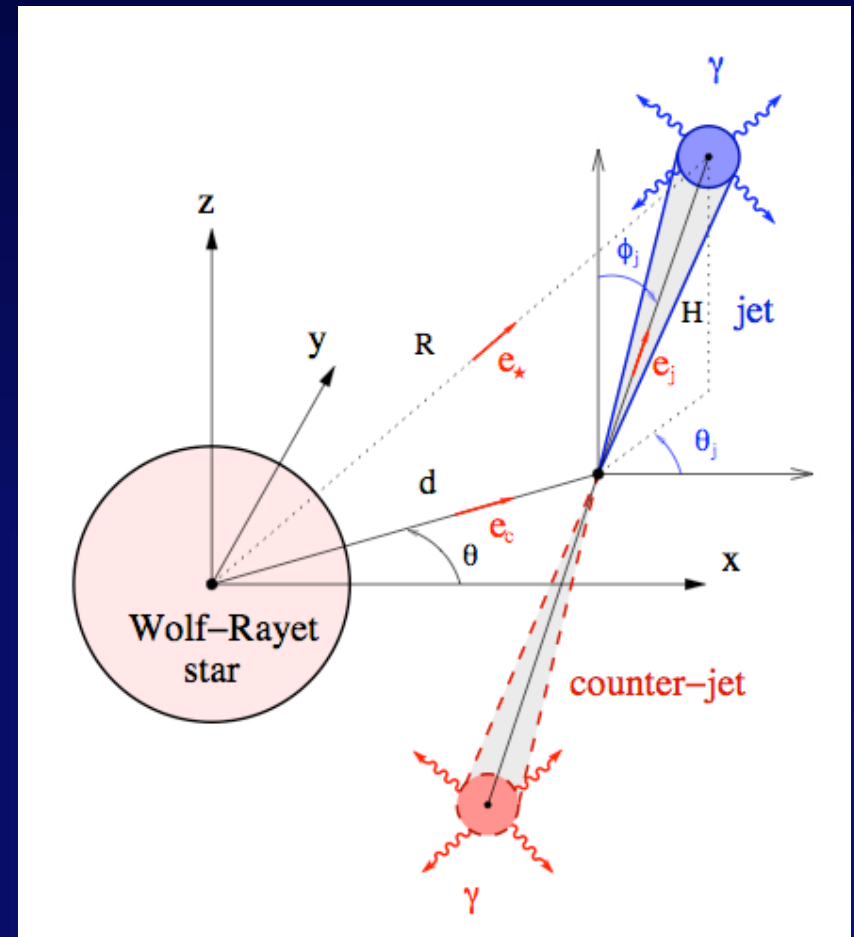


# Probing the Jet

- ✦ Gamma ray origin away from accretion disk to avoid absorption on soft X-rays
- ✦ Modulation provides test of jet inclination
- ✦ Also sensitive to jet precession



Model fits require inclined jet  
and prefer site slightly  
outside orbital separation

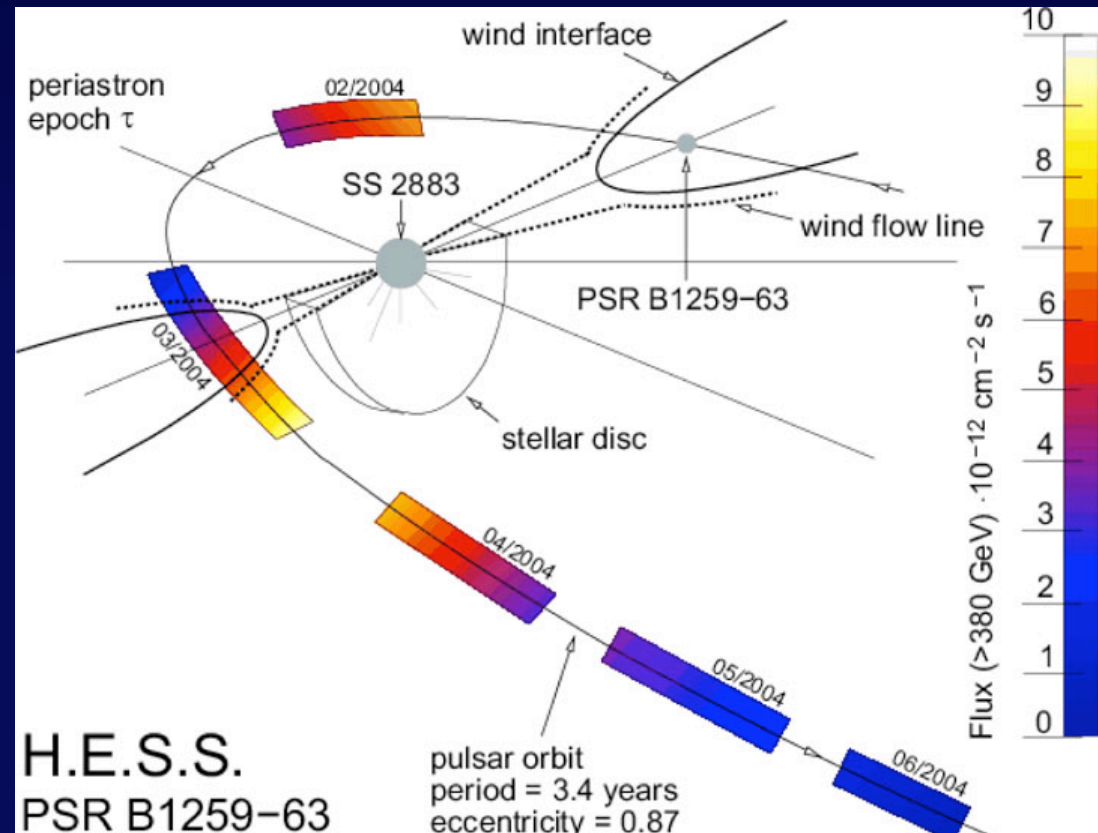


Dubus, Cerutti, and Henri, MNRAS, 404, L55 (2010)



# A Binary Transient in the LAT Future?

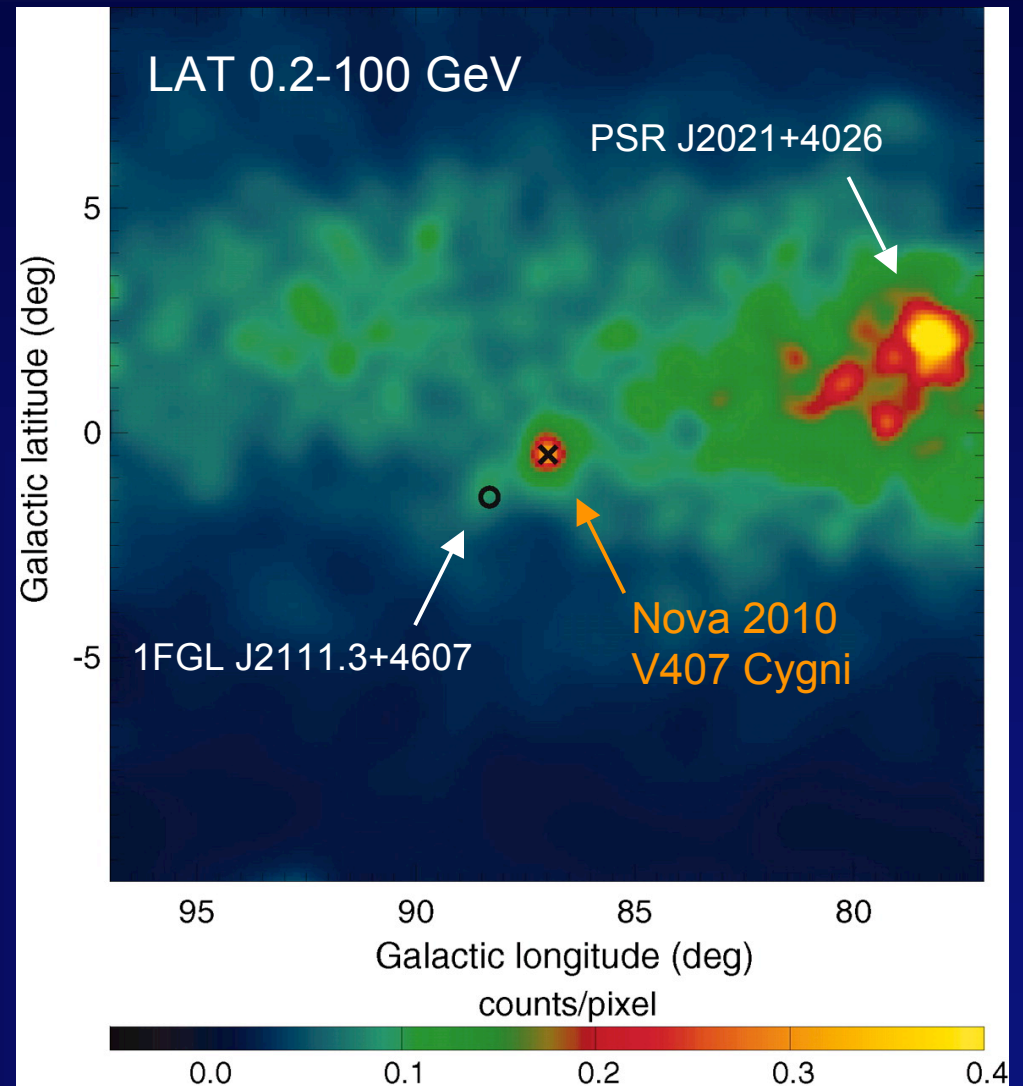
- ✦ First periastron passage of PSR B1259-63 since Fermi launch
  - ✦ Superior conjunction Dec. 7
  - ✦ Closest approach on Dec. 14
- ✦ Multiwavelength campaign Nov. - Feb.
- ✦ LAT contact: aous.abdo at nrl.navy.mil
- ✦ Actively monitored by team - stay tuned!



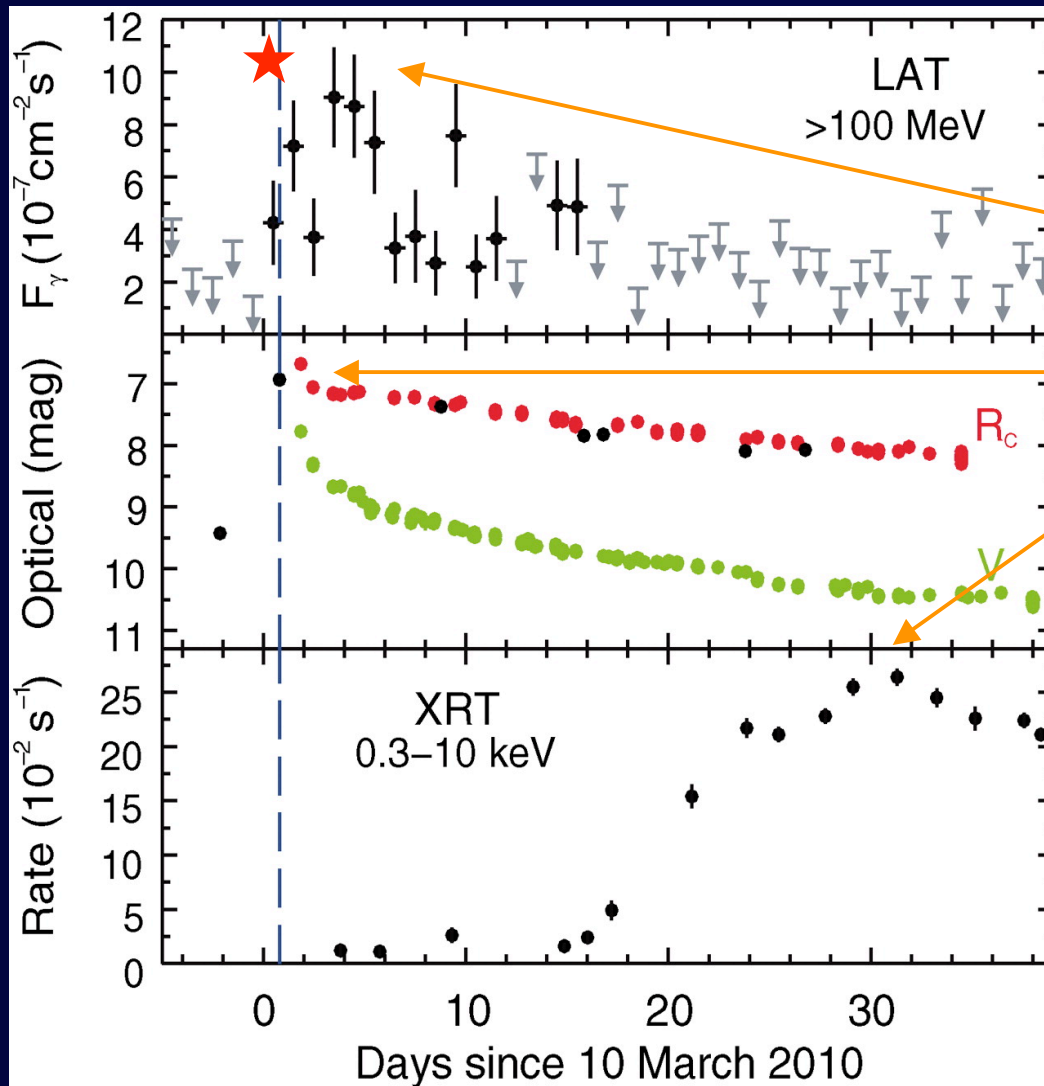
No significant emission in LAT data yet  
Abdo et al. ATEL #3054

# Gamma Rays Concurrent with a Nova

- ✦ Fermi J2102+4542:  
First detection of a nova  
in gamma rays
- ✦  $6-8\sigma$  in automated  
processing on 2010  
March 13, 14 (Cheung et  
al. ATEL #2487)
- ✦ LAT position within  $3.7'$   
of V407 Cygni (white  
dwarf, red giant binary)
- ✦ Further analysis shows  
gamma rays close in time  
to nova discovery on  
March 10 by Nishiyama  
and Kabashima



# Nova Lightcurves



1) Optical peaks first

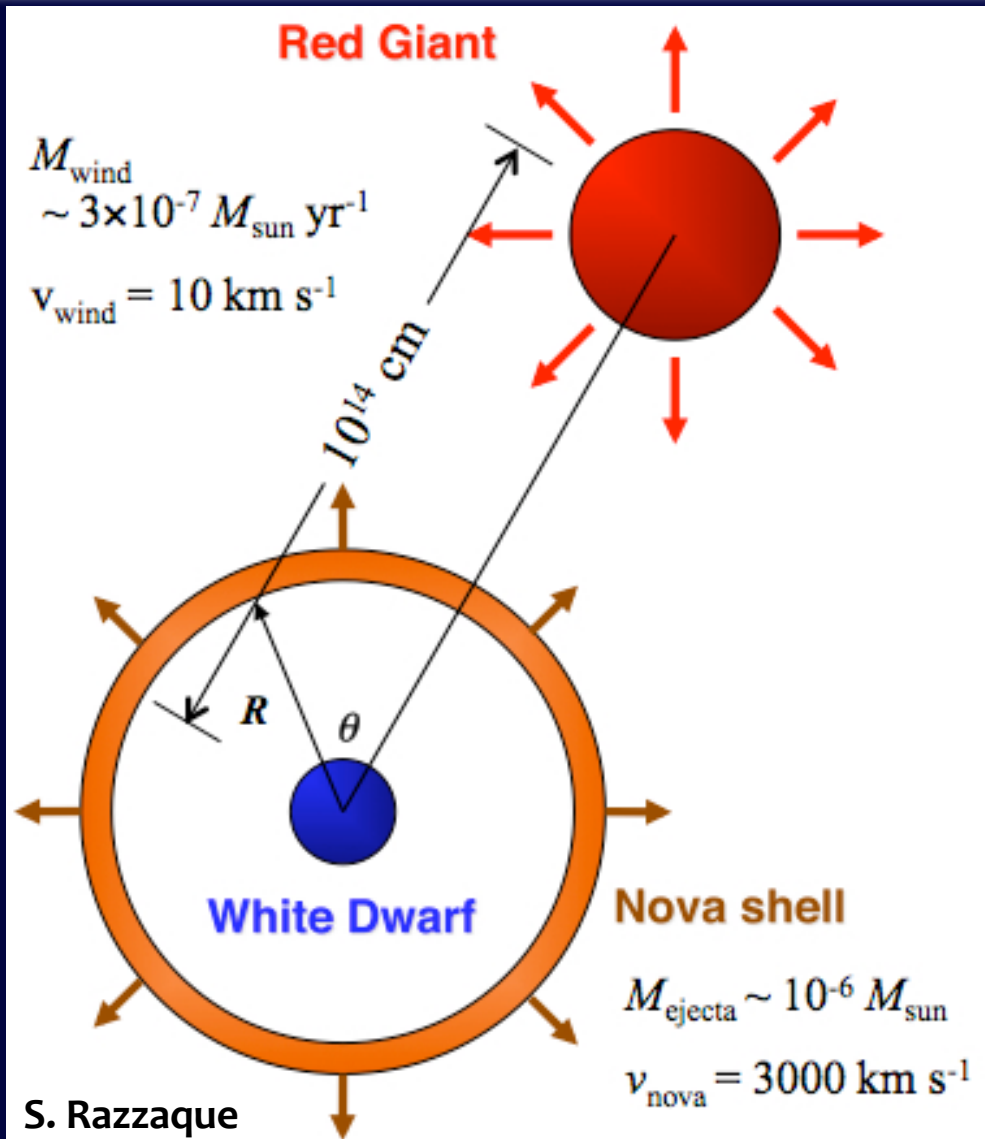
2) Gamma rays peak at 3-4 days and last ~2 weeks

3) X-rays peak at ~30 days, last and longest

Relative timing can be understood from the system geometry



# V407 Cygni System



S. Razzaque

November 30, 2010

Uncommon symbiotic binary - accretion fed by stellar wind

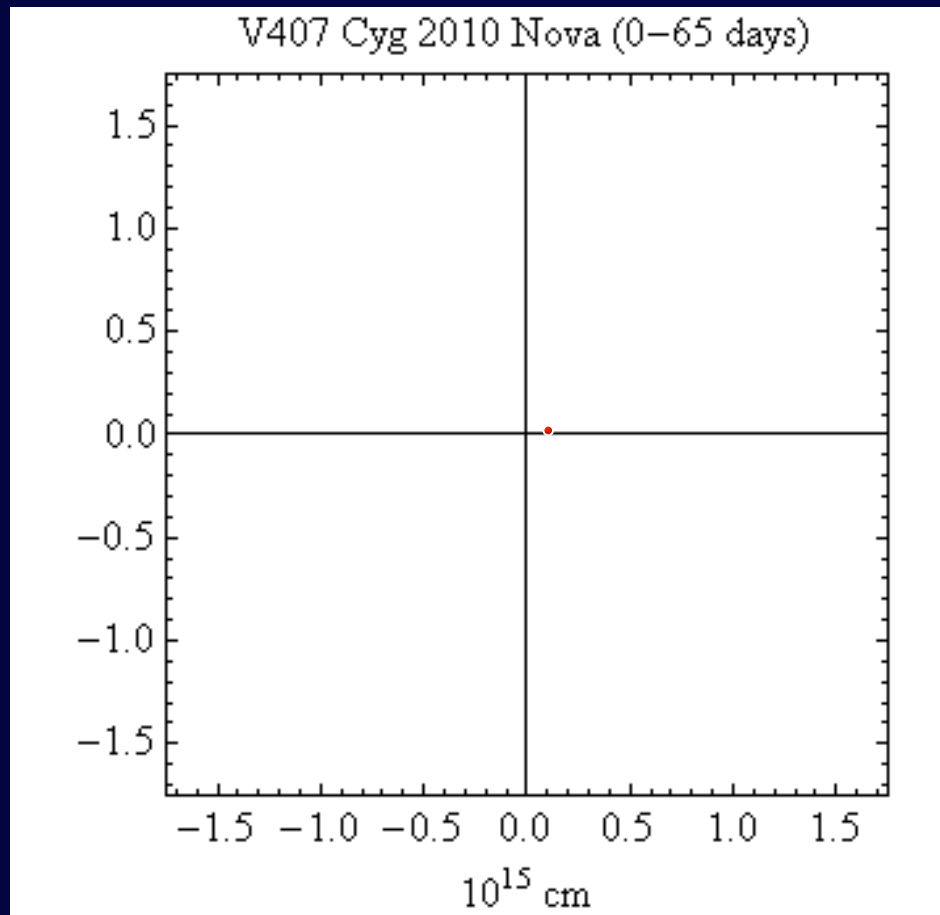
Nova shell provides means to accelerate electrons and ions.

RG atmosphere and wind provide asymmetric distribution of radiation and material for gamma-ray production processes.

E. Hays



# Gamma-ray and X-ray Evolution



S. Razzaque

Sedov condition is reached in a few days toward the red giant

Gamma rays peak early when efficiency for pion and inverse-Compton processes is favorable

X-rays peak later, increasing with volume of shock-heated gas

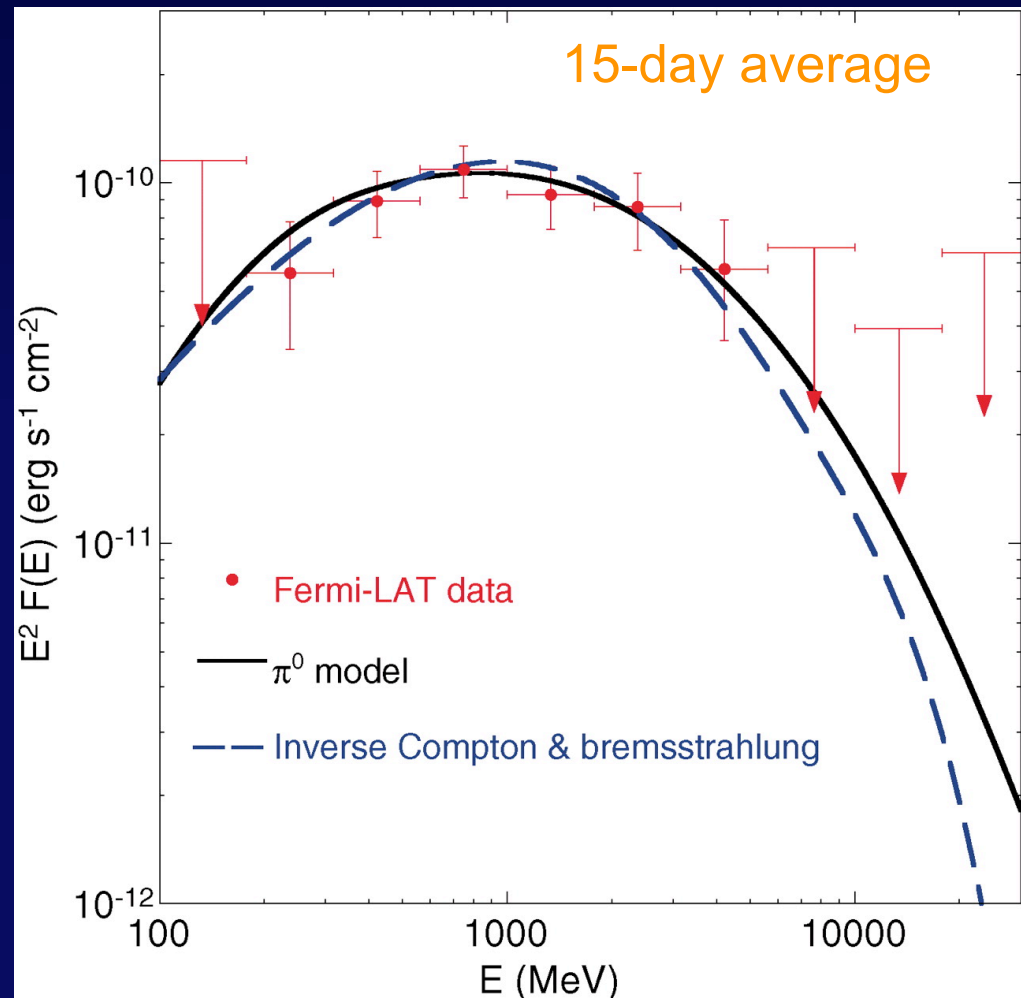
Shell expansion is nonuniform in space

# Emission Mechanisms

Spectral curvature  
does not evolve  
significantly

## ✦ Energetics

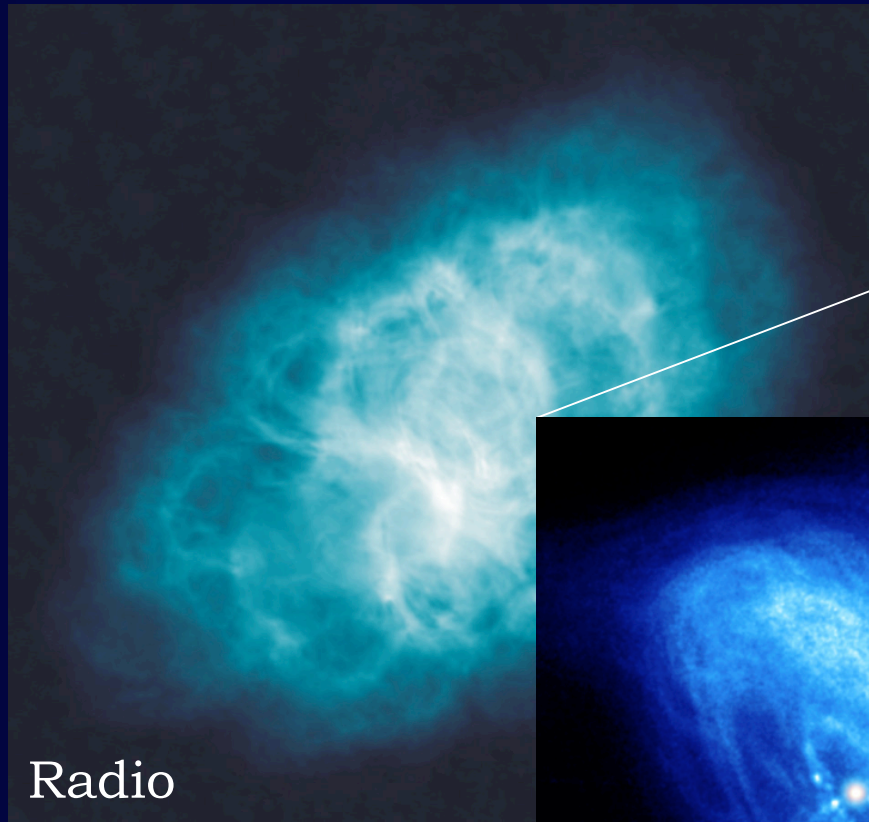
- ✦ Kinetic energy of the shell:  $\sim 10^{44}$  erg
- ✦ Total energy in  $\gamma$ -rays:  $\sim 4 \times 10^{41}$  erg
- ✦ This means 0.4% efficiency for leptonic scenarios
- ✦ Or 9% for hadronic (similar to Fermi SNR)





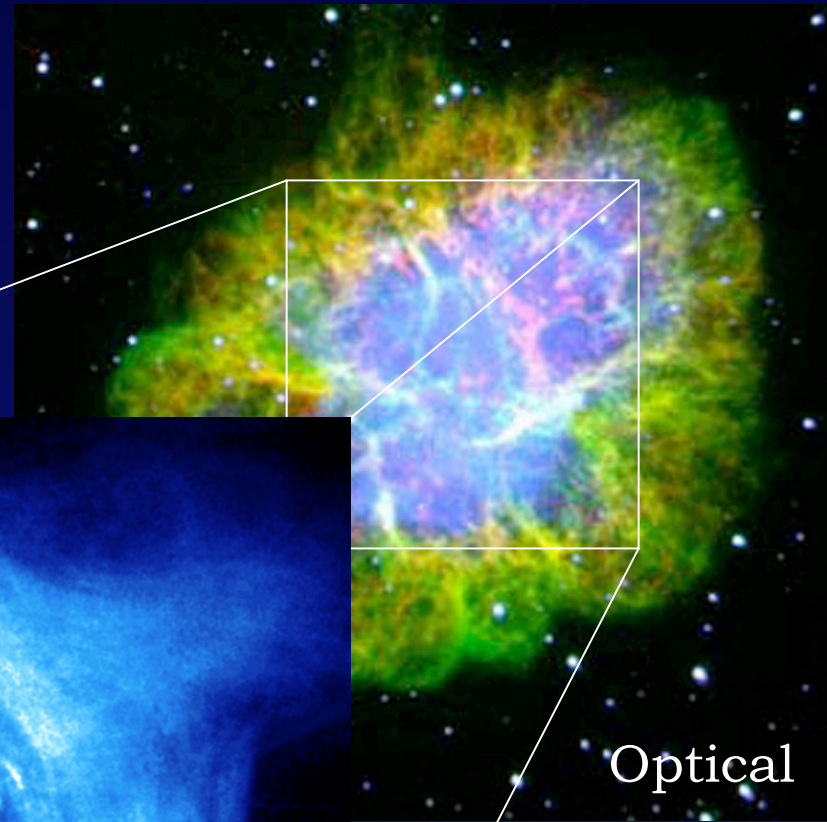


# The Crab Nebula



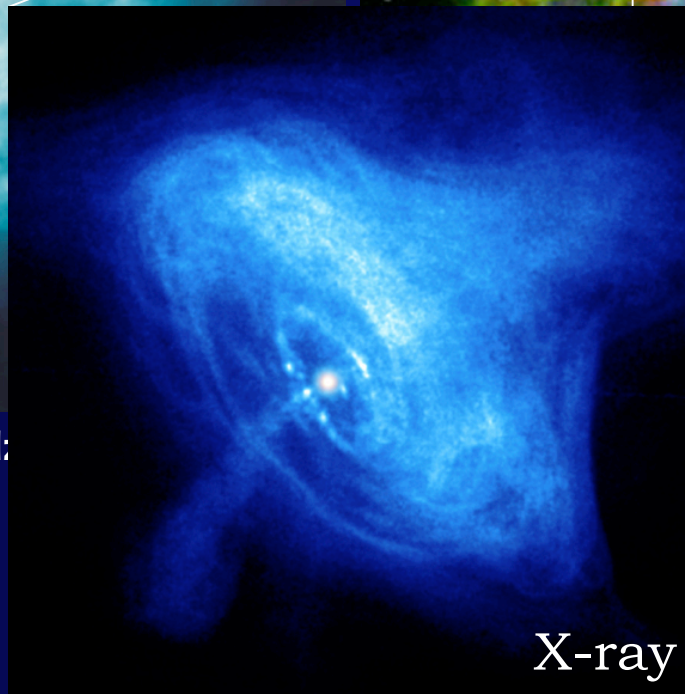
Radio

NRAO/AUI and M. Bietenholz



Optical

ASU/J.Hester & A.Loll)



X-ray

NASA/CXC/ASU/J.Hester et al.

November 30, 2010

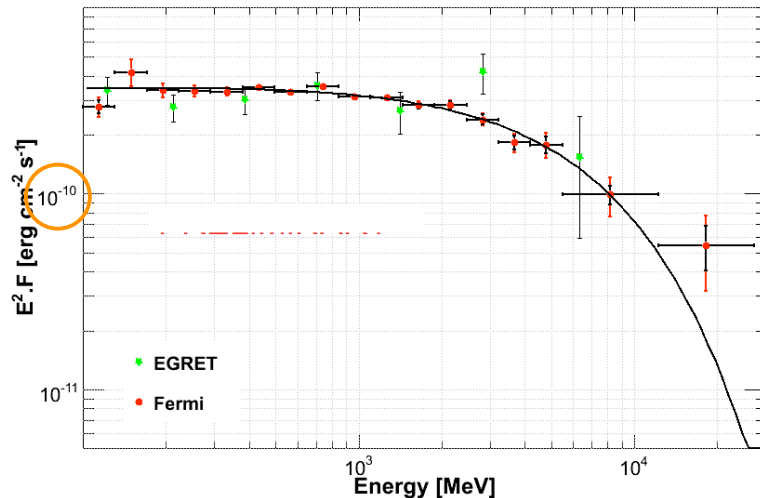
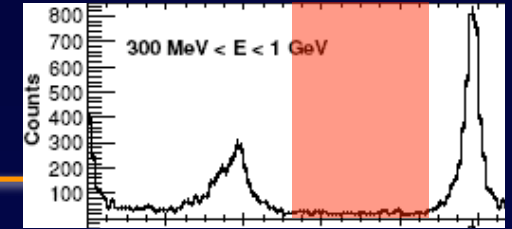
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# The Crab in LAT

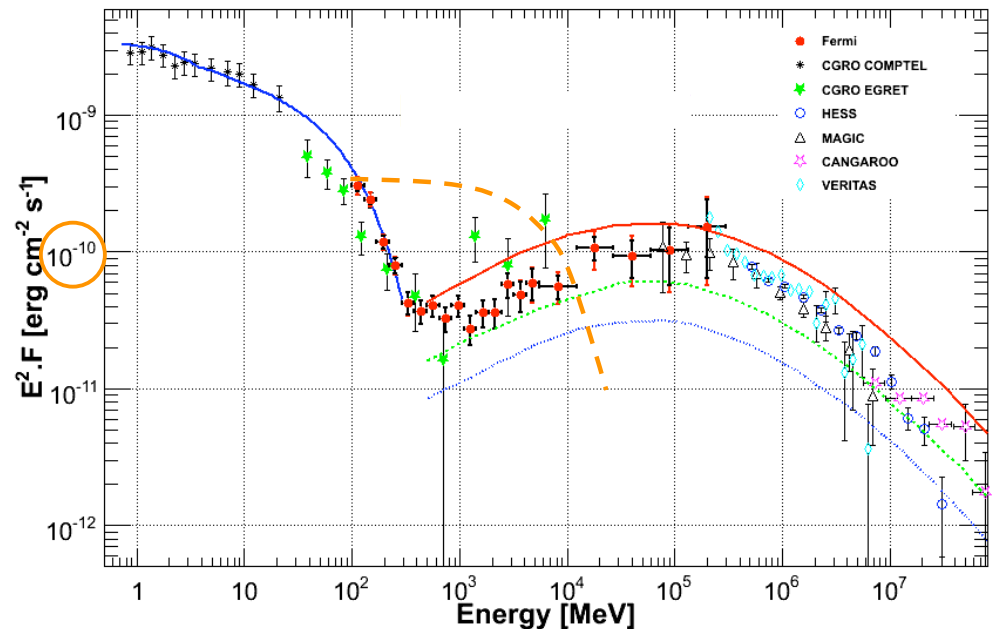
**Pulsar** 100 MeV to 20 GeV

**Nebula** from MeV to TeV



Hyper-exponential cutoff  
excluded at ~5 sigma

Consistent with emission  
well above the neutron  
star surface



Two components: Synchrotron +  
Inverse Compton extending to TeV.  
Fit consistent with mean nebula B  
field of 100 to 200  $\mu$ G



# Our candle is not so standard

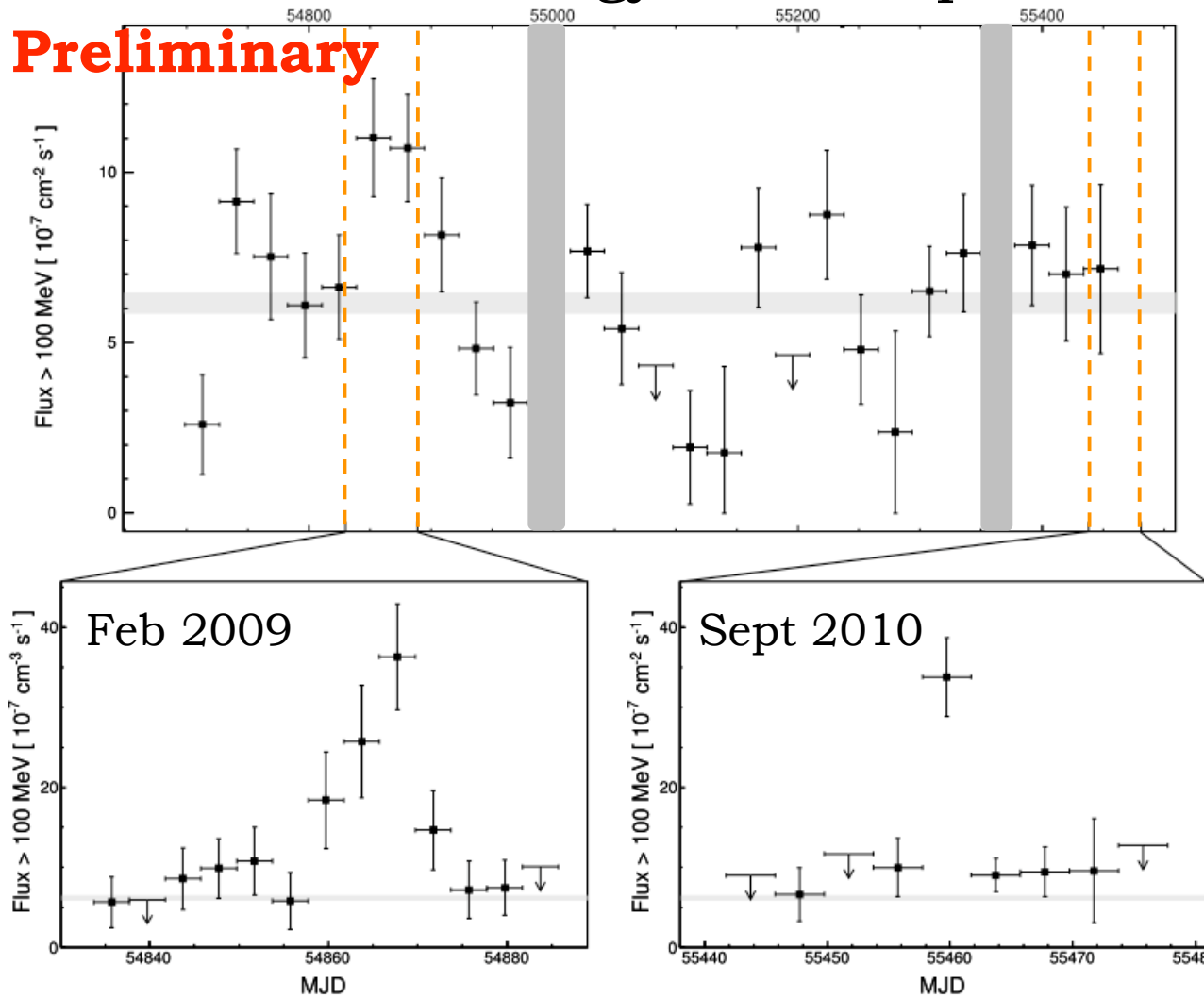
- ✦ Crab flickers in hard X-ray
  - ✦ Fermi GBM reports hard X-ray variability on **~yearly time scales**. Confirmed by multiple instruments (C. A. Wilson-Hodge et al. arXiv:1010.2679v1)
- ✦ Crab flares at high energy ( $>100$  MeV)
  - ✦ AGILE reports enhanced Crab flux over a **few days**, Sept. 19-21 (M. Tavani et al. ATEL #2855)
  - ✦ Fermi LAT confirms flare and triggers LAT ToO (R. Buehler et al. ATEL #2681)
    - ✦ Earlier flare found using new offline all-sky variability search developed by R. Buehler
  - ✦ Fermi LAT reports end of flare. Variability present in off-pulse phase of pulsar (E. Hays et al. ATEL #2893)



# Two Short Flares from the Nebula

Flux of the low energy LAT component

**Preliminary**



No variability  
found in pulsar  
or high energy  
LAT component

4 week intervals  
*Sun passages  
excluded*

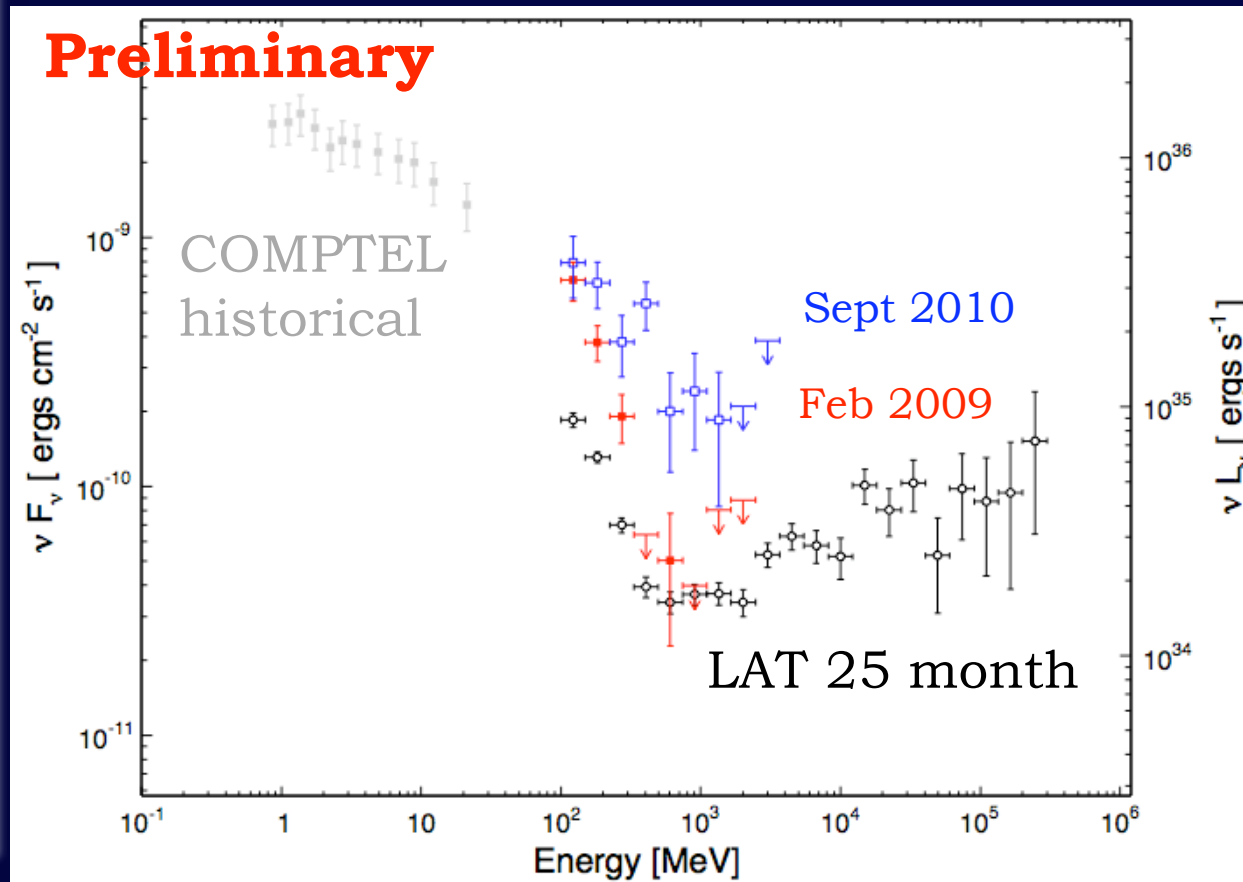
4 day intervals  
covering flare  
periods

arXiv:1011.3855v2

E. Hays



# Crab Flare Spectra



Low energy LAT component shows spectral variability

25 month index:  
 $3.69 \pm 0.11$

Feb 2009 index:  
 $4.3 \pm 0.3$

Sept 2010 index:  
 $2.7 \pm 0.2$



# Origin of the Gamma-ray Flares?

- ✦ Gamma-ray luminosity is a small fraction of the pulsar power ( $10^{35}$  erg/s  $\rightarrow \sim 10^{-3} L_{\text{rot}}$ )
- ✦ 4 day duration implies small region size, diameter  $< 1.4 \times 10^2$  pc (1.5 arcsec)
- ✦ Electron synchrotron cooling time in 200 uG  $< \sim 15$  days
- ✦ LAT low energy spectral form + short timescale variability support a synchrotron interpretation
  - ✦ Implies electrons accelerated to  $> \text{PeV}$  in structures in the inner region near the termination shock and base of the jet



# Searching for the Emission Region



No corresponding variability found in radio, optical, infrared, soft and hard X-rays at time or shortly after the 2nd LAT flare



# Summary

- ✦ LAT all-sky monitoring is producing spectacular results for the GeV transient sky
  - ✦ New blazars and unidentified transients
  - ✦ Probing the jet of the Cygnus X-3 microquasar
  - ✦ Discovery of gamma rays from V407 Cygni nova
  - ✦ Fast high-energy gamma-ray flares from the Crab
  - ✦ All-sky monitoring continues. What's next?

<http://fermi.gsfc.nasa.gov>