

National Aeronautics and Space Administration



**Fermi**  
Gamma-ray Space Telescope



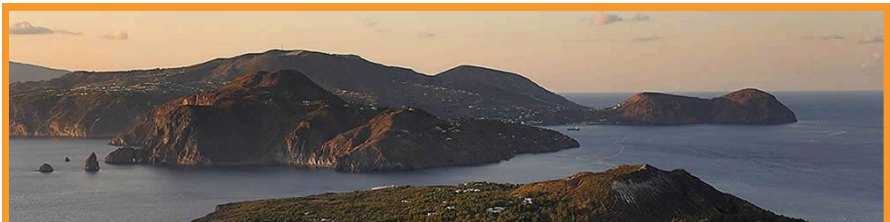
[www.nasa.gov/fermi](http://www.nasa.gov/fermi)

# Flaring gamma-ray AGNs

**Sara Buson**

INFN & Univ. of Padova

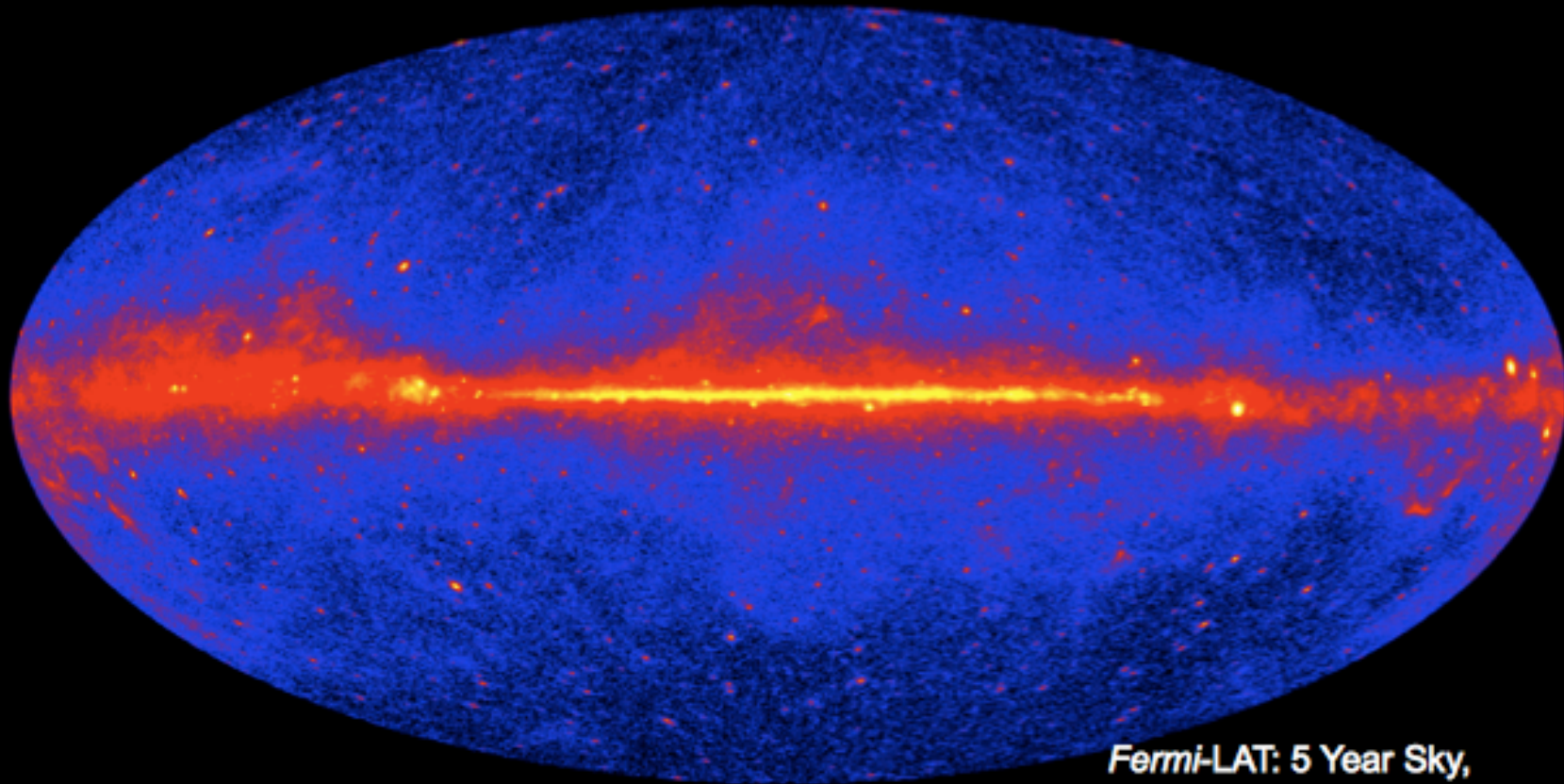
On behalf of the *Fermi* LAT  
collaboration



Vulcano Workshop 2014 - Frontier Objects in Astrophysics and Particle Physics

18-24 May 2014 Vulcano Island, Sicily, Italy

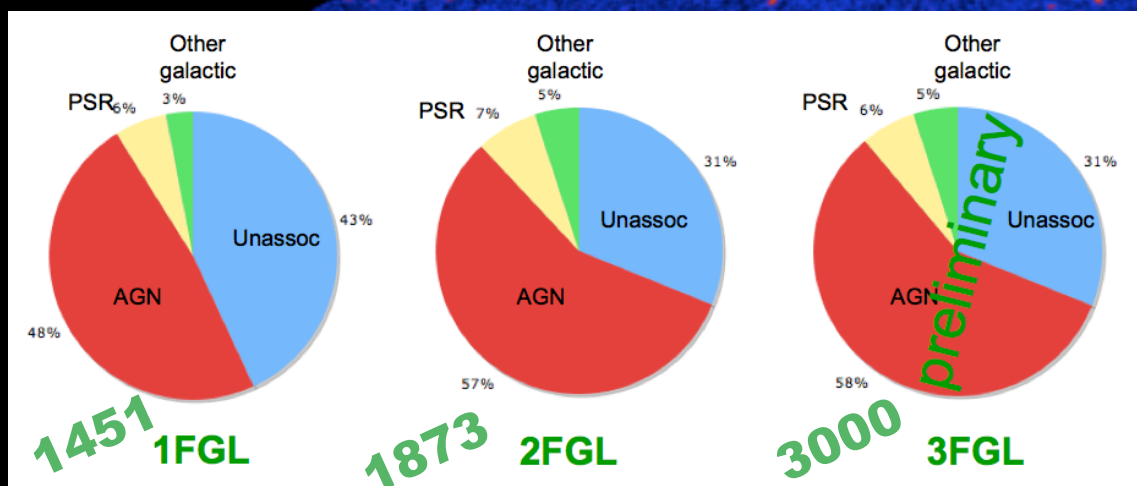
# The Gamma-ray Sky :



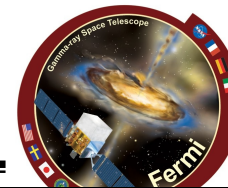
*Fermi-LAT: 5 Year Sky,  
Front-converting events  $> 1$  GeV*



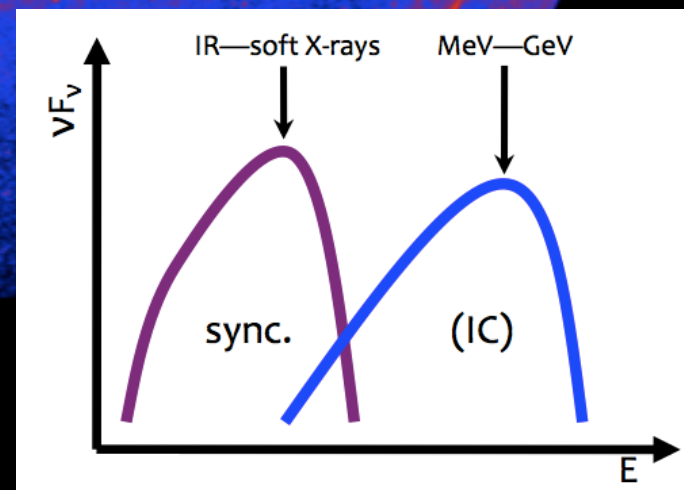
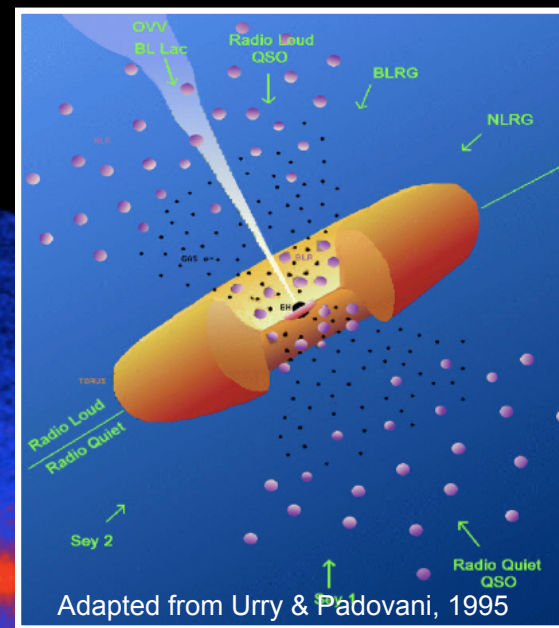
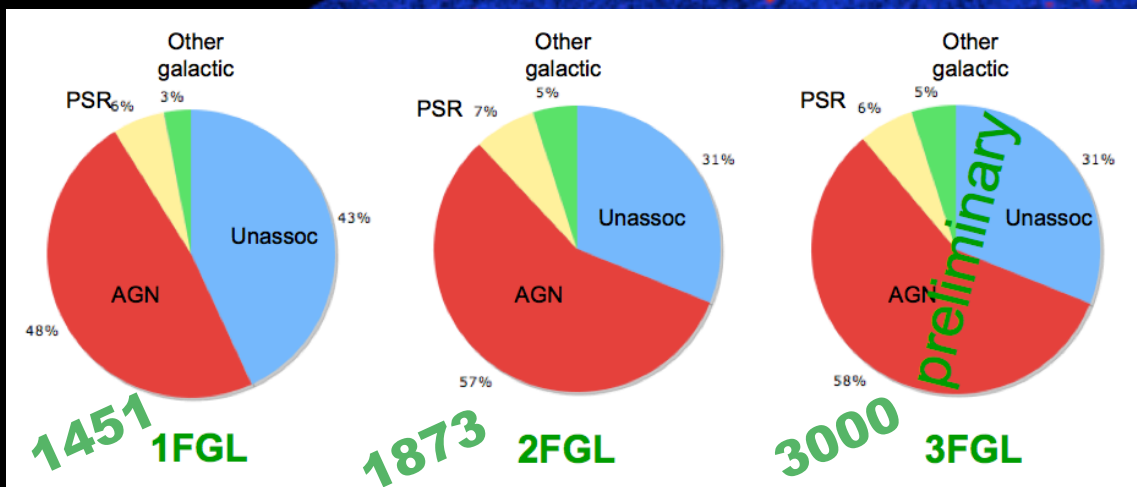
## Catalogues

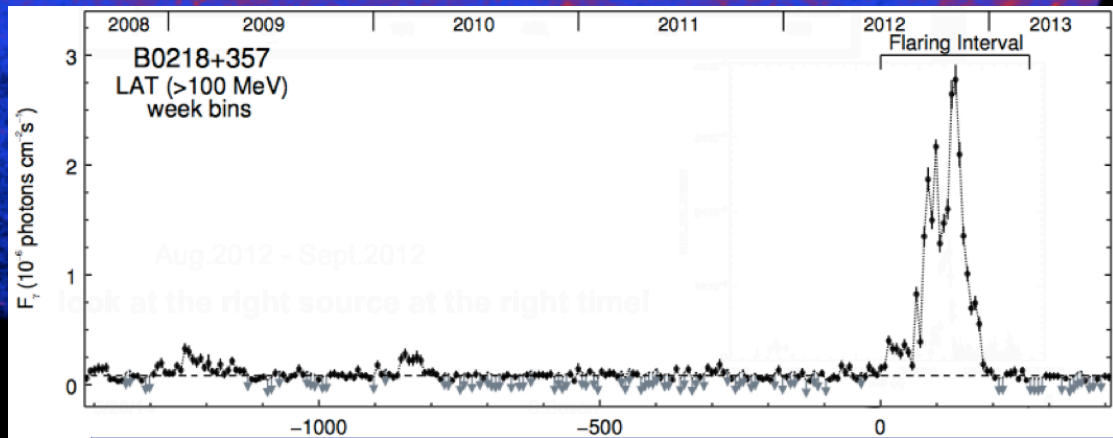
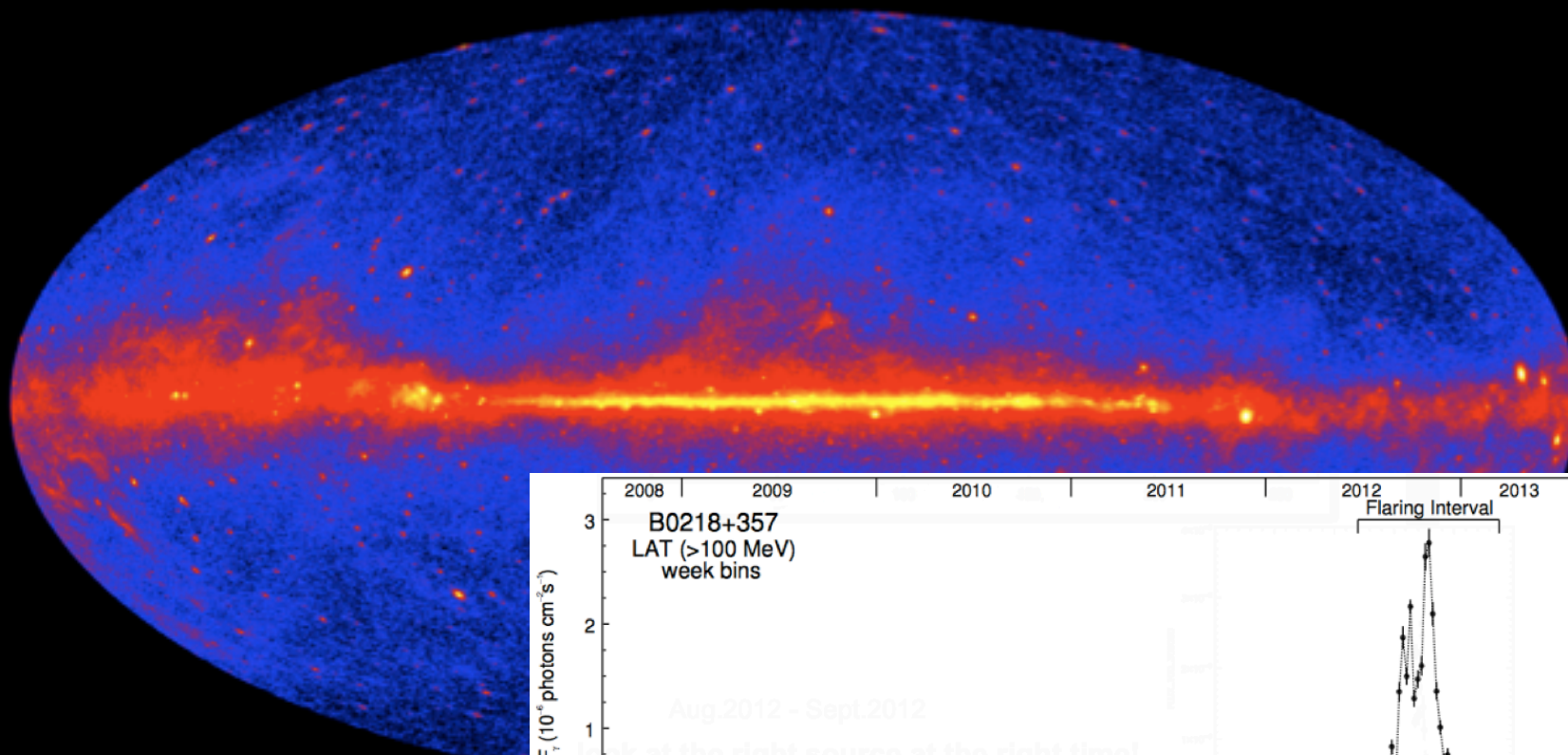


Fermi-LAT: 5 Year Sky,  
Front-converting events > 1 GeV

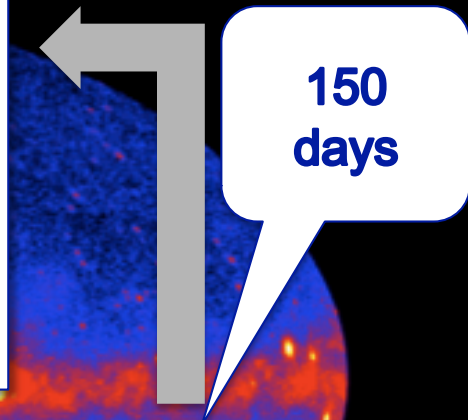
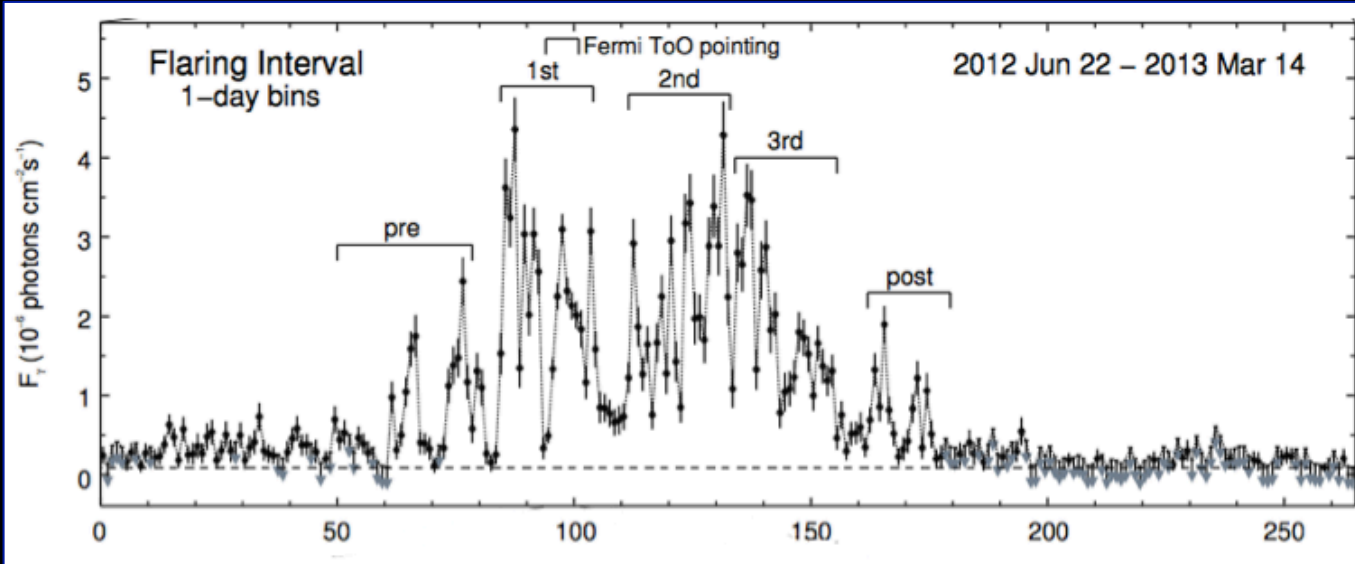
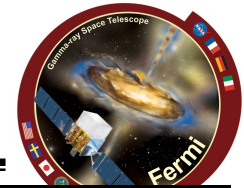


## Catalogues

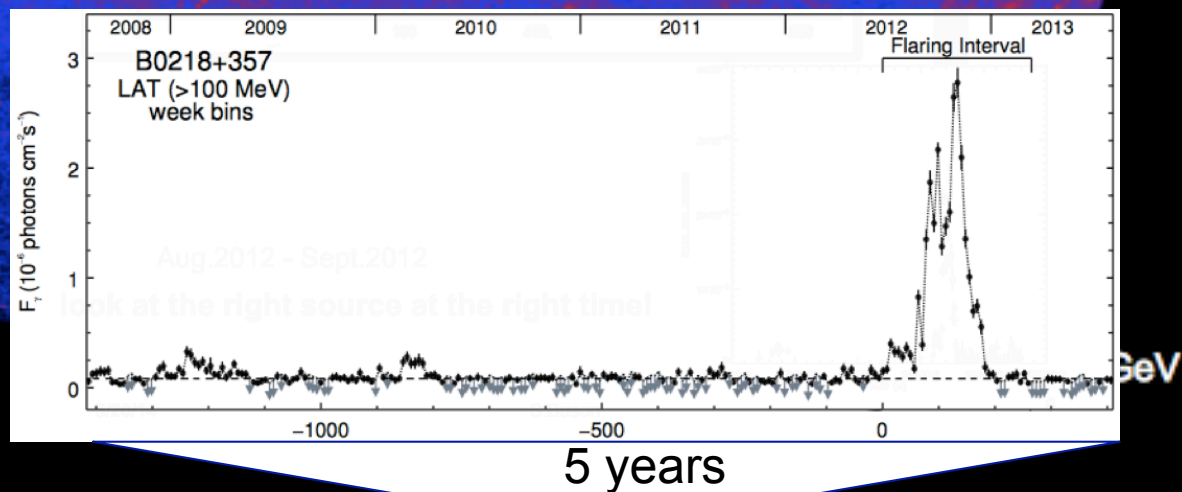




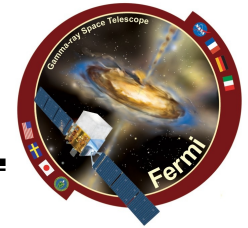
5 years



**Crucial ingredient :**  
**look at the right**  
**source at the right**  
**time!**



# The *Fermi*-LAT: a Sky Monitor

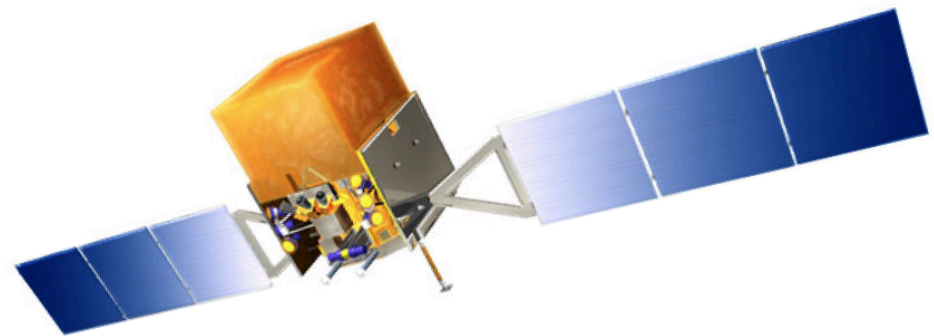


- **Fermi LAT is a permanent all-sky survey, allows a good coverage of the sky (scans the whole sky in ~ 3h)**
- **A prompt alert, an automatic pipeline to release scientific relevant information almost in real time (gamma-ray blazar flares, unidentified transients)**

—————→ *Flare Advocate (FA-GSW)*

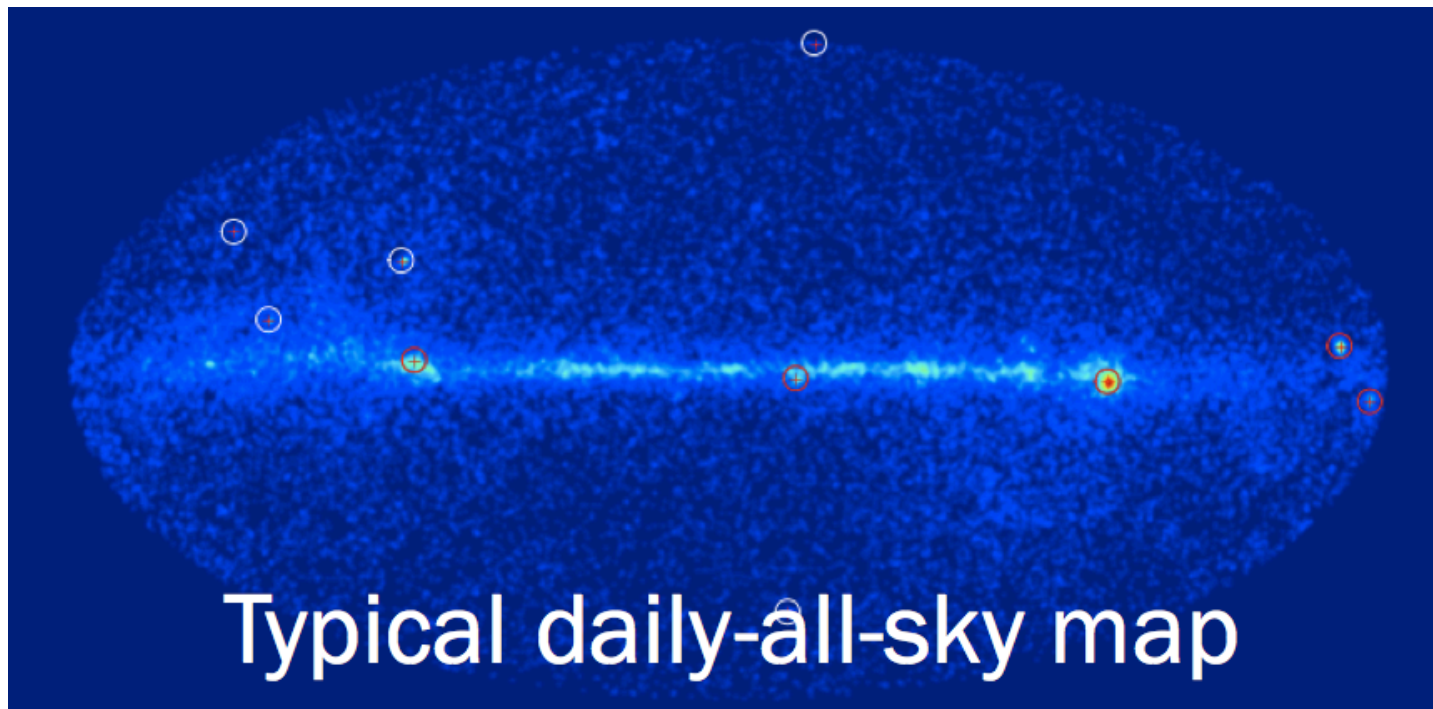
—————→ *Fermi All-sky Variability Analysis (FAVA)*

Energy range: < 100 MeV to > 300 GeV



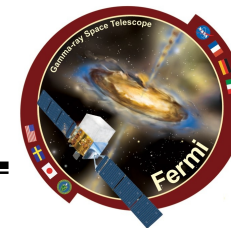


- Quick look data analysis: data automatically processed (ASP) every 6h and 24h, potentially interesting sources are pointed out
- Multi-mission/multi-frequency tools and archives linked to ASP and provided by the Asi Data Center
- Great effort by Flare Advocates (<http://fermisky.blogspot.it/>)
- Threshold to issue ATels on flaring sources:  $F_{E>100\text{MeV}} > 10^{-6} \text{ ph cm}^{-2}\text{s}^{-1}$



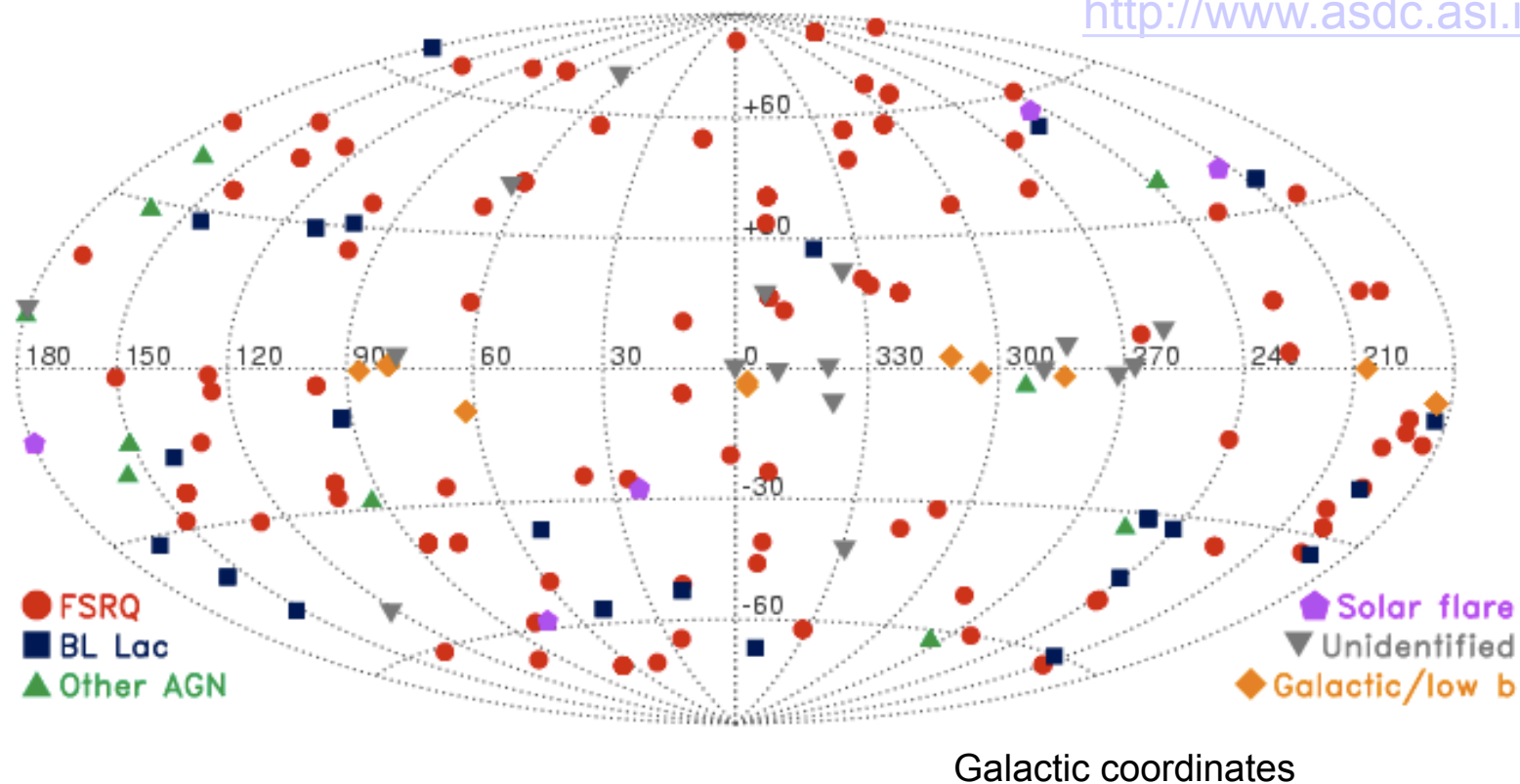


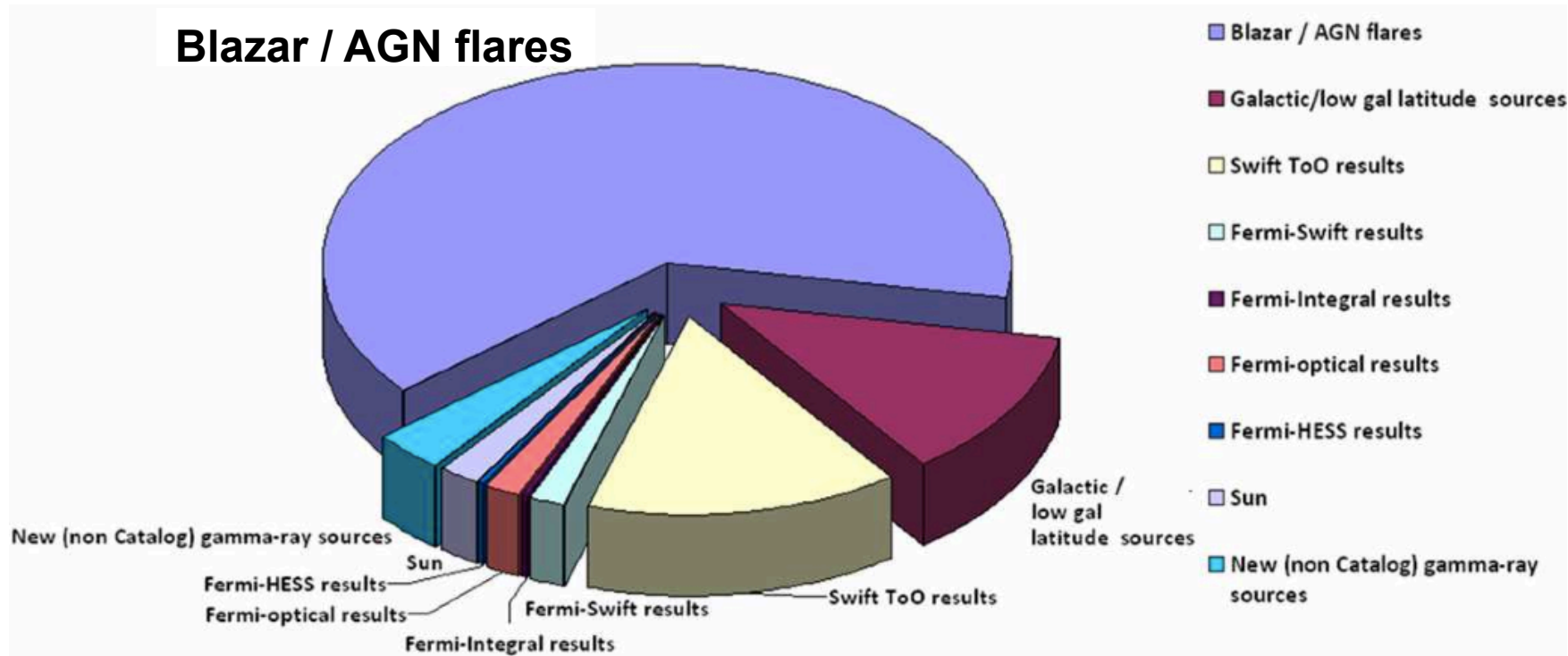
# Flare Advocates -- Output



Outline of the all-sky map distribution, of the new gamma-ray sources, flares and transients found by Fermi LAT and announced through Astronomer's Telegrams. Most of these sources follow the FA-GSW service.

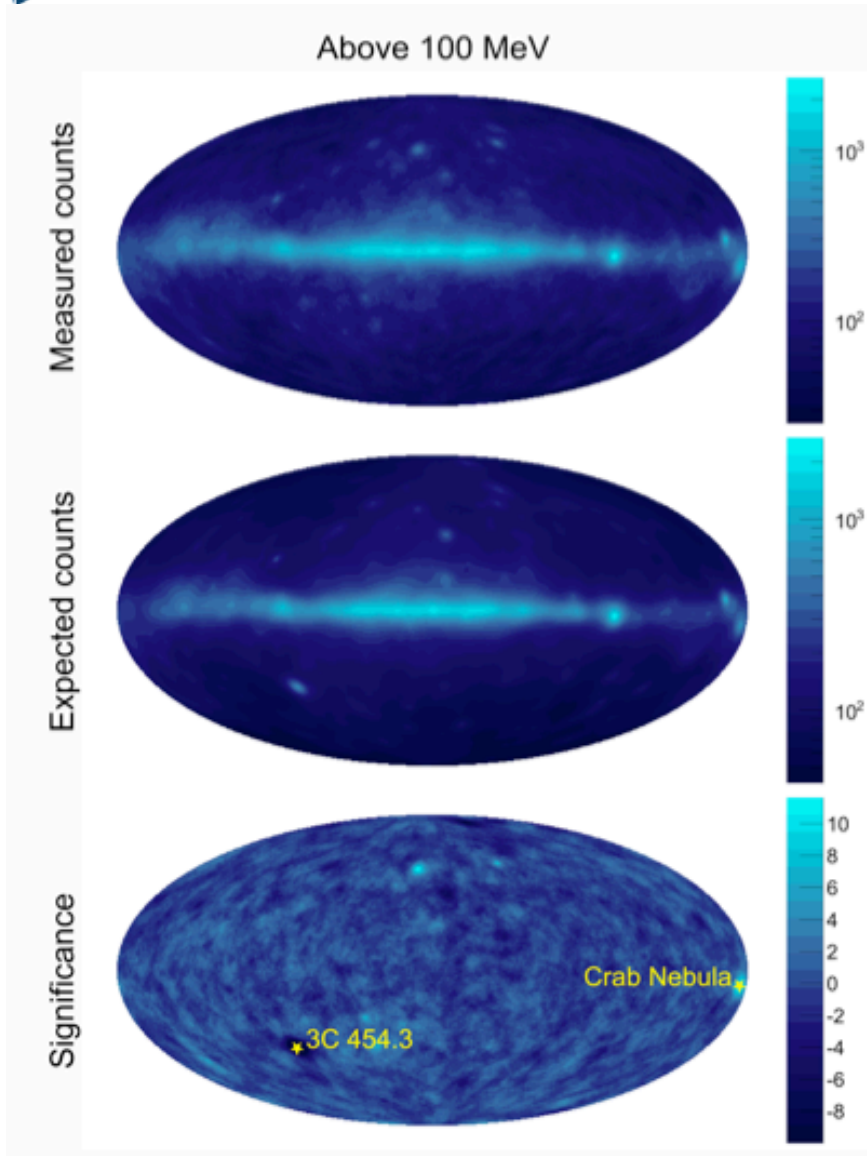
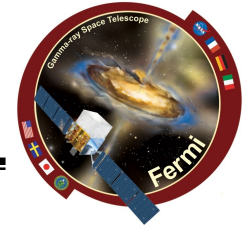
<http://www.asdc.asi.it/feratel/>





The 265 Fermi LAT (ATels) published on behalf of the LAT collaboration from 2008 July 24, to 2014 February 19 (i.e., in 2036 days of Fermi mission)

# FAVA -- How it works



Number of gamma rays observed in a given time window to the number of gamma rays expected for the average emission detected from that direction

Method used in

→ weekly time intervals

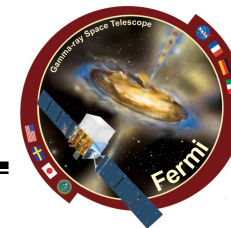
→ two energy ranges,  $E > 100 \text{ MeV}$  and  $E > 800 \text{ MeV}$

derived a list of 215 flaring gamma-ray sources (Ackermann et al. 2013, ApJ, 771, 57A)

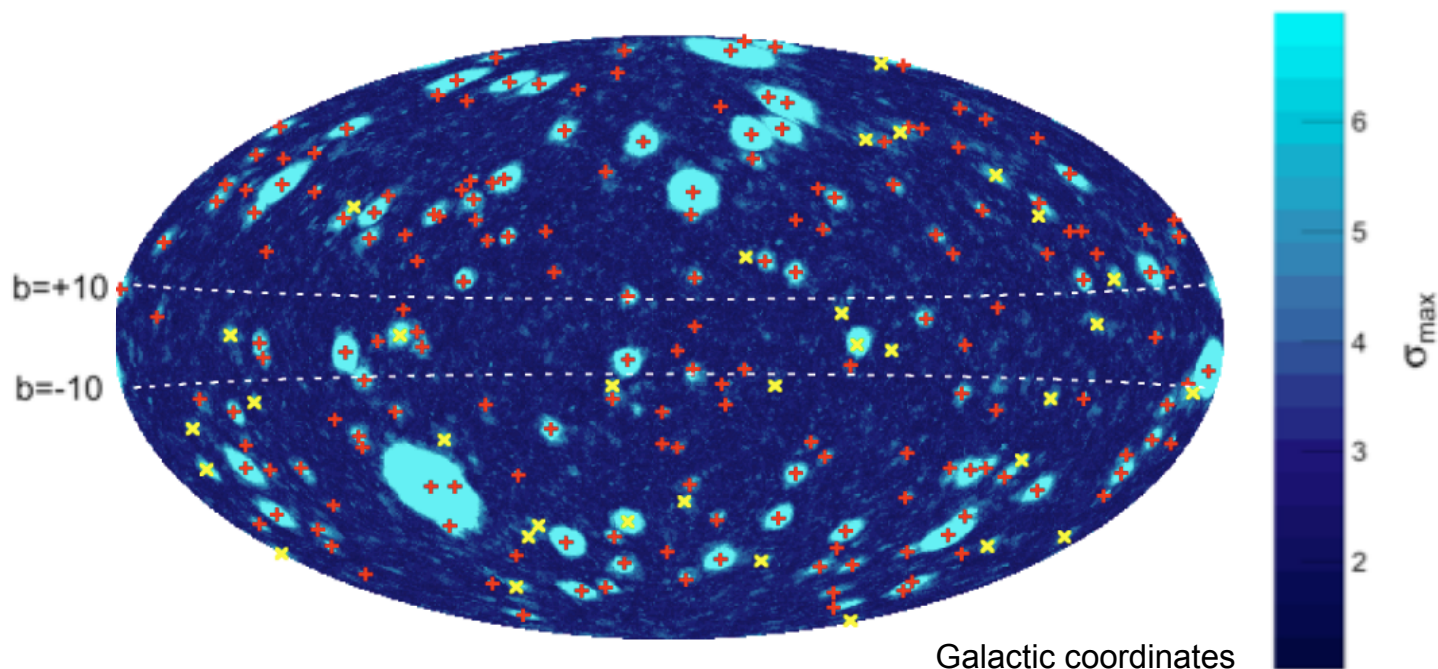
An example of positive flare is shown for the Crab whereas a negative flare (quiescence) is shown for 3C 454.3

Leaders: R.Buehler (DESY), M.Ajello (Clemson), A.Allafort (Stanford), D.Kocevski (NASA/GSFC), S. Funk (Stanford)

# FAVA -- Sources



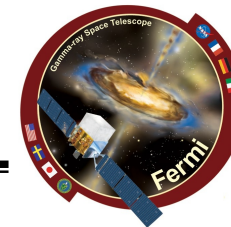
A total of 215 sources were detected with significance greater than  $5.5\sigma$ .



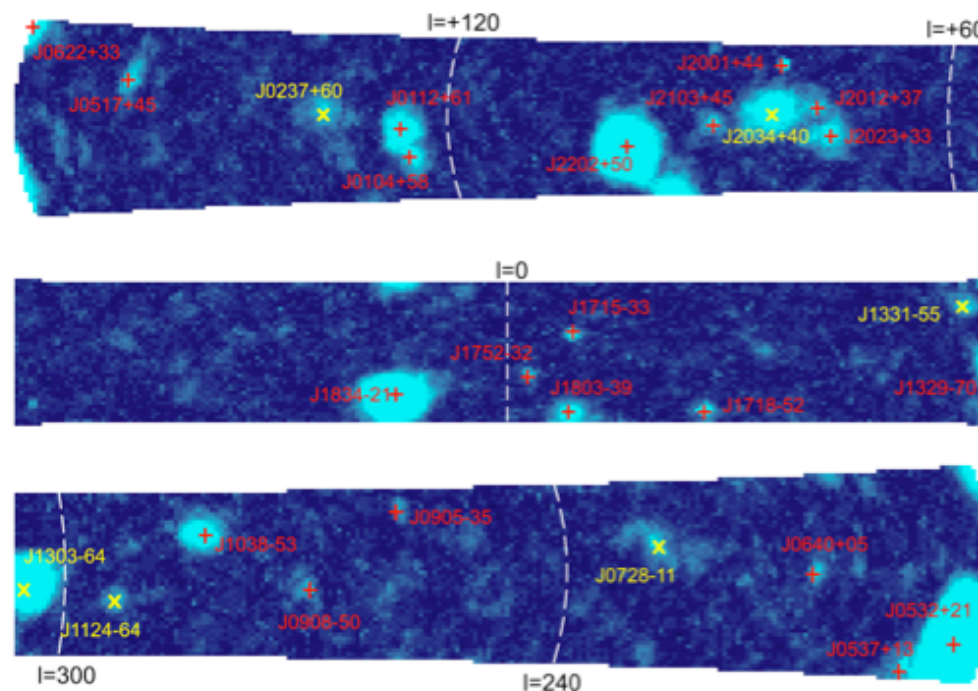
Sources for which at least one flare was detected in the low and high energy band are shown in yellow and red respectively.

[https://www-glast.stanford.edu/pub\\_data/585/](https://www-glast.stanford.edu/pub_data/585/)

<http://www.asdc.asi.it/fava/>



27 sources are detected at Galactic latitudes  $<10^\circ$ . Of these, 4 sources coincide with known variable Galactic sources, 15 coincide with blazars, 1 is associated with an unknown compact radio source.



- FAVA detects an average of  $\sim 1$  new transient source in the Galactic plane ( $|b| < 10^\circ$ ) every 8 weeks.
- ToO observations with Swift and Chandra to follow-up on these new transients planned to constrain the nature of their counterparts.



## The Astronomer's Telegram

### Fermi LAT detection of a new transient gamma-ray source in the Galactic Plane through the Fermi All-sky Variability Analysis (FAVA)

ATel #6098; [D. Kocevski \(GSFC/NASA\)](#), [M. Ajello \(Clemson University\)](#), [R. Buehler \(DESY/Zeuthen\)](#), [J. Becerra \(GSFC/NASA\)](#), [R. Ojha \(GSFC/NASA\)](#) on behalf of the Fermi Large Area Telescope Collaboration

on 25 Apr 2014; 01:51 UT

Distributed as an Instant Email Notice Transients

Credential Certification: [Marco Ajello \(majello@clemsun.edu\)](mailto:marco.ajello@clemsun.edu)

Subjects: Gamma Ray, >GeV, Request for Observations, Transient

Referred to by ATel #: [6100](#), [6122](#), [6139](#)



During the week between April 14 and April 21, 2014, the Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, observed gamma-ray activity from a previously unidentified transient source in the Galactic plane. The significance of the source detection above 100 MeV for the entire LAT exposure from April 14 and April 21, 2014 is approximately 7 sigma. The preliminary best-fit location of the gamma-ray source is RA = 100.383 deg, Dec = -3.294 deg, J2000, with 95% confidence that the source is within 0.25 deg of this position (statistical errors only). A preliminary spectral analysis of the source indicates that the source brightened in gamma rays to a flux ( $E > 100$  MeV) of  $(7.7 \pm 1.3) \times 10^{-7}$  ph cm<sup>-2</sup> s<sup>-1</sup>, with a spectral index of  $2.67 \pm 0.16$  (errors are statistical only). A search of the NASA Extragalactic Database (NED) within the 95% containment radius reveals a bright flat-spectrum radio source, PMN J0641-0320, that is approximately 0.1 degrees from the LAT localization. A Swift ToO has been submitted and accepted for this source. Because Fermi provides all-sky coverage, regular gamma-ray monitoring of this source will continue. Multiwavelength observations during the ongoing activity of this source are strongly encouraged. The Fermi LAT contact person for Fermi J0641-0317 is Daniel Kocevski (e-mail: [daniel.kocevski@nasa.gov](mailto:daniel.kocevski@nasa.gov)). The transient was identified thanks to a new method implemented within the Fermi-LAT Collaboration known as "Fermi All-sky Variability Analysis" that searches the sky for high-energy transients on weekly time scales (Ackermann et al. 2013, ApJ, 771, 57). The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.

## The Astronomer's Telegram

### Fermi LAT detection of gamma-ray flaring activity from the blazar MG J221916+1806 through the Fermi All-sky Variability Analysis (FAVA)

ATel #6020; [M. Ajello \(Clemson University\)](#), [D. Kocevski \(GSFC/NASA\)](#), [D. Gasparrini \(ASDC/INAF\)](#), [R. Buehler \(DESY/Zeuthen\)](#), [D. Thompson \(GSFC/NASA\)](#), [S. Ciprini \(ASDC/INAF\)](#), on behalf of the Fermi Large Area Telescope Collaboration

on 28 Mar 2014; 15:24 UT

Credential Certification: [Dario Gasparrini \(dario.gasparrini@asdc.asi.it\)](mailto:dario.gasparrini@asdc.asi.it)

Subjects: Gamma Ray, >GeV, Request for Observations, Blazar, Quasar



During the week between March 17 and March 24, 2014, the Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed increased gamma-ray activity from a source positionally coincident with the flat-spectrum radio quasar MG J221916+1806 (also known as 2FGL J2219.1+1805, Nolan et al., 2012, ApJS, 199, 31, and CGRaBS J2219+1806, Healey et al. 2008, ApJ, 175, 97). MG J221916+1806 has radio coordinates RA(J2000)=22h19m14.0925s, DEC(J2000)=+18d06m35.580s (Beasley et al. 2002, ApJS, 141, 13) and has a redshift of  $z=1.071$  (Shaw et al. 2012, ApJ, 748, 49). Preliminary analysis indicates that the source brightened in gamma rays to a flux ( $E > 100$  MeV) of  $(1.0 \pm 0.4) \times 10^{-7}$  ph cm<sup>-2</sup> s<sup>-1</sup> (errors are statistical only). This corresponds to a factor of 20 increase in the source flux with respect to its average flux as reported in the Fermi-LAT 2FGL source catalog.

Because Fermi provides all-sky coverage, regular gamma-ray monitoring of this source will continue. Multiwavelength observations during the ongoing activity of this source are strongly encouraged. The Fermi LAT contact person for MG J221916+1806 is Marco Ajello (e-mail: [majello@clemsun.edu](mailto:majello@clemsun.edu)).

The transient was identified thanks to a new method implemented within the Fermi-LAT Collaboration known as "Fermi All-sky Variability Analysis" that searches the sky for high-energy transients on weekly time scales (Ackermann et al. 2013, ApJ, 771, 57).

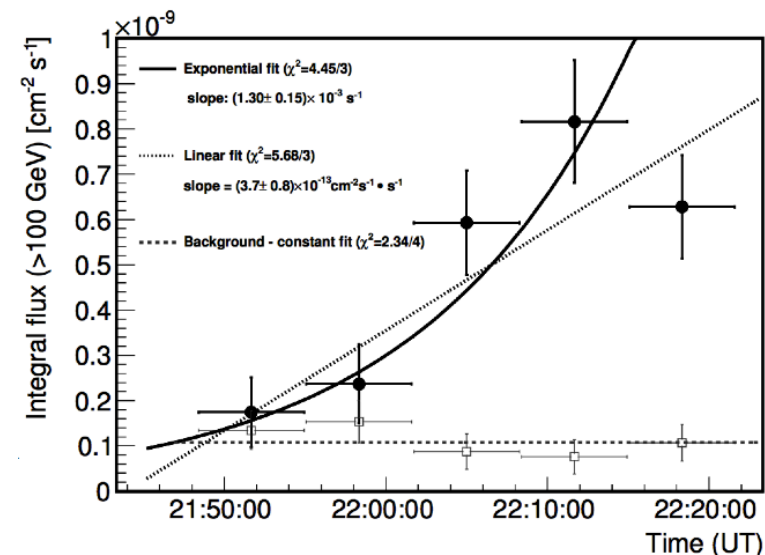
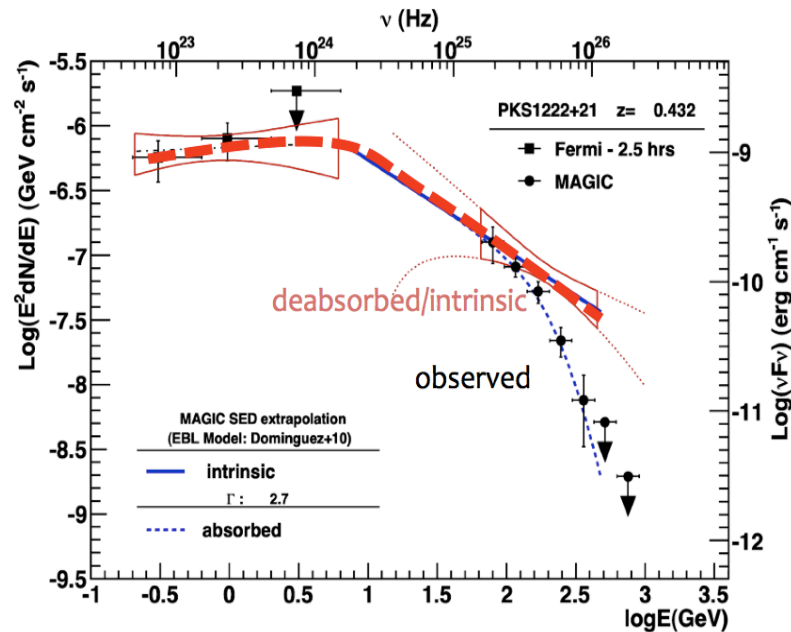
The Fermi LAT is a pair conversion telescope designed to cover the energy band from 20 MeV to greater than 300 GeV. It is the product of an international collaboration between NASA and DOE in the U.S. and many scientific institutions across France, Italy, Japan and Sweden.



- **PKS 1222+216** (FSRQ, aka 4C+21.35,  $z=0.435$ )
- MAGIC detection (2010) during high activity
- Simultaneous Fermi-LAT 2.5hrs encompassing MAGIC obs.
- Very fast variability
- Doubling flux scale of 9 minutes approx

→ **Constraint on the emission region: location and size ( $R=10^{14}\text{cm}$ )**

MAGIC Coll. ApJL 730 (2011)  
Tanaka+ ApJ, 733, 19 (2011)



# PKS 1510-08: mwl context



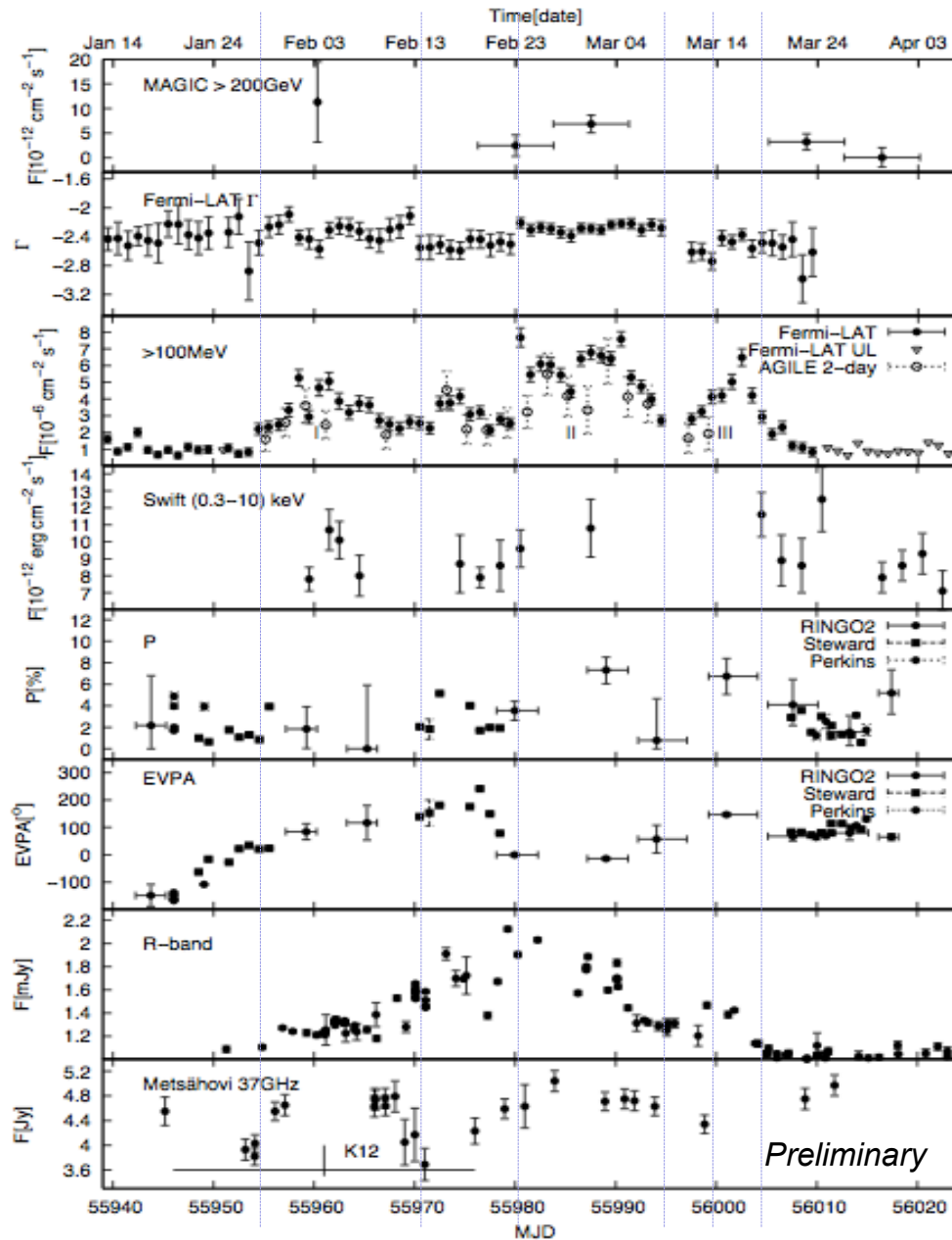
VHE (>200GeV)

HE (>100MeV)

X-rays  
(2-10 keV)

Optical

Radio 37 GHz

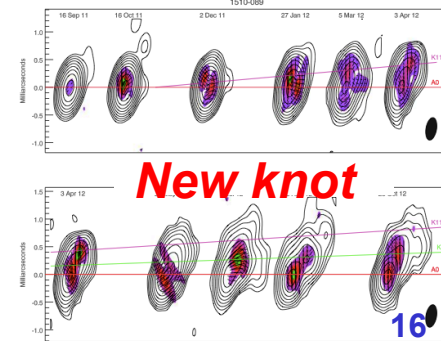


no significant variability

3 distinct flares

modest variability

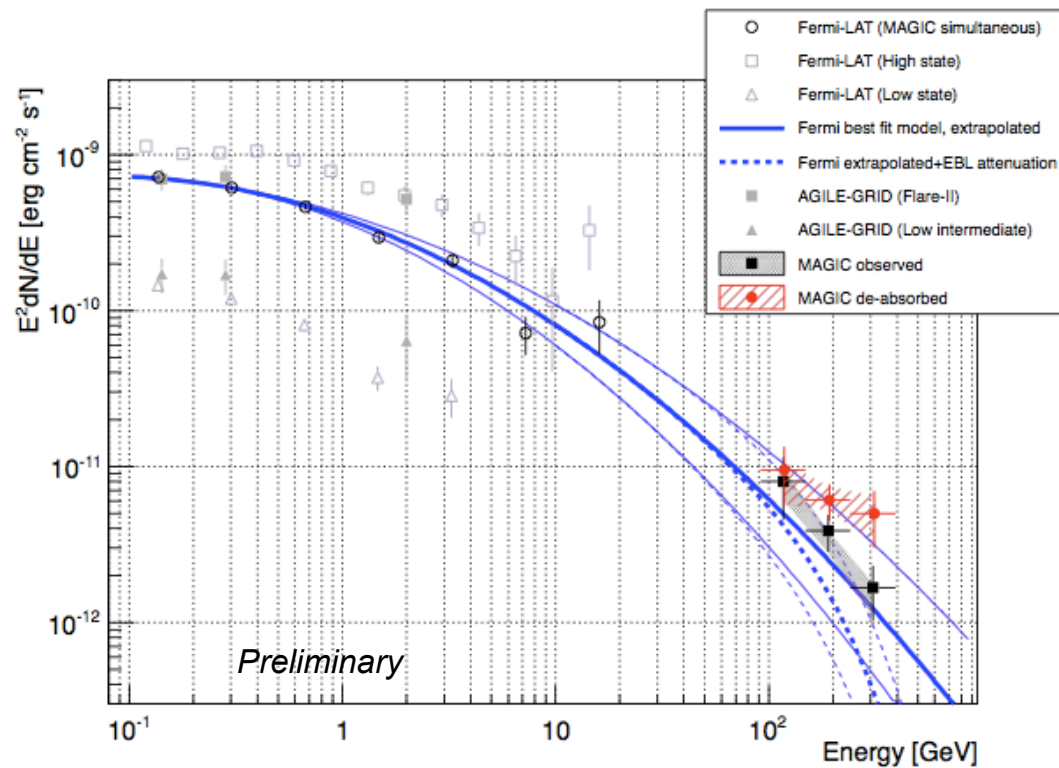
3 distinct EVPA Rotations >180°







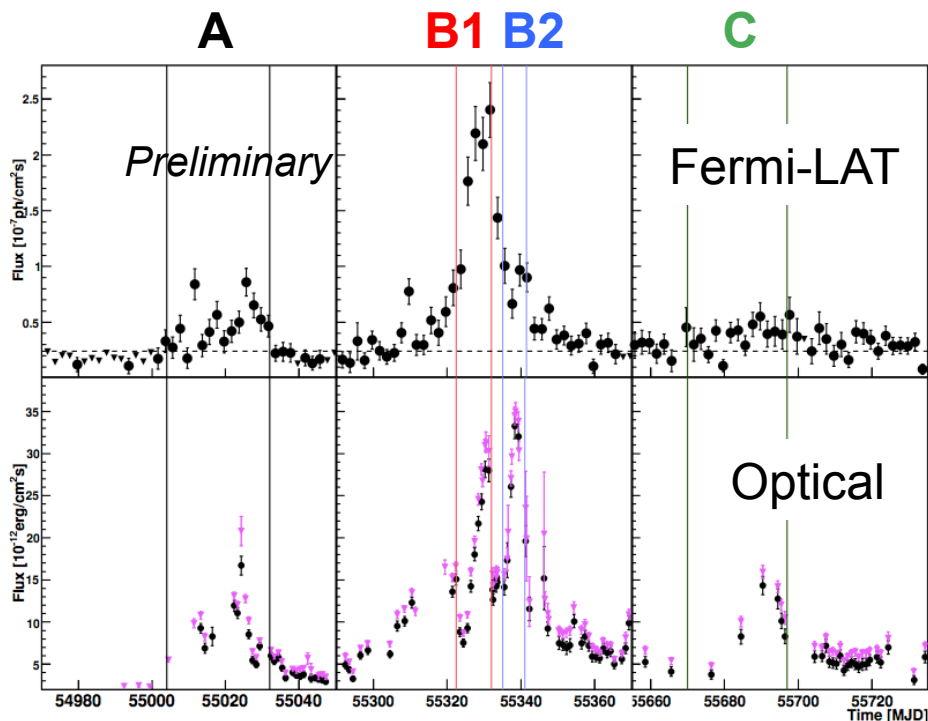
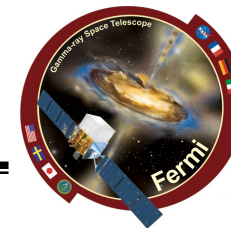
- The **HE and VHE spectra connect smoothly**



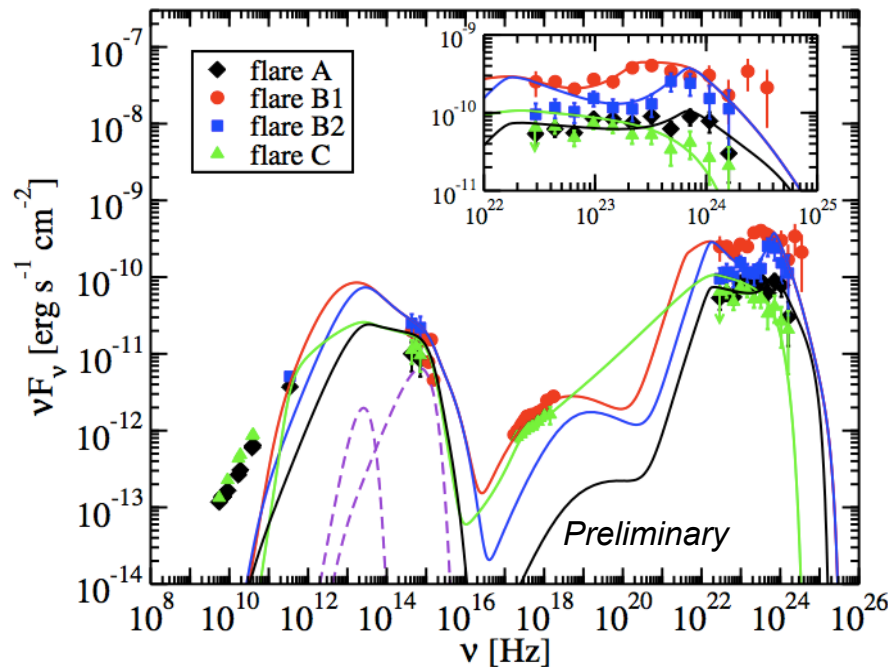
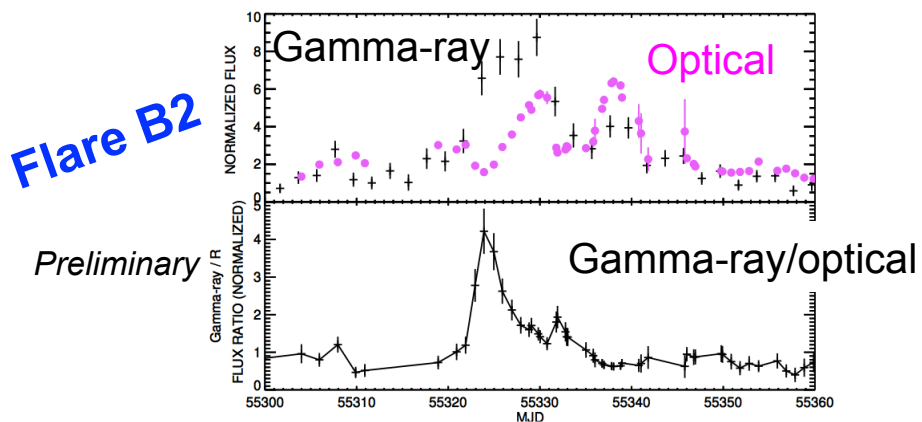
Aleksić+ submitted



- The **HE and VHE spectra connect smoothly** → suggests radiation originates from a **single emission region** located far from the central region
- the HE variability indicates that within the larger emission region, there **must exist more compact emission regions** producing the **fast variability**
- Several emission sites were also suggested by Nalewajko et al. (2012), Barnacka et al. (2013)
- The model **turbulent plasma flowing at a relativistic speed down the jet and crossing a standing shock**, would naturally lead to such behavior (Marscher 2014)
- The **common variability patterns seen in the HE and 37 GHz** light curves + ejection of a new component from the 43 GHz VLBA core support this emission scenario



- different optical – gamma-ray trend for flaring episodes
- upwards shape of the LAT spectra in the SED



(Buson+ submitted)



## ATel #2943

**Fermi LAT detection of an intense GeV flare from the high-redshift and gravitationally lensed blazar PKS 1830-211**

ATel #2943; *S. Ciprini (Perugia Univ. / ASI-INAF, Italy), on behalf of the Fermi Large Area Telescope Collaboration*  
on 15 Oct 2010; 16:52 UT  
Distributed as an Instant Email Notice Request For Observation  
Credential Certification: Stefano Ciprini (stefano.ciprini@p

Subjects: Gamma Ray, >GeV, Request for Observations

Referred to by ATel #: 2950, 4158

## ATel #4158

**Fermi LAT detection of renewed GeV gamma-ray activity from the gravitationally lensed blazar PKS 1830-211**

ATel #4158; *Stefano Ciprini (ASI Science Data Center and INAF Rome, Italy), on behalf of the Fermi Large Area Telescope Collaboration*  
on 7 Jun 2012; 21:53 UT  
Credential Certification: Stefano Ciprini (stefano.ciprini@asdc.asi.it)

Subjects: Gamma Ray, >GeV, Request for Observations, AGN, Blazar, Quasar

## ATel #4343

**Fermi LAT detection of a GeV flare from the gravitationally lensed blazar S3 0218+35**

ATel #4343; *S. Ciprini (ASI ASDC & INAF OAR, Rome), on behalf of the Fermi Large Area Telescope Collaboration*  
on 28 Aug 2012; 20:45 UT  
Credential Certification: Stefano Ciprini (stefano.ciprini@asdc.asi.it)

Subjects: Gamma Ray, >GeV, Request for Observations

## ATel #4361

**Fermi LAT Detection of Gamma-ray Flaring from Gravitationally Lensed Blazar S30218+35**

ATel #4361; *M. Giroletti (INAF-IRA Bologna), M. Orienti (Univ. Bologna, INAF-IRA Bologna), C. C. Cheung (NRL/NRL) on behalf of the Fermi Large Area Telescope Collaboration*  
on 8 Sep 2012; 09:10 UT  
Credential Certification: Marcello Giroletti (giroletti@ira.inaf.it)

Subjects: Gamma Ray, >GeV, Request for Observations

## ATel #4371

**Fermi LAT detection of a potential echo gamma-ray flare from gravitational lens S3 0218+35**

ATel #4371; *M. Giroletti (INAF-IRA Bologna), M. Orienti (Univ. Bologna, INAF-IRA Bologna), C. C. Cheung (NRC/NRL); on behalf of the Fermi Large Area Telescope Collaboration*  
on 11 Sep 2012; 20:42 UT  
Credential Certification: Teddy Cheung (ccheung@nrl.navy.mil)

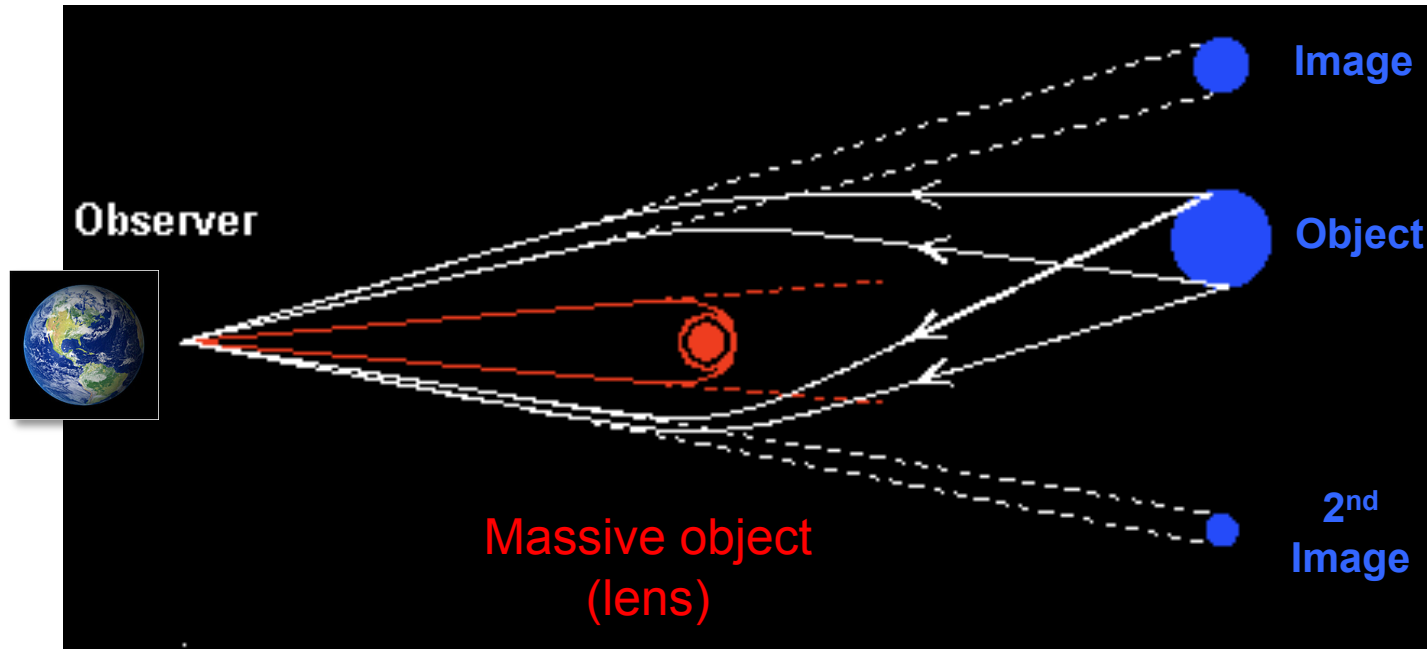
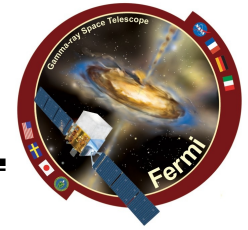
Subjects: Gamma Ray, >GeV, AGN, Blazar

## ATel #4411

**Fermi LAT Detection of New Gamma-ray Flaring from Gravitationally Lensed Blazar S3 0218+35 and Scheduled Fermi Pointed Observations from 2012 September 24 - October 1**

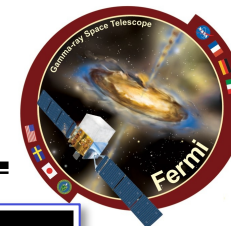
ATel #4411; *C. C. Cheung (NRC/NRL), R. Ojha (NASA/GSFC), M. Orienti (Univ. Bologna, INAF-IRA Bologna), D. L. Wood (Praxis/NRL); on behalf of the Fermi Large Area Telescope Collaboration*  
on 22 Sep 2012; 03:01 UT  
Credential Certification: Teddy Cheung (ccheung@milkyway.gsfc.nasa.gov)

Subjects: Gamma Ray, >GeV, AGN, Blazar

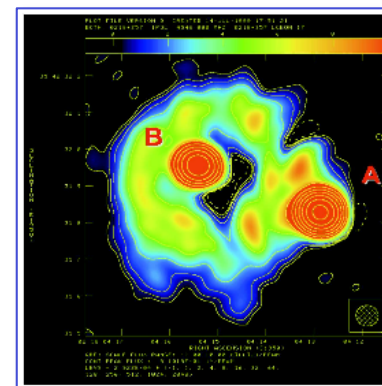


Gamma rays (Fermi-LAT) can not resolve the two images but can **estimate the time delay** between components of lensed AGN

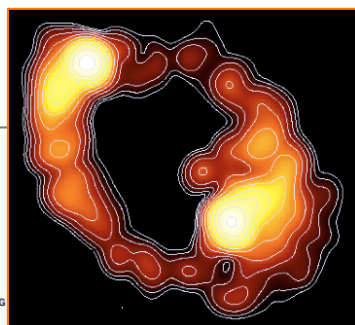
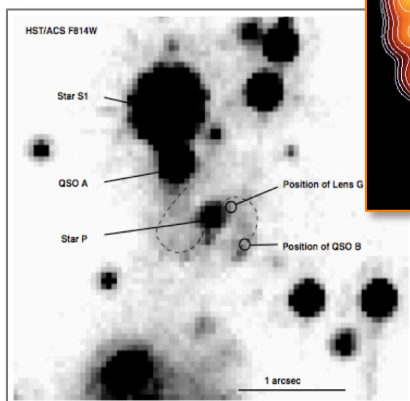
# PKS1830-211 – B0218+357



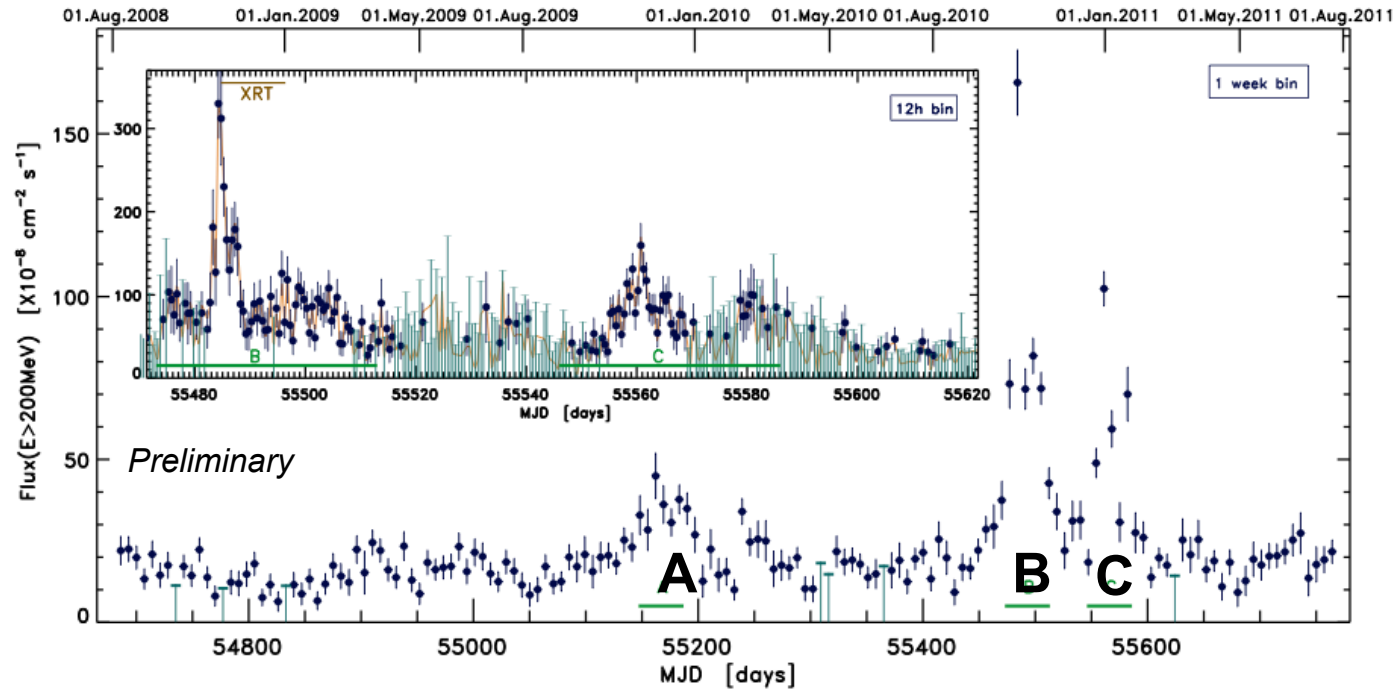
- FSRQ at  $z=2.507$ ;
- lens separation of  $0.98''$ ;  
Einstein ring
  - Lensing galaxy  $z=0.886$
  - Intervening galaxy  $z=0.19$
- Radio delays claimed:  $26\pm 5$  days,  $24\pm 5$  days
- magnification ratio  $\sim 1.5$



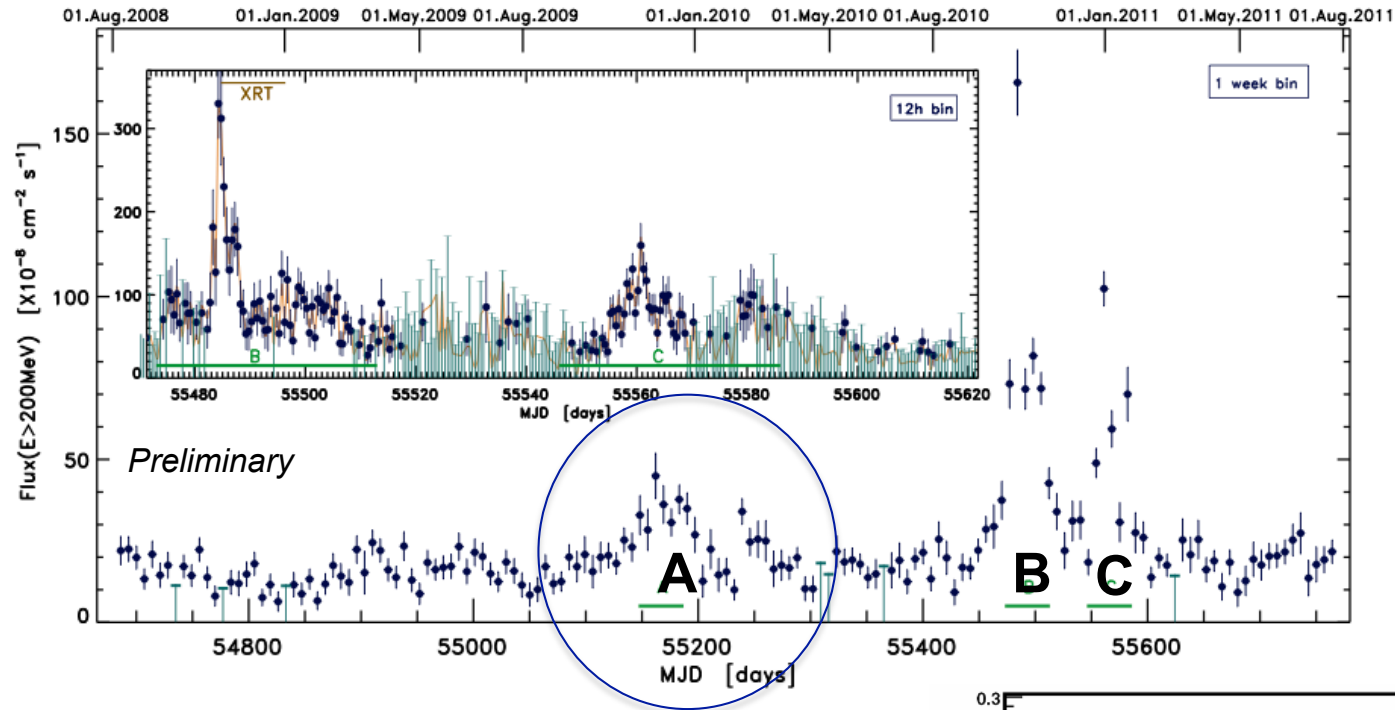
- $z = 0.944$
- Smallest separation lens from CLASS survey ( $0.335''$ );  
Einstein ring
  - Lensing galaxy  $z = 0.6847$
- Delay  $10.5 \pm 0.4$  day (95% CL, Biggs et al. 1999)
- Associated with LAT gamma-ray source (2FGLJ0221.0+3555)



# Flares of Lensed Blazars: PKS1830-211



# Flares of Lensed Blazars: PKS1830-211



Gamma-ray lensing delay claimed:  
 $27.1 \pm 0.6$  days (Barnacka et al. 2011)

Signal feature at 53.4-day timescale: precession period of the spacecraft orbit  $\rightarrow$  systematics by effective area variation in P6 data/IRFs (27 day delay claimed is the first harmonic of that).

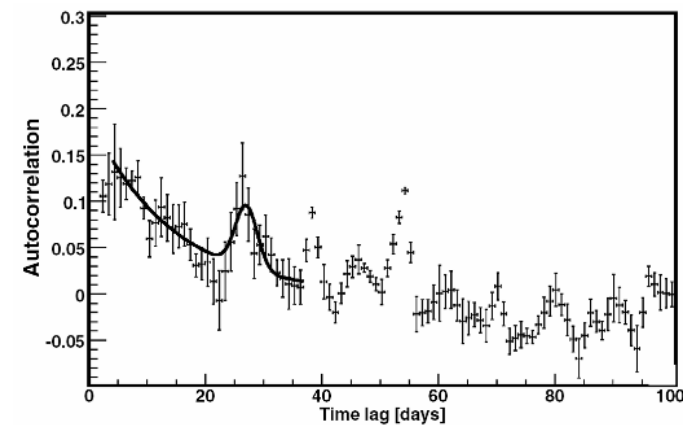


Fig. 7. Measured autocorrelation function of PKS 1830-211. The solid line is a fit to an exponential plus Gaussian profile.

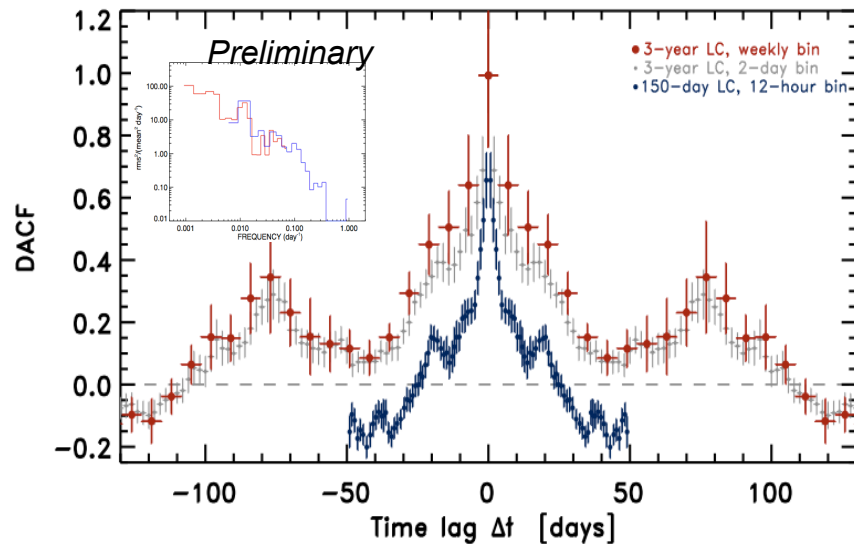




## No evident sign of delayed gamma-ray flares caused by lens (The Fermi-LAT coll., submitted)

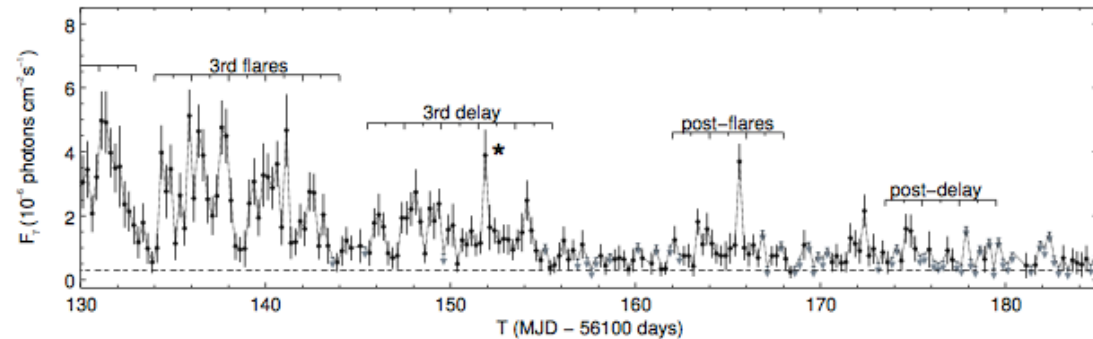
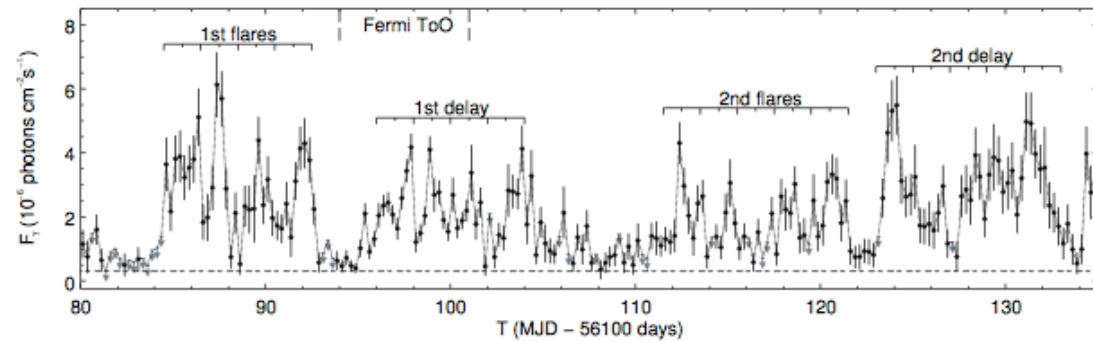
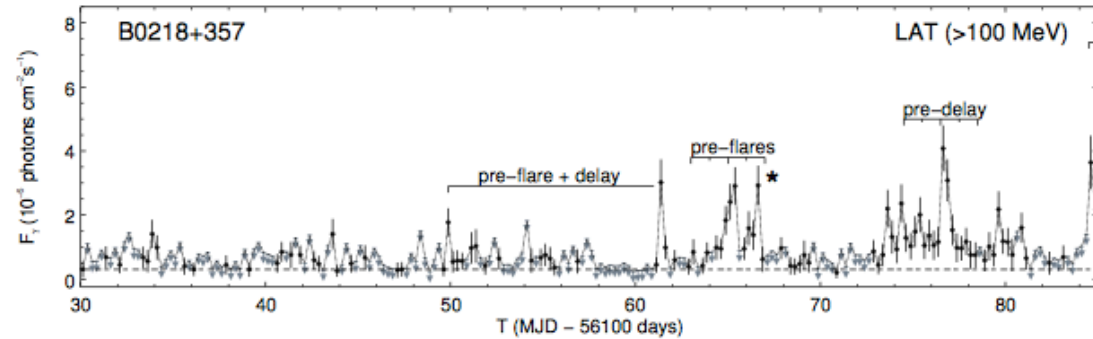
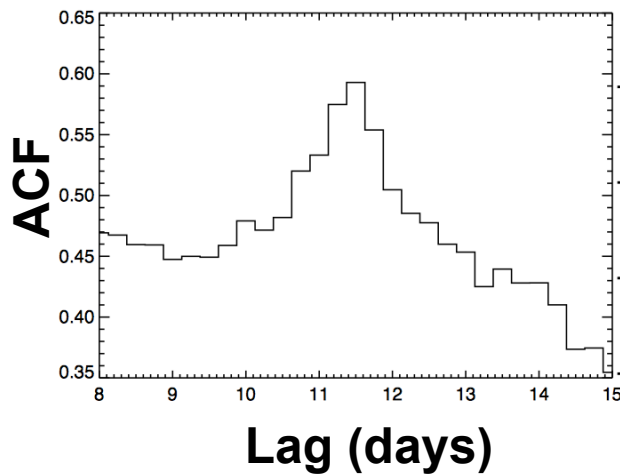
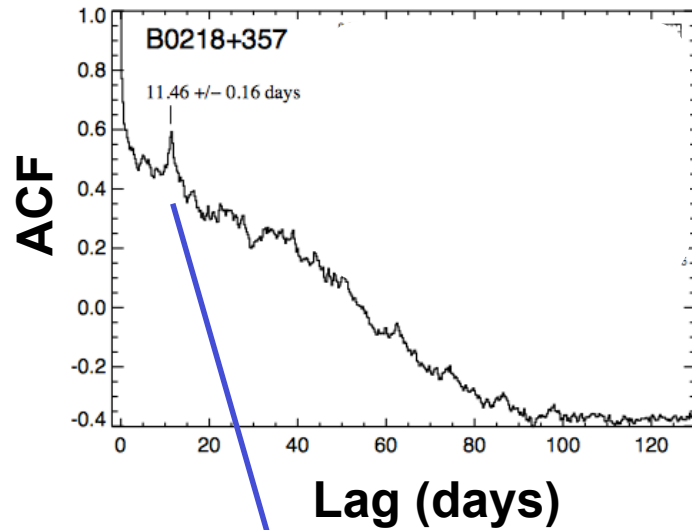
To be noted:

- Different spatial origin of the emission at different wavelengths
- Magnification ratio different for radio and gamma-ray emission
- Lower limit of  $\sim 6$  in the gamma-ray flux ratio  $\rightarrow$  upper limit on the size of the gamma-ray emitting region (in agreement with SED modeling)
- ALMA remarkable frequency-dependent behavior of the flux ratio of the two images (Marti-Vidal et al. 2013)

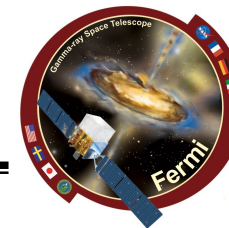




## Structured gamma-ray light curve



# First gamma-ray delay measurement



**B0218+35**

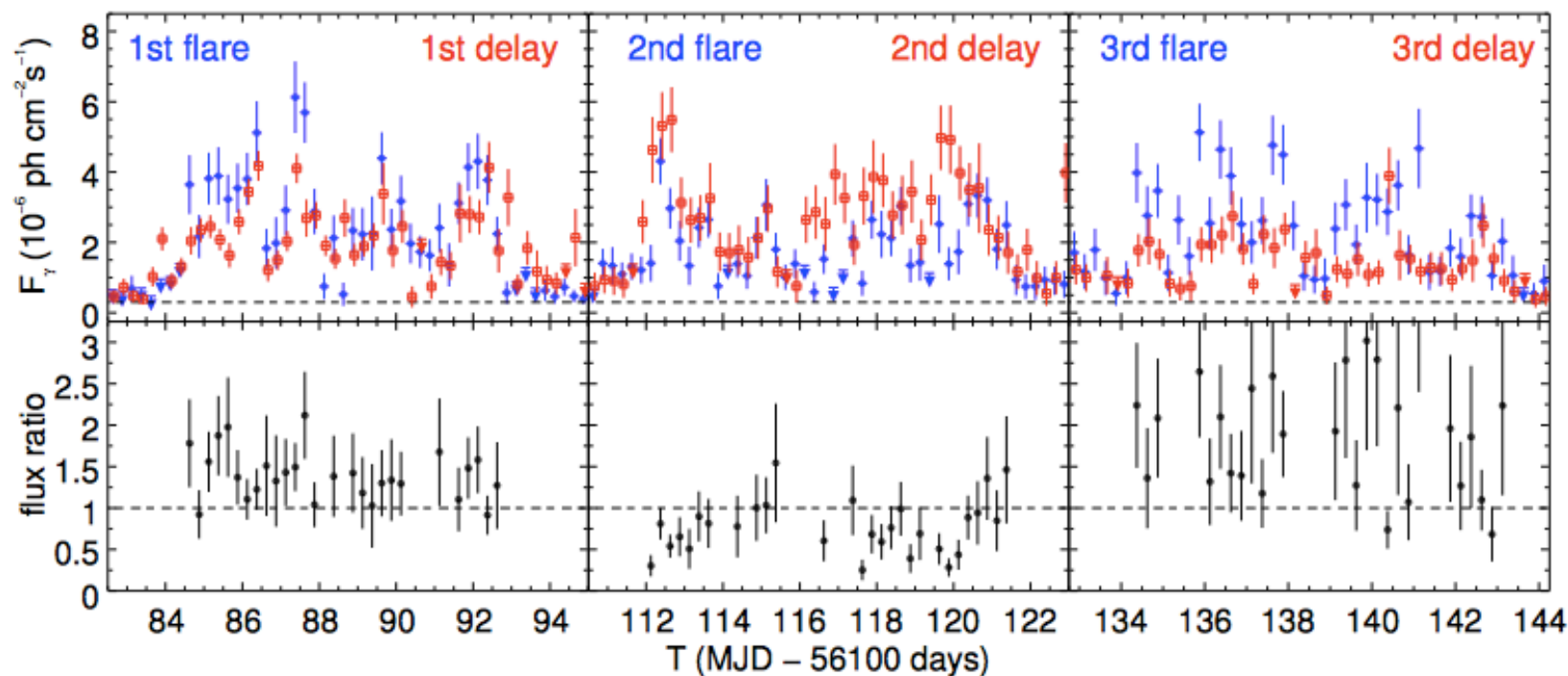
**Delay estimated = 11.46 +/- 0.16 days**

**Flux ratio = 1.16 +/- 0.07**

**Magnification ratio = 1.32 +/- 0.09**

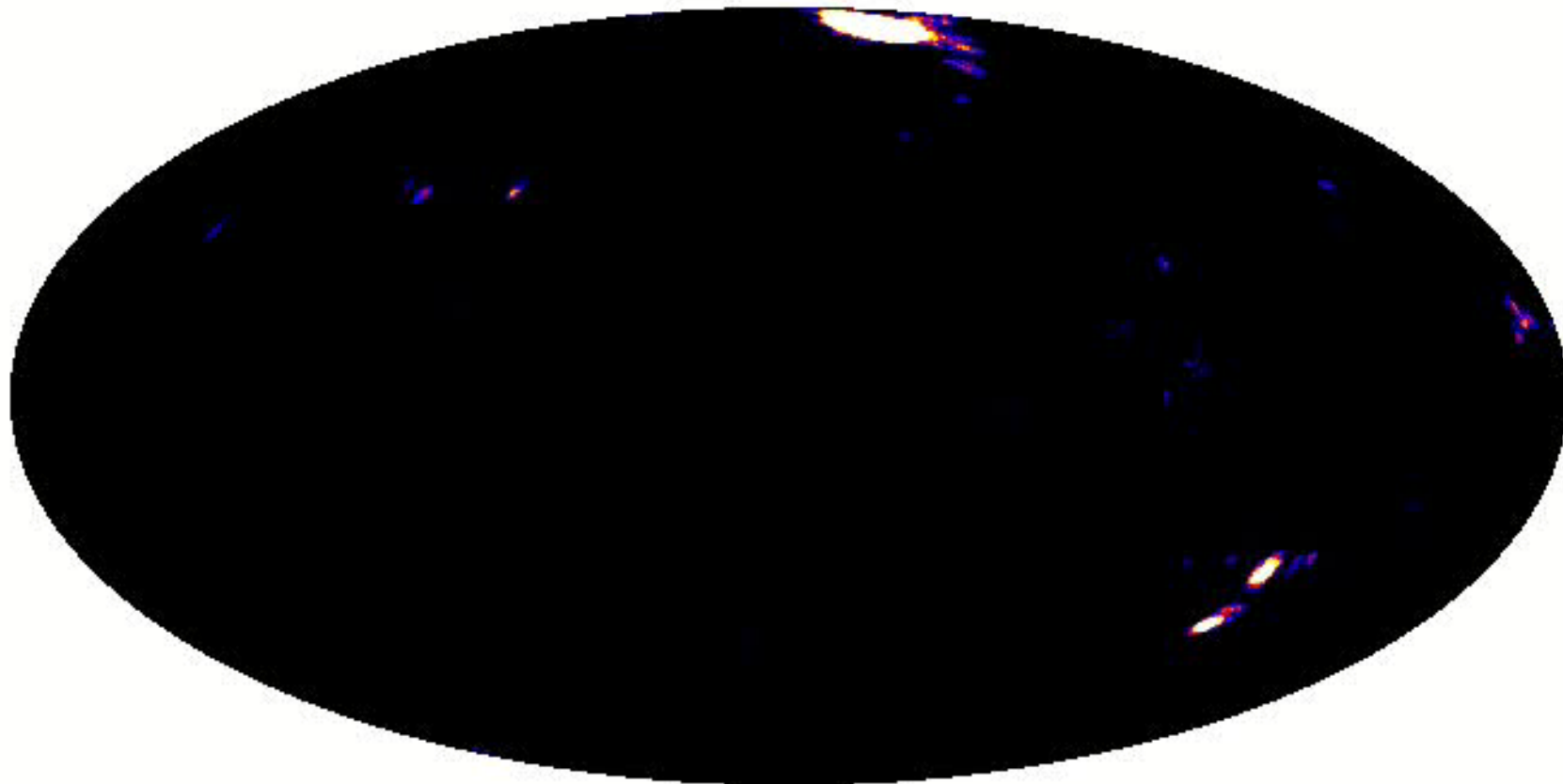
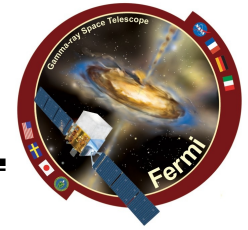
Cheung+ 2014,  
ApJL, 782, L14

Flare emission divided by the observed flux ratio of 1.16 and shifted by +11.46 days to match the delayed emission





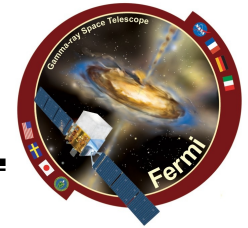
- **Incrementing the number of objects helps to draw a better picture of the population**
- **The high duty cycle and sky-survey capabilities of the Fermi LAT have allowed us to follow up many AGN in flaring states.**
- **Correlated variability studies at different energy bands (especially simultaneous) promise substantial progress in gaining insights in the intrinsic object physics**
- **Near future for Fermi, major upgrades:**
  - **Pass 8: larger acceptance, better Point Spread Function at high energies and a wider energy range**
  - **will provide a dramatic improvement in capability for time-domain high-energy astronomy**



# Back up



# The Fermi Telescope



**GBM (not pictured):**

Covers entire un-occulted sky  
from 8 keV to 30 MeV

**Fermi-LAT Collaboration:**

~400 Scientific Members,  
NASA / DOE & International  
Contributions



**Si-Strip Tracker:**

convert  $\gamma \rightarrow e^+e^-$   
reconstruct  $\gamma$  direction  
EM v. hadron separation

**Hodoscopic CsI Calorimeter:**

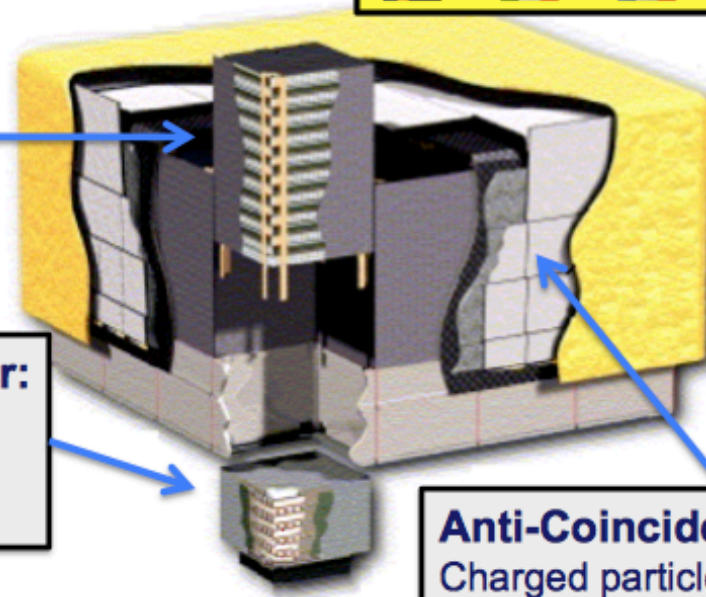
measure  $\gamma$  energy  
image EM shower  
EM v. hadron separation

**Sky Survey:**

With 2.4 sr field-of-view LAT  
sees whole sky every 3 hours

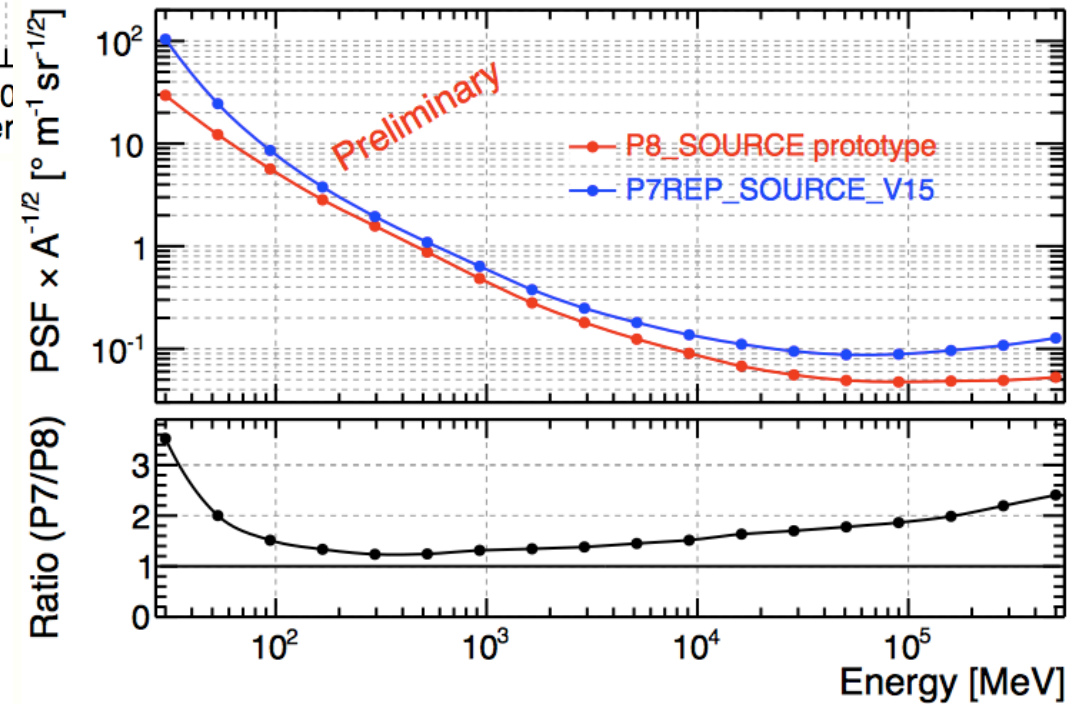
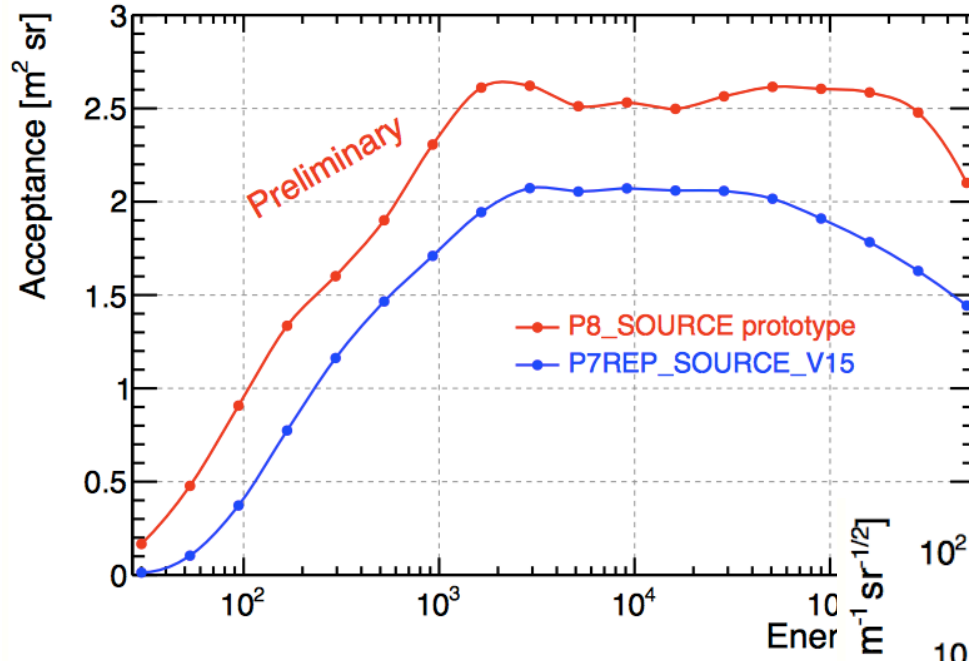
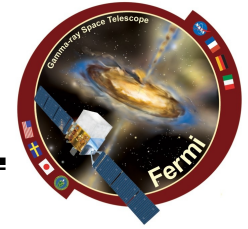
**Trigger and Filter:**

Reduce data rate from ~10kHz  
to 300-500 Hz



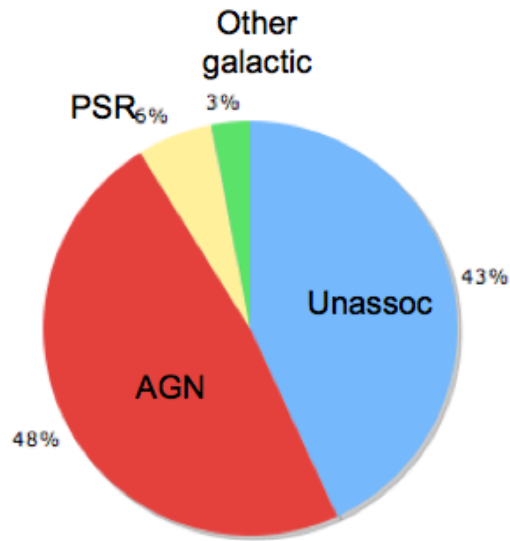
**Anti-Coincidence Detector:**

Charged particle separation

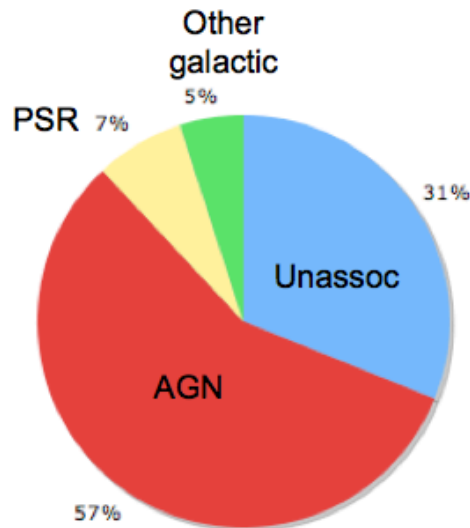




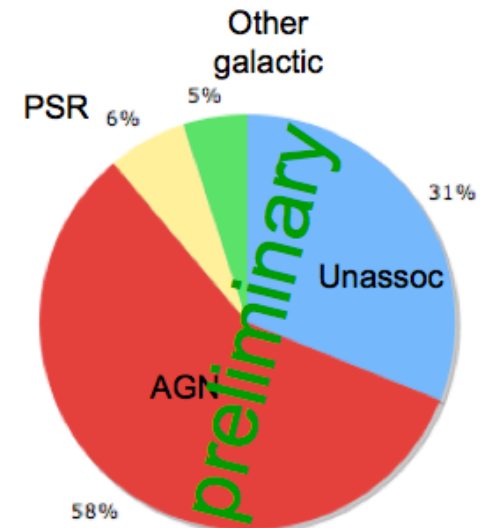
# 1FGL – 2FGL – 3FGL



**1FGL**



**2FGL**



**3FGL**

N. sources	1FGL	2FGL	3FGL
Total	1451	1873	~ 3000
High/Low  b	72%/28%	71%/29%	~ 72%/28%

	Sources in common 1,2,3 FGL	3FGL new sources
All	~ 1100	~ 1300
AGN	~ 760	~ 580
Unassoc	~ 200	~ 700