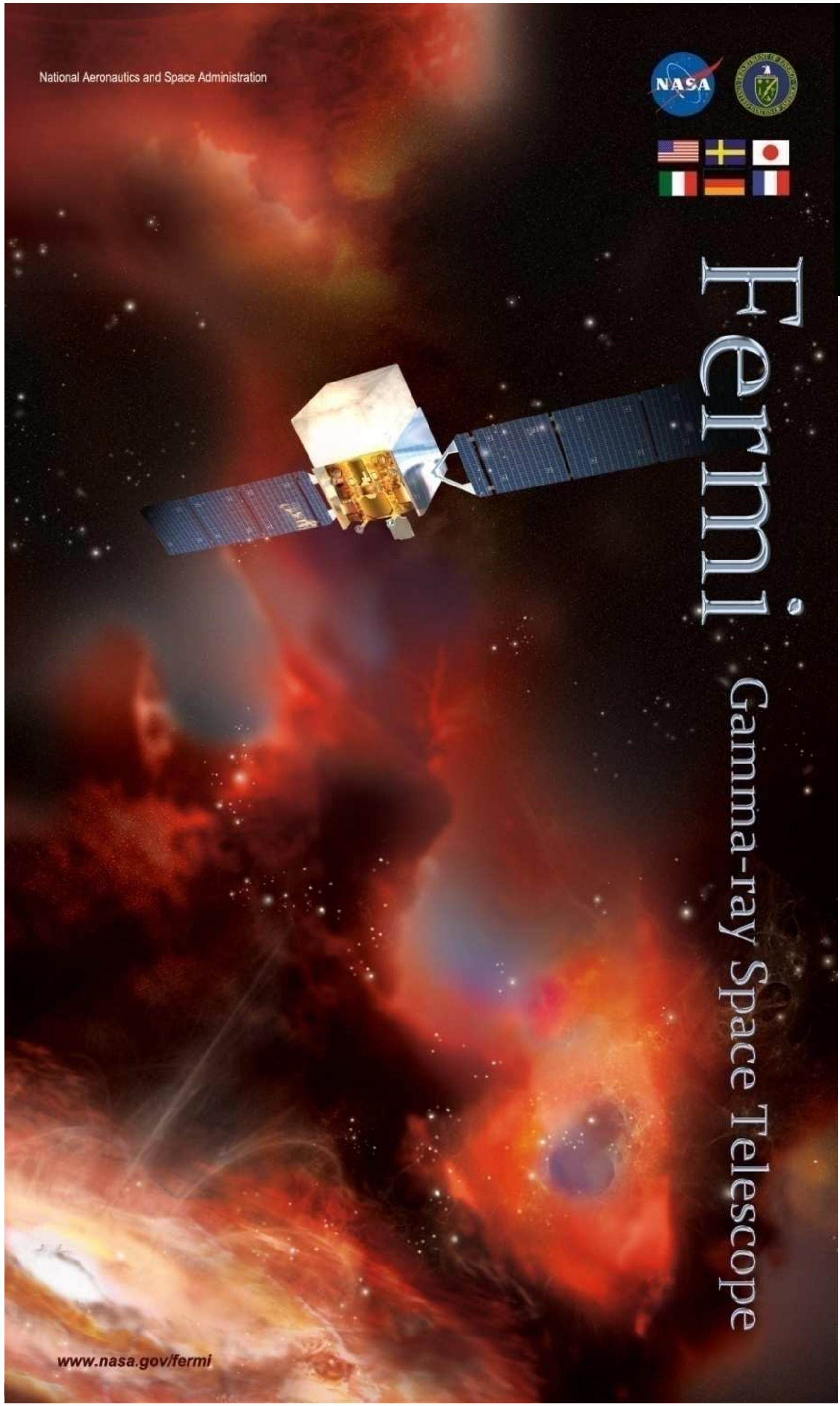


Gamma-ray Variability of *Fermi* LAT Detected AGN

Stefano Ciprini

(ASI Science Data Center & INAF Obs. of Rome, Rome, Italy)

On behalf of the Fermi Large Area Telescope collaboration

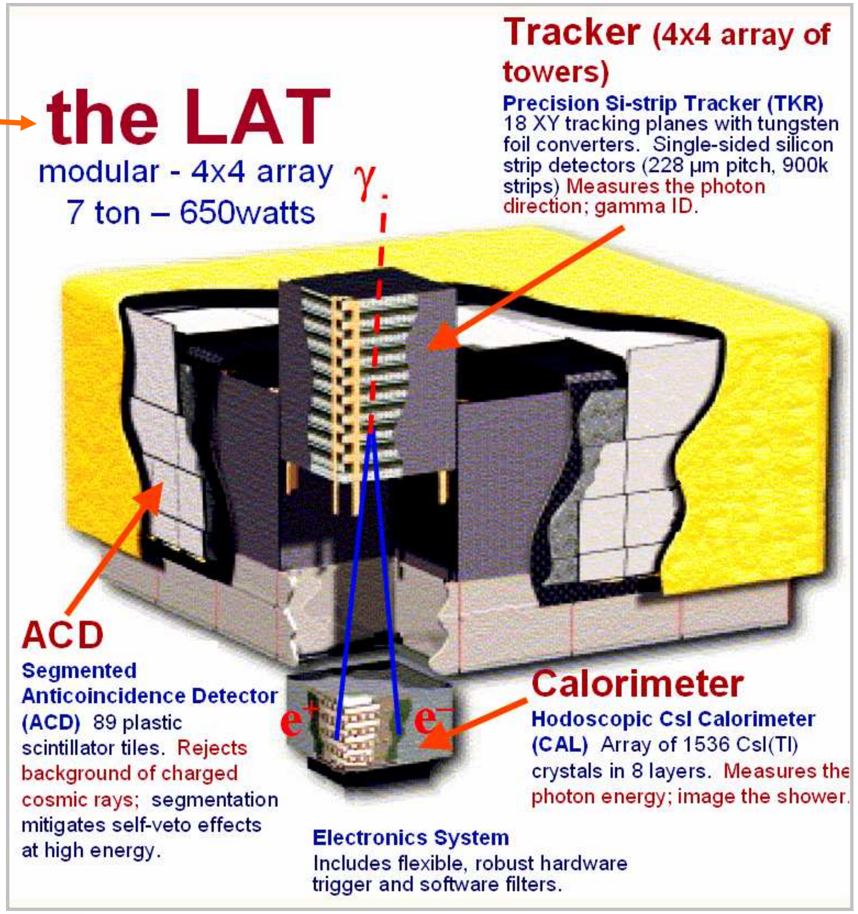
www.asdc.asi.it

Fermi Gamma-ray Space Telescope

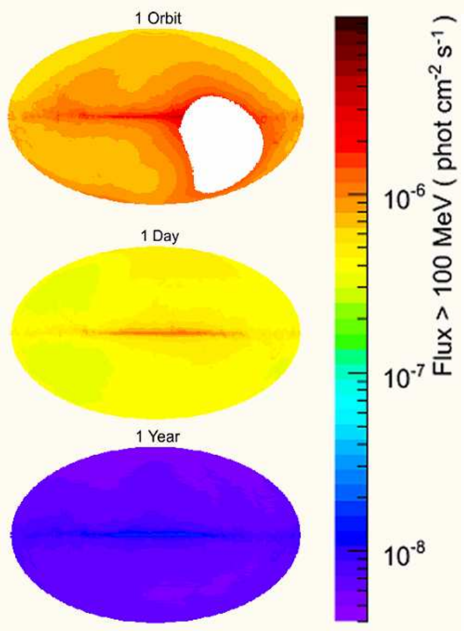
Fermi (formerly GLAST): two Instruments

The Large Area Telescope (LAT)
20 MeV - 300 GeV
>2.5 sr FoV

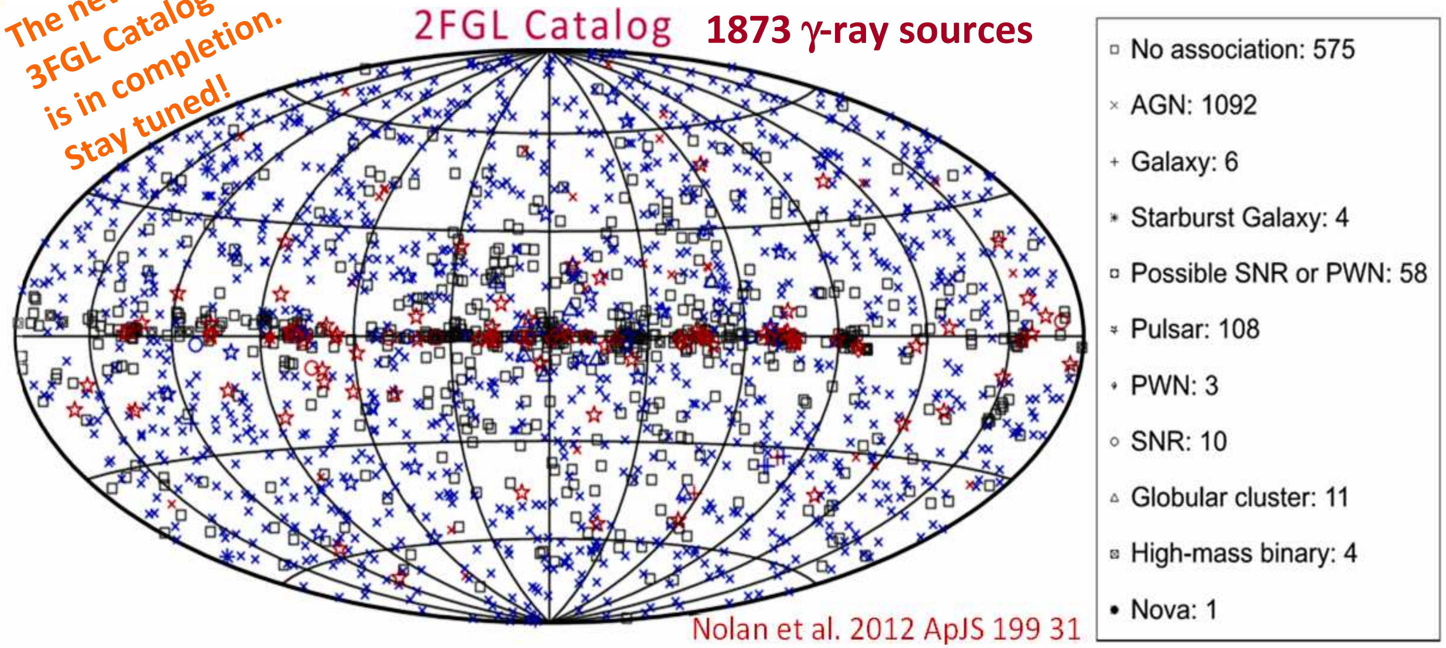
The Burst Monitor (GBM)
8 keV – 40 MeV
9.5 sr FoV



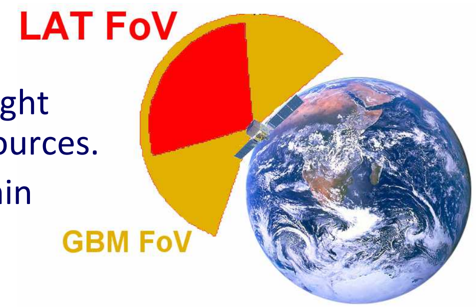
Fermi LAT: an all-sky survey and time monitor



The new 3FGL Catalog is in completion. Stay tuned!



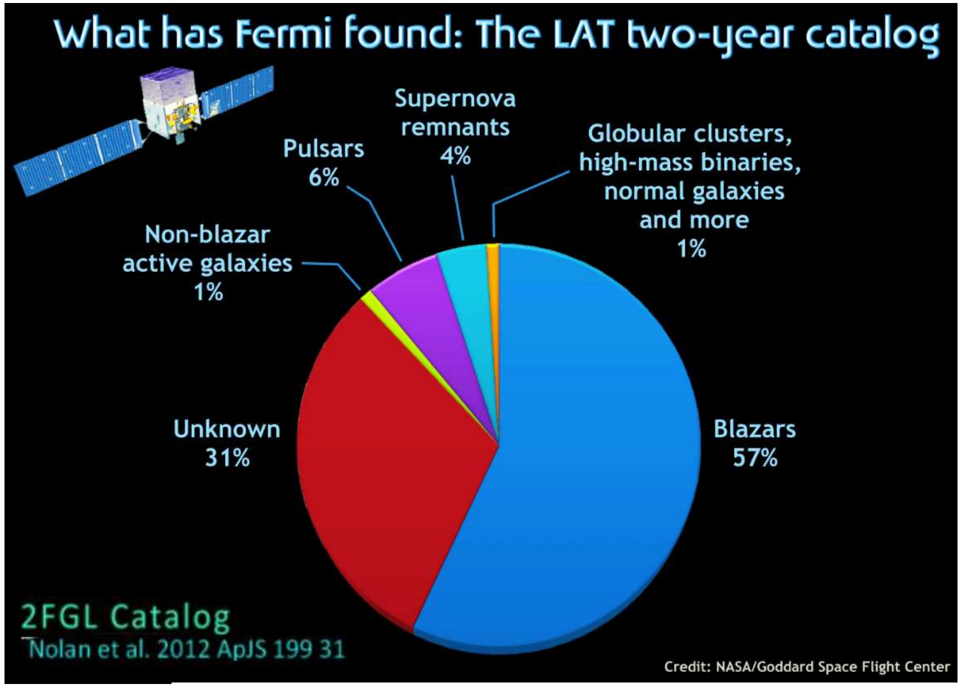
- Wide field of view >20% of the sky (>2.5 sr) → Excellent to "catch" transients, GRBs, AGN/blazars flares, Galactic transients, microquasar flares, HMB and novae burst, pulsar timing / variability and, in general, to time-monitor (from days to years scales) bright irregularly-variable/periodic/multi-pseudo-periodic/constant gamma-ray (E>100 MeV) sources.

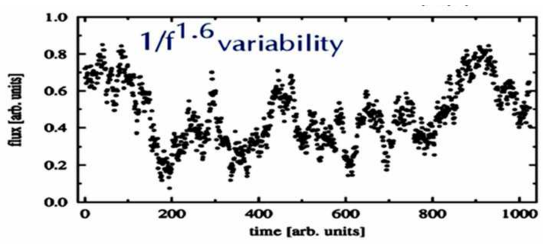


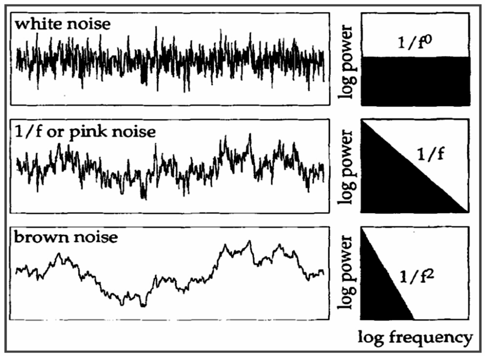
- Survey mode: the LAT observes entire sky every 2 orbits (~3 hours). Each sky point ~30min exposure. The LAT is an all-sky hunter and monitor for transients, flares, variability in the violent and restless high-energy GeV gamma-ray sky.
- In some cases (e.g., Crab nebula, blazar 3C 454.3 flares…) significant 3h/6h-bin light curves obtained. For about 80% of the other, weaker, sources, 1- or few-month time intervals have significant detections in each bin.

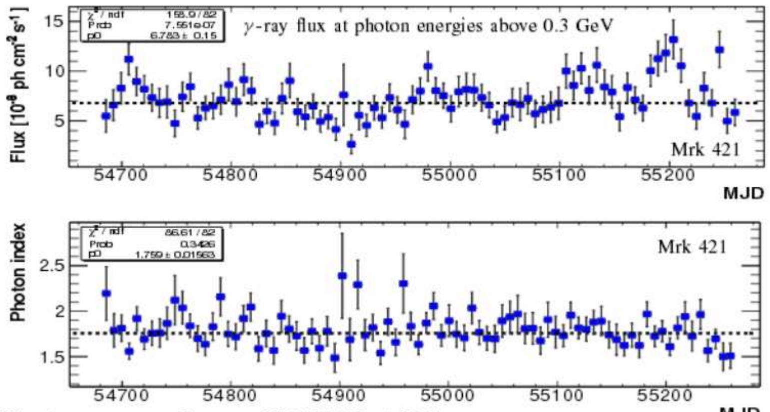
Single waveband variability of γ-ray blazars

- → Variability: the "range of change" .
  → Time series: sequence of observations.
  Variability → Time series analysis
- Blazars: irregular/aperiodic variability, at all the frequencies → also seen in GeV-energy gamma-ray emisson (EGRET, Agile, *Fermi* LAT missions).
- Irregular blazar variability is boring (no correlation, no memory, full random behavior…) or is interesting (the power of unexpected, emergence of complexity, modulations, characteristic timescales, multi-scale / pseudo periodicities, jet precession, binary SMBH, long-term memory, turbulence, complexity, self-organization signatures, etc…) instead?
- Observed flux variability (radio, optical, X-ray bands) shows $1/f^{\alpha}$ PDS in a wide range of frequencies (f=1/t). Power/scaling law index α generally is placed between about 1 and 3.
  → Between flickering (pink-noise) to shot-noise (red/brown/Brownian/ relaxation noise).









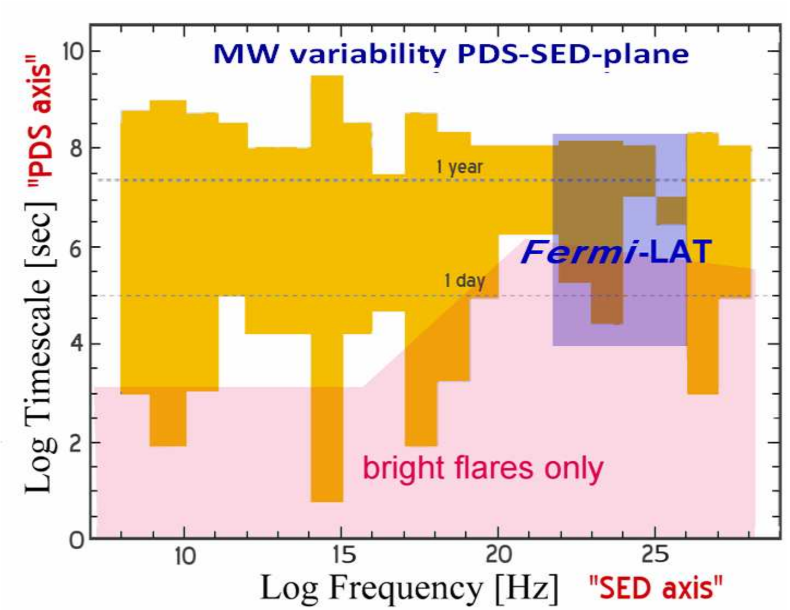
THE ASTROPHYSICAL JOURNAL, 736:131 (22pp), 2011

Multi-waveband variability of γ-ray blazars

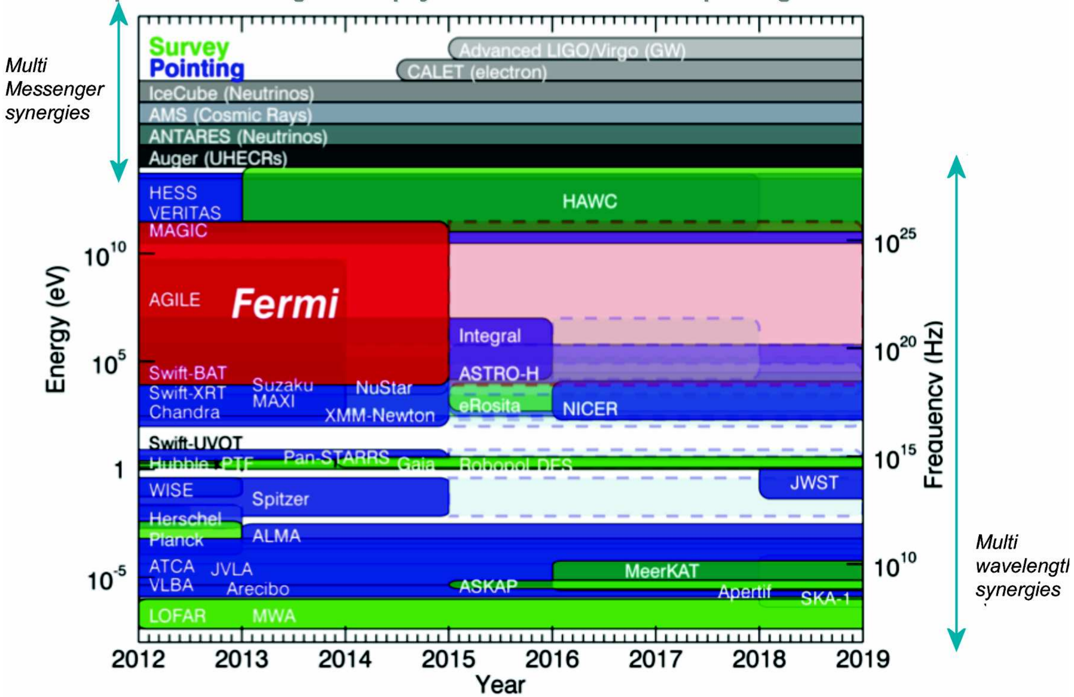
- Variability found everywhere in blazars: on all time-scales in all photon frequencies.
- Multi-wavelength (MW) variability: measures in the PDS-SED-plane (i.e. timescale-energy plane). Physical parameter space of multi-wavelegth (MW) variability for blazars: (L, v/c, D, m_{BH}, B, …)
- Mono-band (mono-mission) studies: variability behaviors, broad Power Density Spectra/Structure Functions, PDS slopes/breaks, local analysis (wavelets, flare pulse fitting,…), photon index hysteresis, etc. → standalone Fermi LAT data.
- Broad-band MW studies: cross-correlation, time lags. MW Spectral Energy Distribution (SED) modeling.

Gamma-ray-synchrotron vs Inverse Compton amplitude ratio studies, orphan flares, emission region localization, in/external jet model, leptonic vs hadronicmodels, physics of gamma-ray AGNs, identification of newly discovered gamma-ray sources.

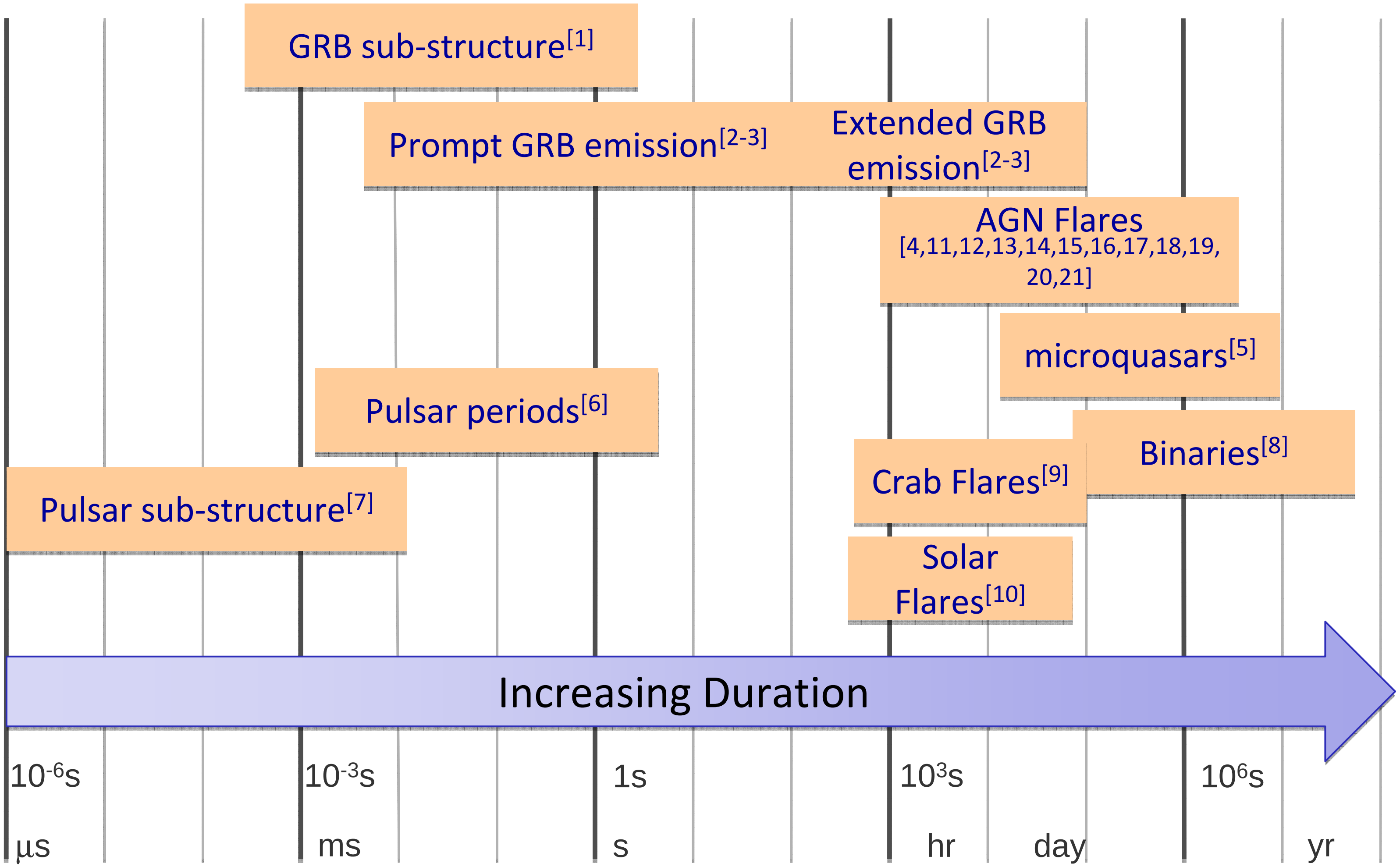
→ Fermi LAT and MW coordinated campaigns (ground-based and space-borne instruments)



http://science.nasa.gov/astrophysics/2014-senior-review-operating-missions/



Fermi (LAT + GBM) Time Domain Astronomy

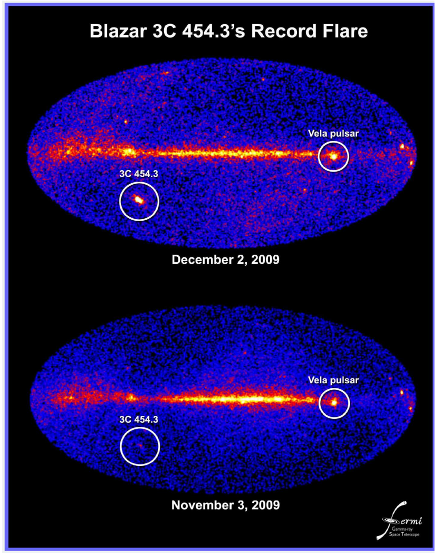


[1] Vasileiou et al.2013PhRvD..87l2001V. --- [2] Paciesas et al.2012ApJS..199...18P [3,10,11,13,15,20,21] Ackermann et al. 2013ApJS..209...11A, , 2012ApJ...745..144A, 2010ApJ...721.1383A, 2013ApJ...771...57A, 2013ApJ...771...57A, 2014ApJ...786..157A, variability-II in prep. --- [4,5,6,7,8,9,12,14,16,18] Abdo et al. 2010ApJ...722..520A, 2009Sci...326.1512A, 2013ApJS..208...17A , 2010ApJS..187.., 2010Sci...329..817A, 2011Sci...331..739A, 2011ApJ...733L..26A, 2010Natur.463..919A, 2010ApJ...714L..73A, 2010ApJ...710..810A, 2010ApJ...721.1425A. --- [17] Fuhrmann et al. 2014MNRAS.441.1899F.

Fermi LAT Flare Advocates activity (FA-GSW)

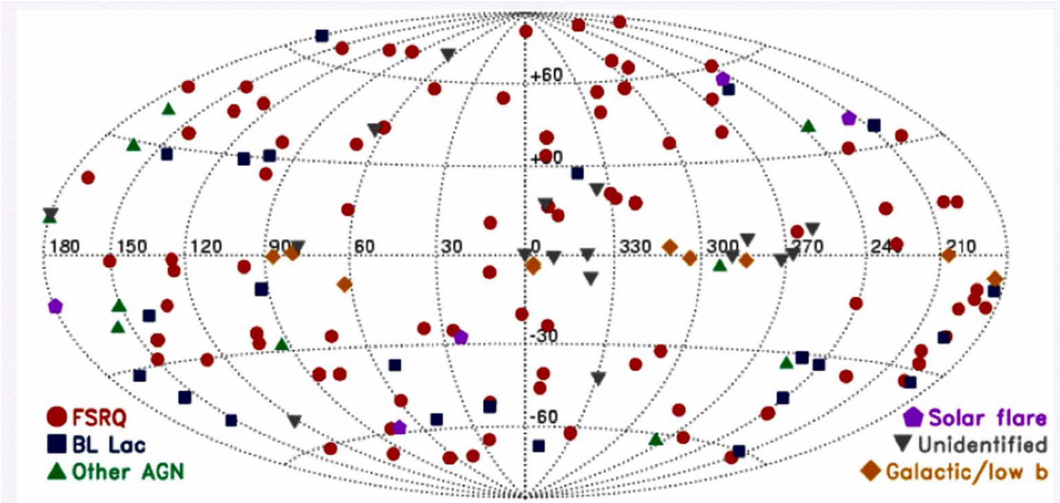
FA-GSW is a twofold service:

- Flare Advocate (FA): look for flares, transients, sources wit daily flux >1E-6 ph/cm2/s; publish ATels, internal emails to science groups, ToO requests (ex. to Swift), MW campaigns, papers on flares and MW simultaneous data.
- Gamma-ray Sky Watcher (GSW): look at daily / 6hour all sky maps, revise Automatic Science Processing results and check source detections, day-by-day internal report; weekly summary for the Fermi Gamma-ray Sky Blog; look for new sources (not published in LAT Catalogs), first-guess for source associations.

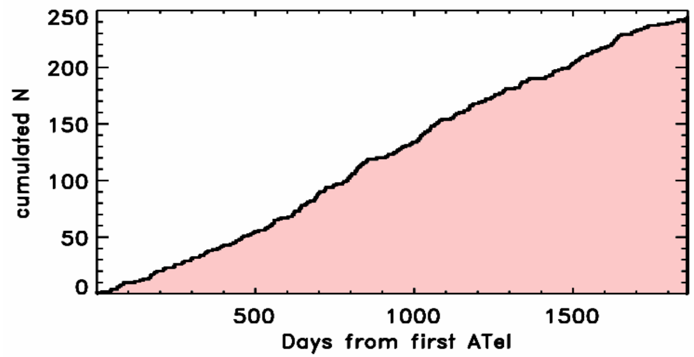


First ~5.5 years of Fermi all-sky survey mission:

- 290 weekly reports in Fermi Sky Blog.
- 265 ATels posted.



Outline of the all-sky map distribution of new gamma-ray sources, flares and transients found by *Fermi* LAT and announced through Astronomer's Telegrams (ATels).



- **fermisky.blogspot.com**
- **www-glast.stanford.edu/cgi-bin/pub_rapid**
- **www.asdc.asi.it/feratel/**

Examples: LAT γ-ray flares discovered from gravitational lensed blazars (PKS 1830-211, S3 0218+35, GB 1310+487)

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 Observations
Credential Certification: Stefano Ciprini (stefano.ciprini@pg.infn.it)

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

Fermi LAT detection of a GeV flare from GB6 B1310+4844

ATel #2306; K. V. Sokolovsky (MPIfR/ASC Lebedev), S. E. Healey (Stanford/KIPAC), F. Schinzel (MPIfR); on behalf of the Fermi Large Area Telescope Collaboration, and Y. Y. Kovalev (ASC Lebedev/MPIfR)
on 21 Nov 2009; 01:33 UT
Distributed as an Instant Email Notice Request For Observations
Credential Certification: Teddy Cheung (ccheung@milkyway.gsfc.nasa.gov)

Subjects: Gamma Ray, >GeV, Transient

Referred to by ATel #: 2310, 2316

... observation of ongoing GeV activity ... spectrally hard blazar GB6 B1310+4844 (GB1 1310+487)

ATel #2316; E. Hays (NASA/GSFC), L. Escande (CNRS/IN2P3 Bordeaux) on behalf of the Fermi Large Area Telescope Collaboration
on 28 Nov 2009; 00:29 UT
Credential Certification: Elizabeth Hays (elizabeth.a.hays@nasa.gov)

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, AGN, Blazar, Quasar

Referred to by ATel #: 4351, 4361, 4371, 4411

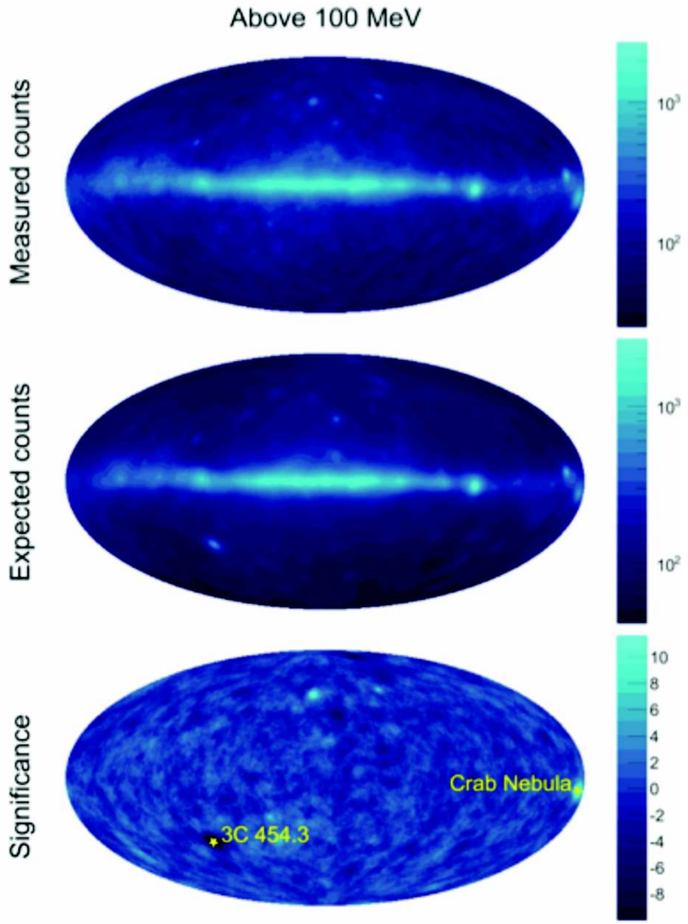
Fermi LAT detection of renewed GeV gamma-ray activity from the gravitationally lensed blazar PKS 1830-211

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)

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

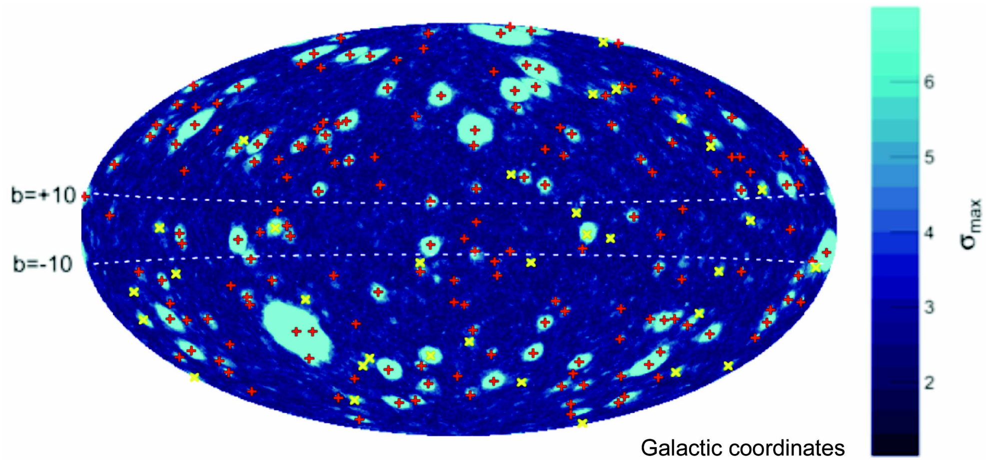
ATel #4371; M. Giroletti (INAF-IRA Bologna), M. Orienti (Univ. Bologna, INAF-IRA Bologna), C. C. Cheung (NRC/NRL); on behalf of the Fermi Large Area Telescope Collaboration
on 11 Sep 2012; 20:42 UT
Credential Certification: Teddy Cheung (ccheung@milkyway.gsfc.nasa.gov)

Fermi All-sky Variability Analysis (FAVA)



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

- ❑ 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: 1) weekly time intervals, 2) two energy ranges, E>100MeV and E>800MeV.
- ❑ A total of 215 sources were detected with significance greater than 5.5σ: the first FAVA catalog.

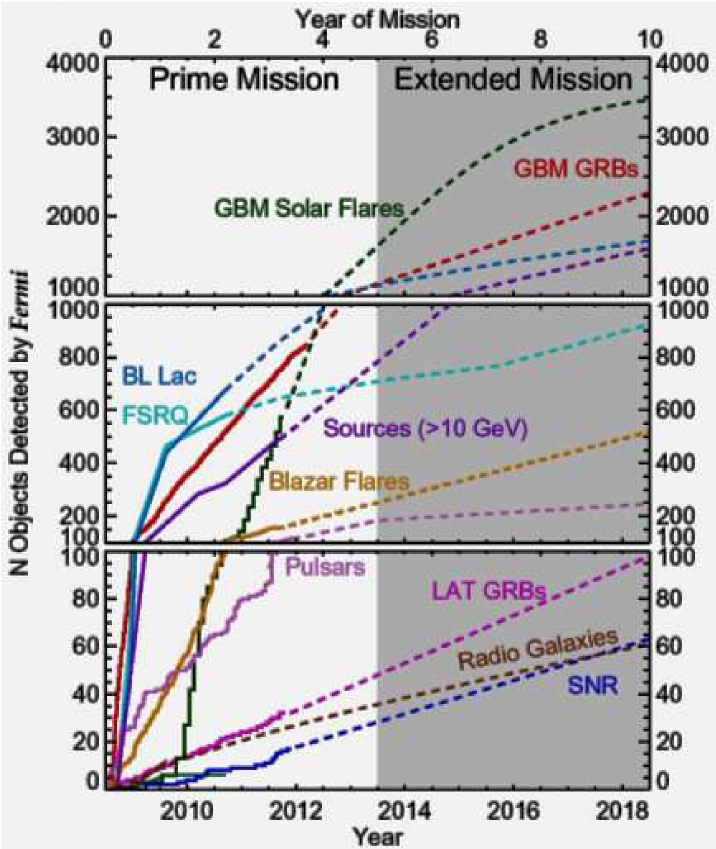


Ackermann et. al. 2013, ApJ, 771, 57

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

Fermi LAT Source Catalogs

Catalog	Energy Range (GeV)	Data Interval (months)	Sources	Event Selection	Release Date
0FGL	0.2-100	3	205	P6V1 DIFFUSE	Feb. 2009
1FGL	0.1-100	11	1451	P6V3 DIFFUSE	Feb. 2010
2FGL	0.1-100	24	1873	P7V6 SOURCE	Aug. 2011
1FHL	10-500	36	511	P7V6 CLEAN	Jun. 2013
3FGL	0.1-300	48	>2500	P7V15 SOURCE	TBD



The catalogs are analyses over successively deeper data sets, and also represent successive analysis refinements, from event classification on up

1st catalog of sources above 10 GeV (1FHL)

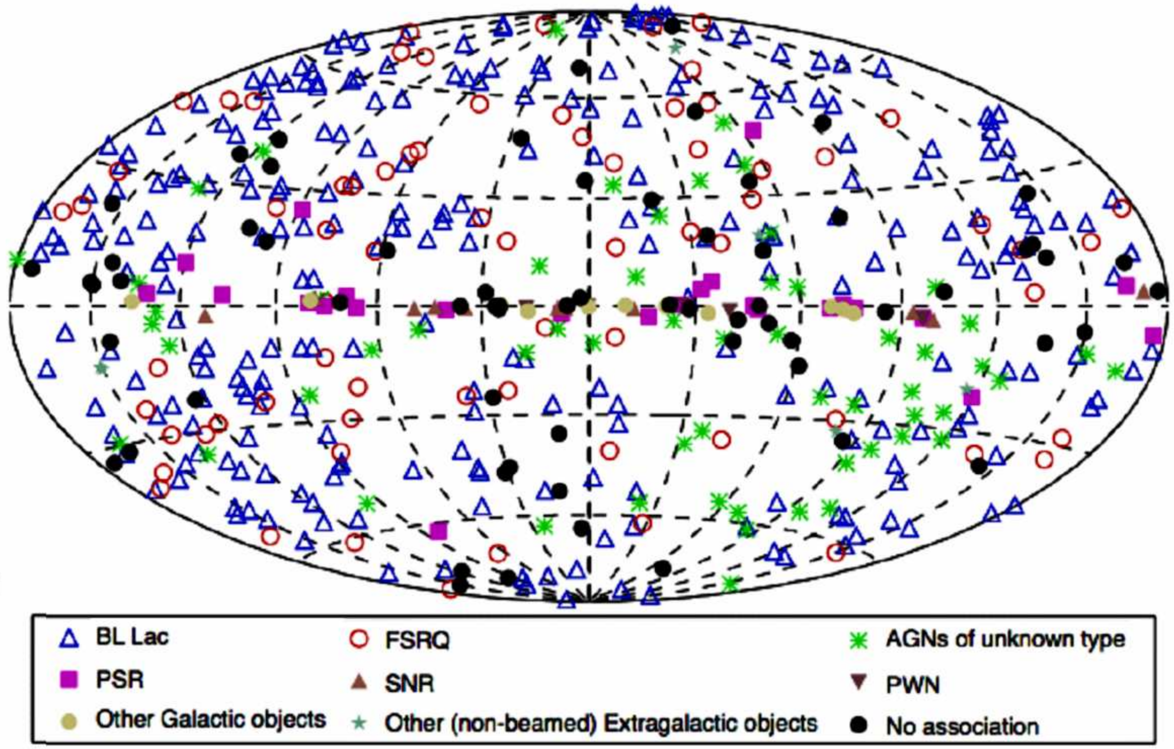
- 1FHL: first catalog of significant detected sources in 3 years of cumulated gamma-ray event data above 10 GeV → 514 sources.
- 1FHL sources (Fermi Hard source list, >10GeV) get softer with increasing redshift --> possibly due to attenuation on optical/UV photons of the Extragalactic Background Light. This trend is less clear with photon indexes from E>100 MeV Second LAT AGN Catalog (2LAC assembled from the 2FGL).

Class	#	Fraction of 1FHL (%)
Blazar BL Lac	259	50.4
Blazar FSRQ	71	13.8
Unknown type AGN	55	10.7
Pulsar	27	5.2
SNR	11	2.1
PWN	6	1.2
Other Galactic	11	2.1
Other extragalactic	9	1.8
Unassociated	65	12.7

54 1FHL sources not in 2FGL

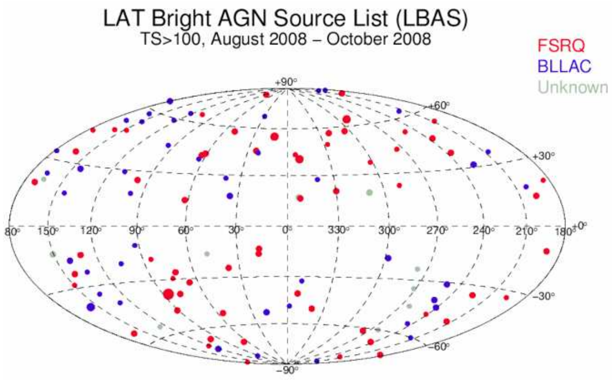
84 1FHL sources associated with known VHE sources

213 1FHL sources identified as good candidate VHE emitters



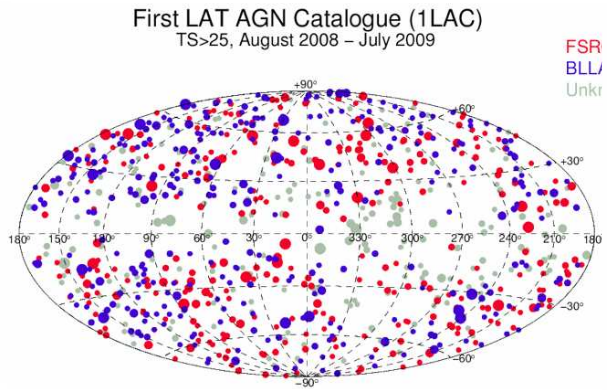
Fermi LAT AGN Catalogs (LBAS, 1LAC, 2LAC)

www.asdc.asi.it/fermilbas



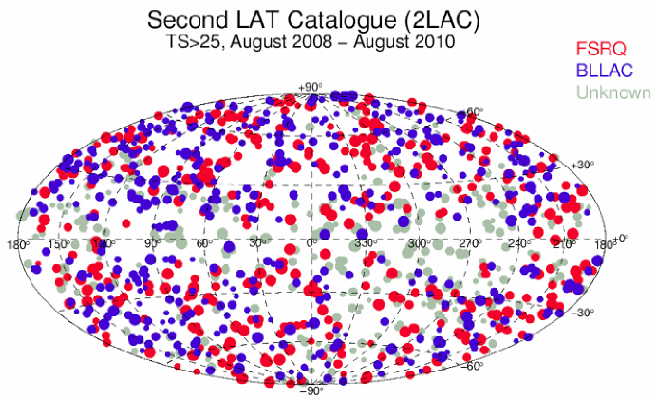
LBAS-high latitude:
58 FSRQs
42 BL Lacs
6 AGNs

www.asdc.asi.it/fermi1lac



1LAC-clean sample:
248 FSRQs
275 BL Lacs
50 Blazars with unknown type
26 AGNs

www.asdc.asi.it/fermi2lac



2LAC-clean sample:
310 FSRQs
395 BL Lacs
156 Blazars with unknown type
24 AGNs

- 2LAC clean sample include 286 more sources than the 1LAC clean sample, i.e. 48% increase
- BL Lac outnumbers the FSRQ ➔Fermi-LAT detection limits
- Smaller error ellipse due to longer integration results in a fewer multiple source counterpart associations with respect to 1LAC
- The fraction of unknown AGN type objects has increased ➔due to improved association procedure

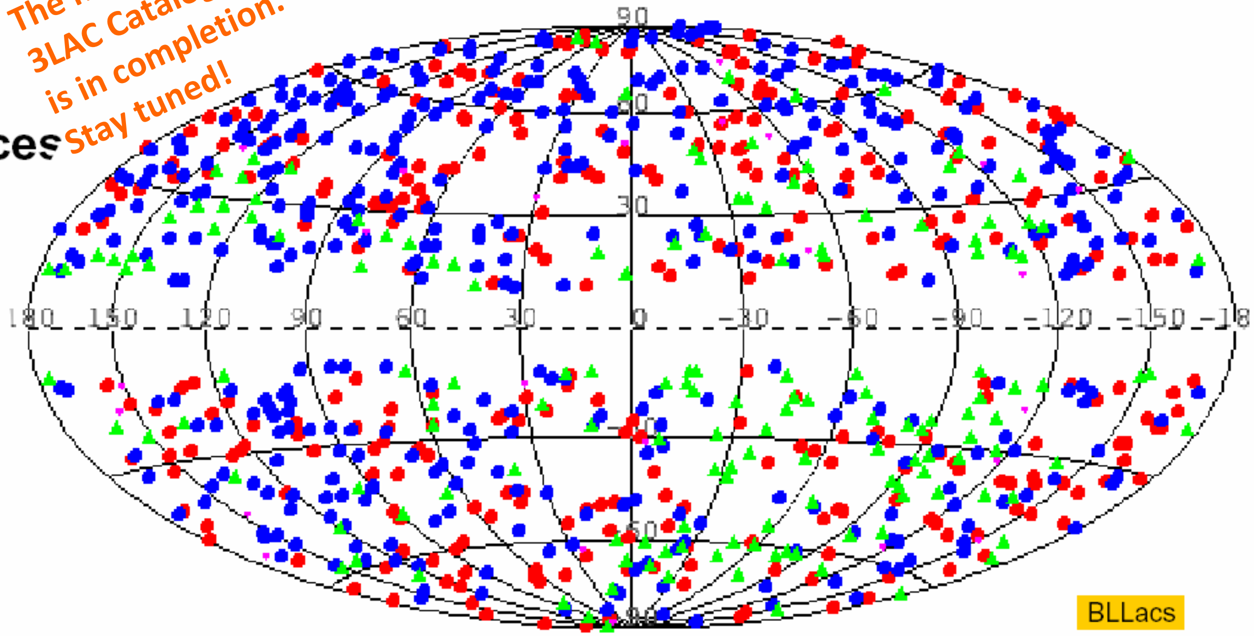
The Second LAT AGN catalog (2LAC)

The new
3LAC Catalog
is in completion.
Stay tuned!

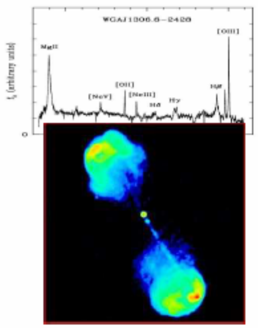
Ackermann M. et al., 2011 ApJ, 743, 171

- 24 month data set

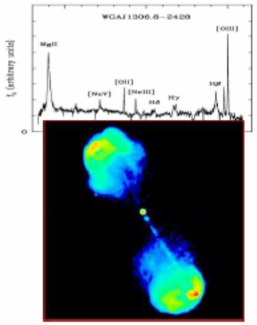
- 1319 TS>25, |b|>10° sources
- 2LAC: 1017 counterparts
  991 sources
- 886 high-confidence (P_{assoc}>80%) AGNs in *clean sample*
- Census :
  - 310 FSRQs
  - 395 BLLacs
    (~45% with measured z)
    61 LSP, 81 ISP,160 HSPs, 93 no class.
  - 157 of unknown type
  - 24 other AGNs



FSRQs

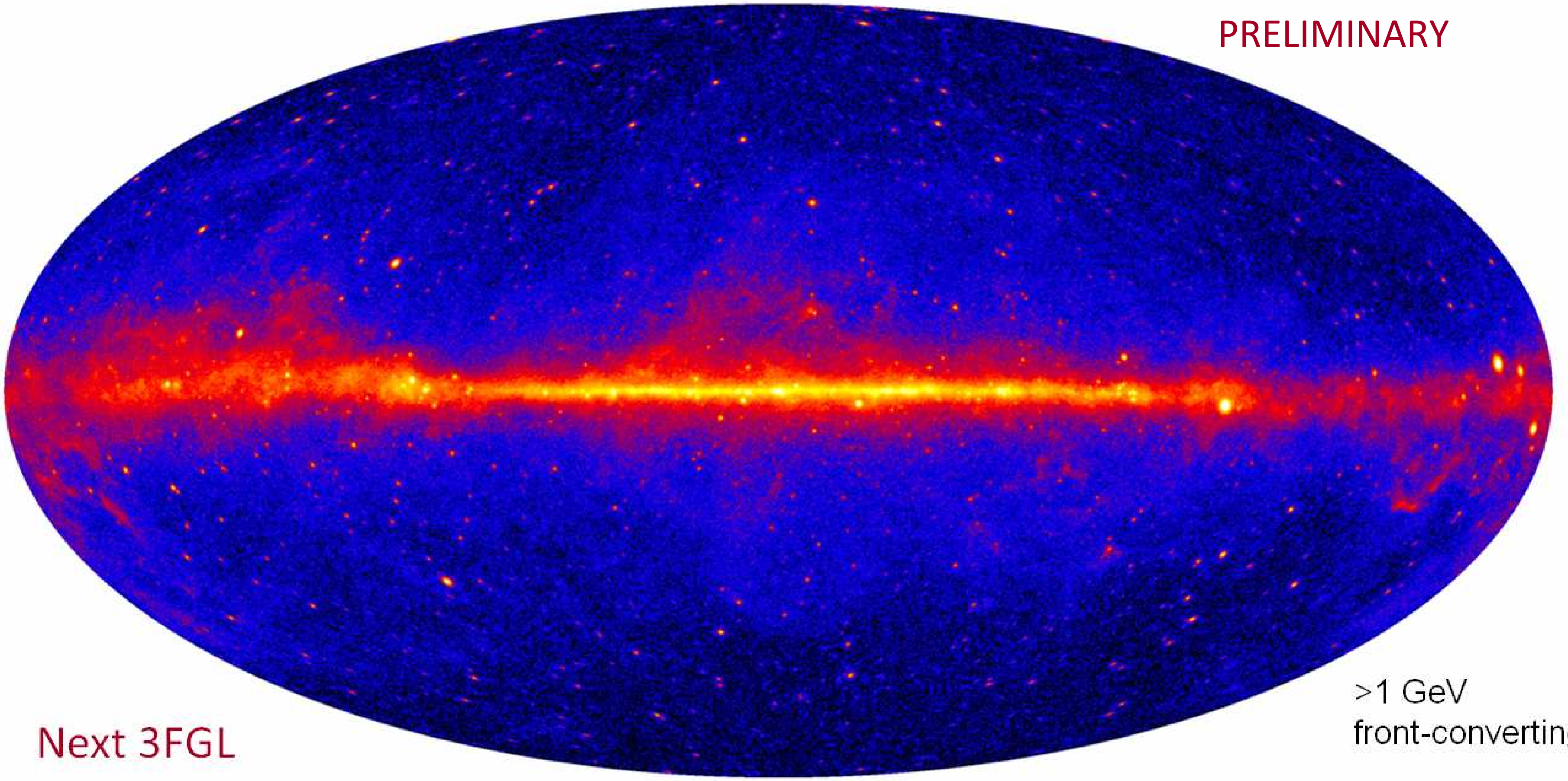


BLLacs



Differences between Northern Hemisphere and Southern one (38% BLLACs in Southern Hemisphere)

Highlights of 3FGL Development

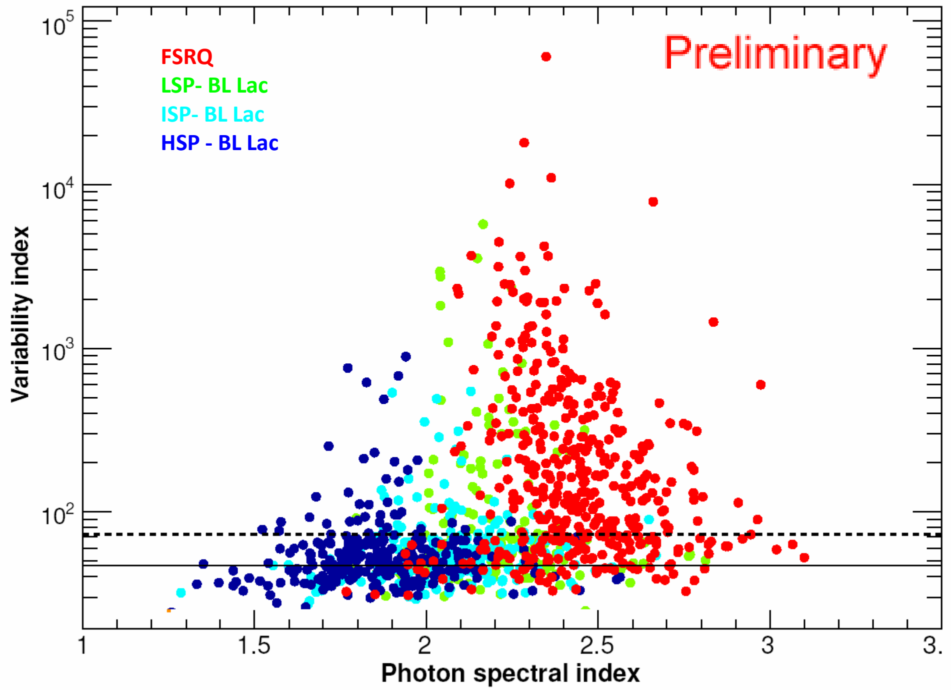


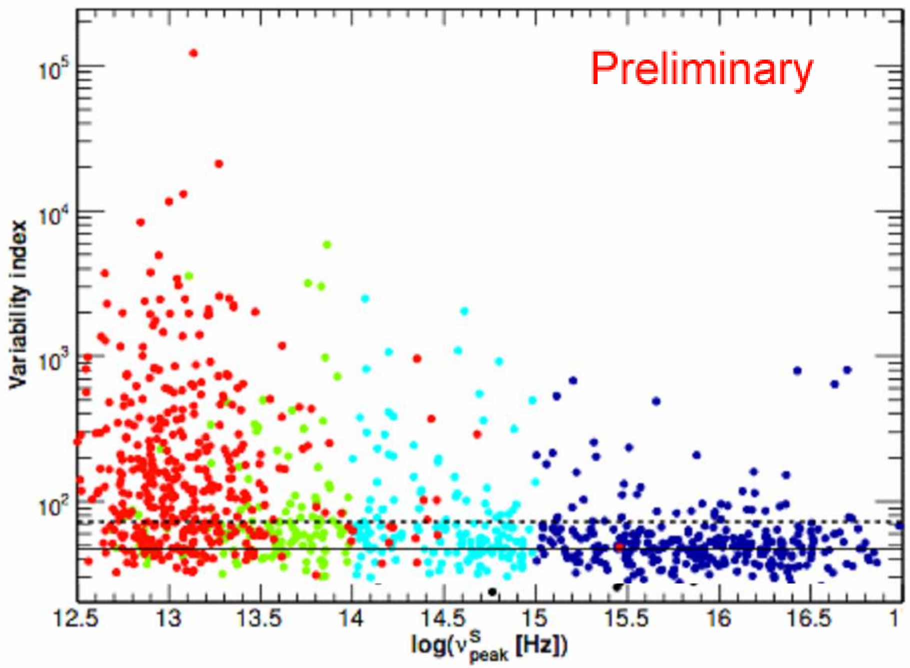
Next 3FGL

- First 4 years of LAT data (August 2008-August 2012), 100 MeV-300 GeV
- Source detection is based on average flux

The Third LAT AGN catalog (3LAC)

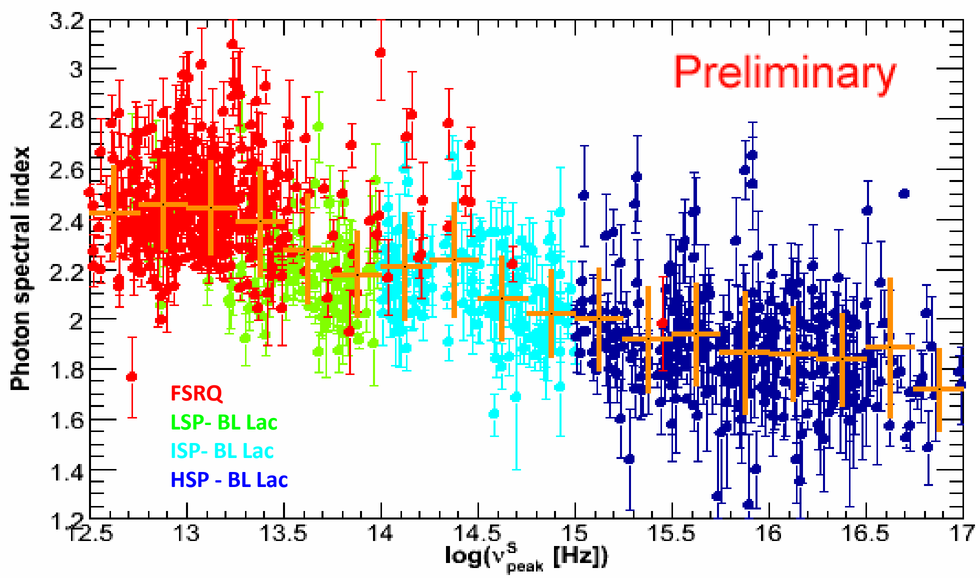
- 3LAC: (48 months of data, TS>25, P7REP data selection):
  ~29% FSRQ; ~39%BL Lacs; ~31% blazars uncertain type; ~1% Other types of AGNs
- More associations thanks to improvement of source association procedures.
- Reduced uncertainties thanks to the doubling of exposure, refinement of the analysis and the upgrade of the LAT Instrument Response Functions (IRFs) and data selection (Pass-7REP).
- The 3LAC should allow for a deeper understanding of the blazar phenomenon and the relations between blazar classes, despite not being free of biases in the classification and associations.

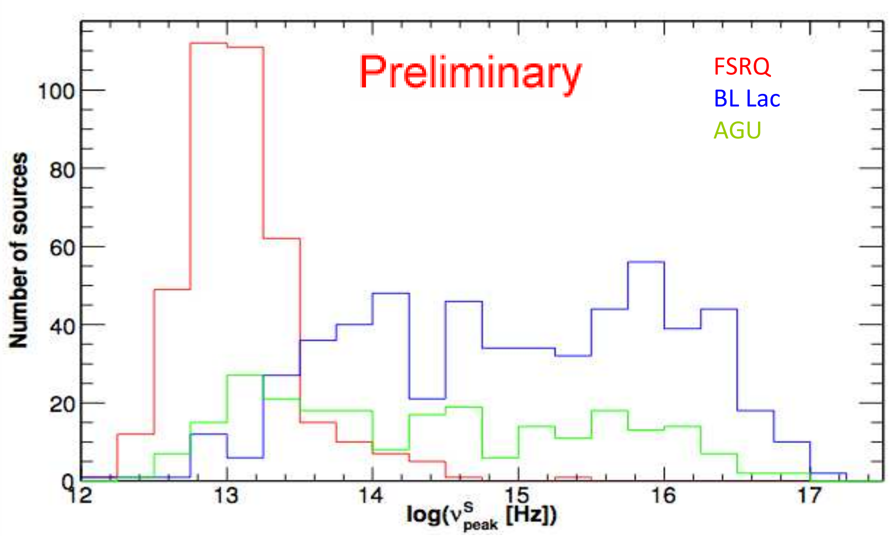




The Third LAT AGN catalog (3LAC)

- The third catalog of active galactic nuclei (AGNs, 3LAC) detected in gamma-rays by the *Fermi* LAT in four years of scientific operation will be ready about this summer joined with the 3FGL Catalog.
- Blazars are further classified based on their MW SEDs. Many new objects with respect to the 2LAC, and most of the newly detected AGNs (50%) are of unknown type, and lack spectroscopic information of sufficient quality to determine the strength of their emission lines. More broadband radio-to-X-ray data are required to understand their nature and class.
- 3LAC data and properties presented and discusses: gamma-ray fluxes, photon power-law spectral indices, redshifts, gamma-ray luminosities, variability, synchrotron peaks, archival radio/X-ray luminosities, and their MW correlations, trends, populations.



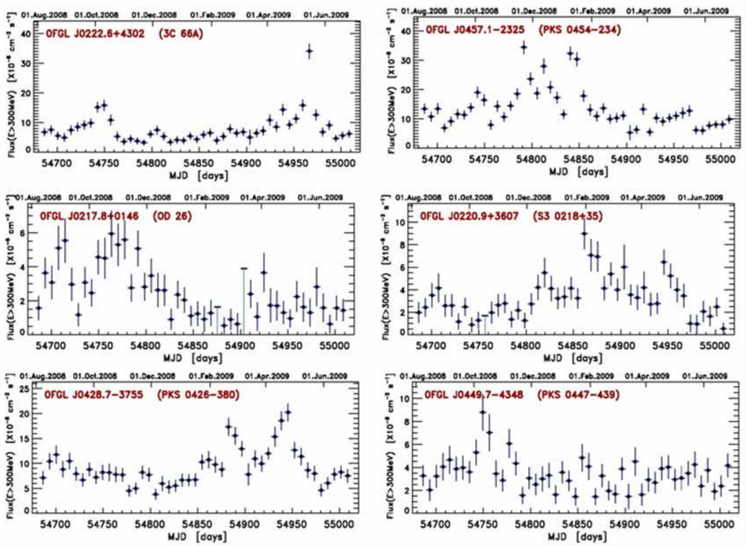


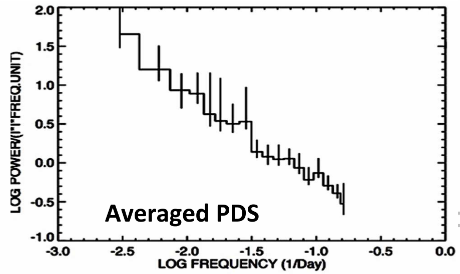
1st list of *Fermi* LAT blazar γ-ray light curves

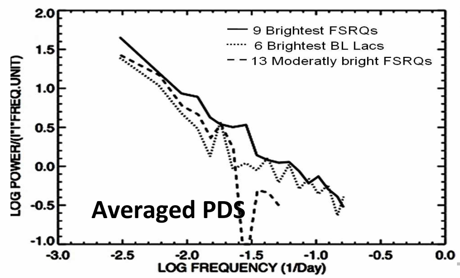
- LAT 3-month high confidence list of blazars (LBAS, 106 AGN/blazars) over first 11 months of all-sky survey observations light curves: integral photon fluxes (E>300 MeV); weekly time bins all (3-/4-day bins for 15 brightest).

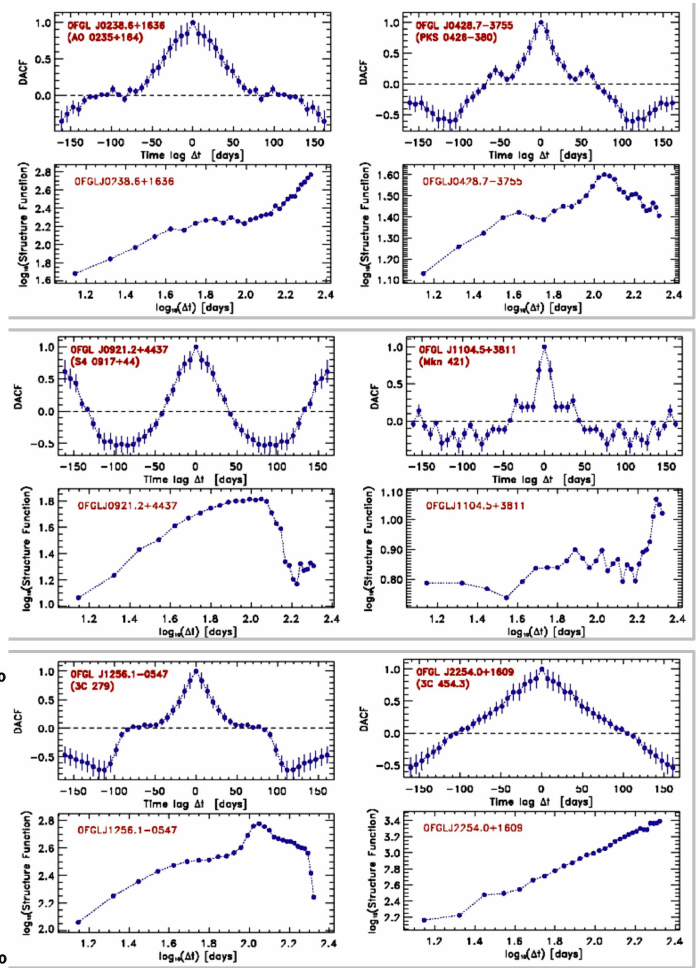
- A first-time consistent, homogeneous sample of GeV LCs.
chi^2 / excess tests: variability in 68 over 106. Low synchrotron freq. peaked (LSP) blazars have larger variability than interm./high synch. P. (ISP/HSP) blazars.

- Discrete Auto Correlation Function (DACF), first-order Structure Function (SF): → different patterns, zero lag peak amplitudes, power-law slopes (distributions peaks around alpha 1.1-1.6 range). Direct PDS calculation (averaging more sources) point out similar average index for BL Lacs and FSRQs populagtions: 1.5+/-0.2.









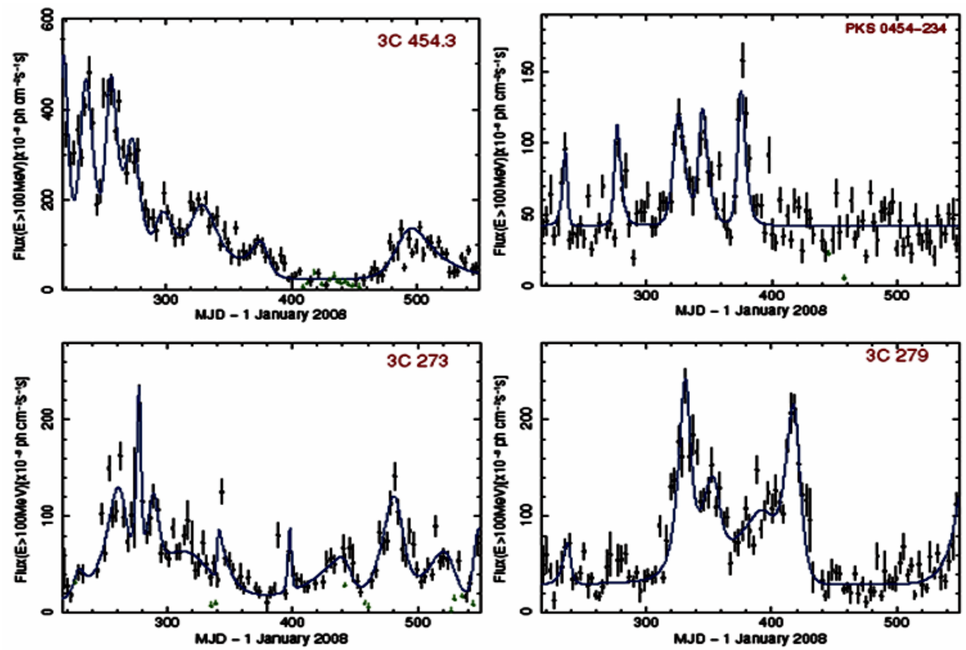
Abdo et al. 2010, ApJ, 722, 520

1st list of *Fermi* LAT blazar γ-ray light curves

❑ High flux states < 1/4 of the light curve duration (most sources active in periods shorter than 5%).
❑ FSRQs and LSP/ISP BL Lac objects: the largest variations. HSP: lower variability but persistent emission (detections in about all the time bins detected). Also substantially Brownian LCs (examples: AO 0235+164, 3C 454.3).

Fit with phenomenological function (sum of two exponential terms, with flare symmetry and flare duration parameters)

$$F(t) = F_b + F_0 \left(e^{\frac{t_0 - t}{T_r}} + e^{\frac{t - t_0}{T_d}} \right)^{-1}$$



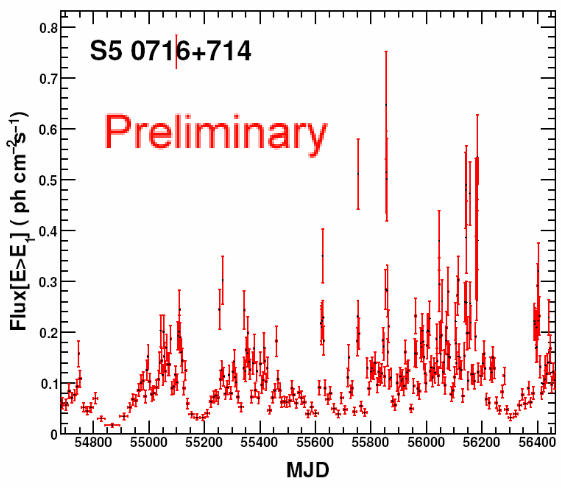
Abdo et al. 2010, ApJ, 722, 520

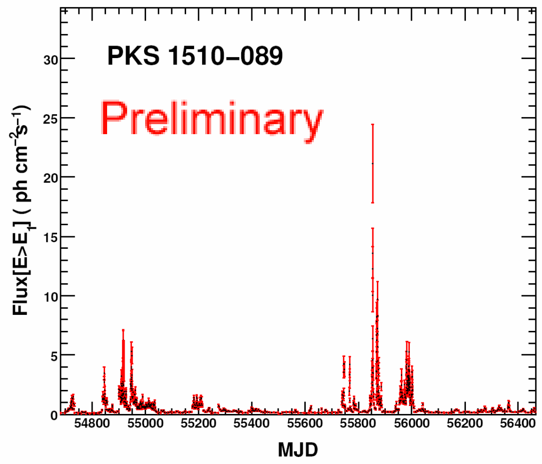
❑ Essentially steady with perturbations or with a series of discrete, though possibly overlapping, flares (traveling shock fronts). Multiple emission regions (inhomogeneous blazar emission zone) or in an essentially homogenous region (all particles are accelerated).
❑ Random walk processes, such as instabilities and turbulence in the accretion flow through the disk or in the jet, can origin intermittent behavior. Stochastic processes with a large number of weakly correlated elements.
❑ Symmetric peak shapes: also explained by the superposition of a series of peaks. Marked asymmetric profile can mean fast injection of accelerated particles and a slower radiative cooling and/or escape from the active region.

❑ Summary: LAT blazars → 2 time-behaviors:
1) sources with a stable baseline and sporadic flaring activity (→ rare events or intermittence ?)
2) sources with a strong activity and complex and structured patterns (→ more Brownian behavior, longer timescales, flare event superposition, different underlying physics ?)

2nd list of *Fermi* LAT blazar γ-ray light curves

- ❑ Better characterization of variability of bright LAT γ-ray blazars:
--> over 4 years into the mission
--> new adaptive time binning (ADB) method (Lott et al. 2012, A&A, 544)
- ❑ Principle: adapt the bin widths of a light curve according to a user-defined condition, constant relative uncertainty on flux or constant significance in each time bin.
- ❑ Method complementary to fixed, regular, binning and Bayesian-block methods for LCs.
- ❑ Paper and dataset on variability properties of 90 of the brightest LAT blazars using 44 months of data is in completion. It contains LAT ADB light curves using constant flux relative uncertainties of 15% and 25%, as well as using 5-day and 1-month fixed regular binnings.

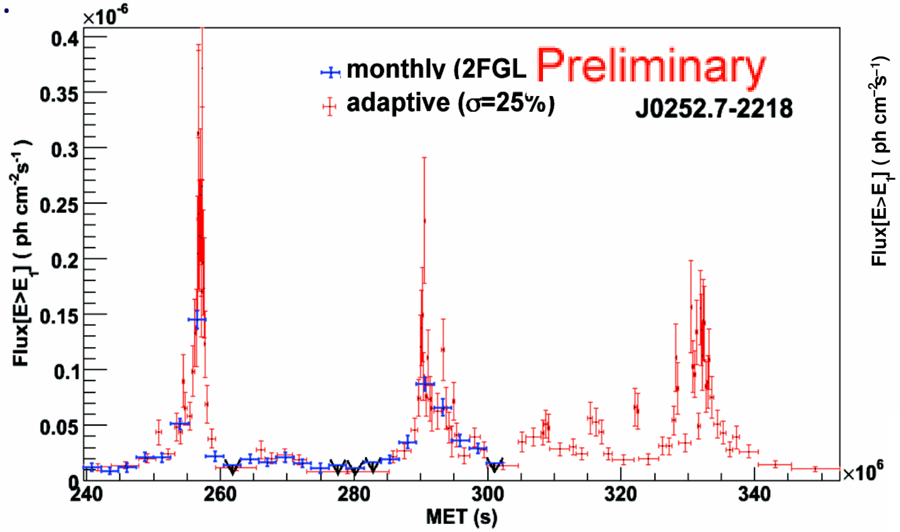




Dataset:

- ❑ 90 brightest blazars detected by the Fermi-LAT. Light curves: first 44 months of all-sky survey, adaptive time binning, 5-day bining, 1-month binning.

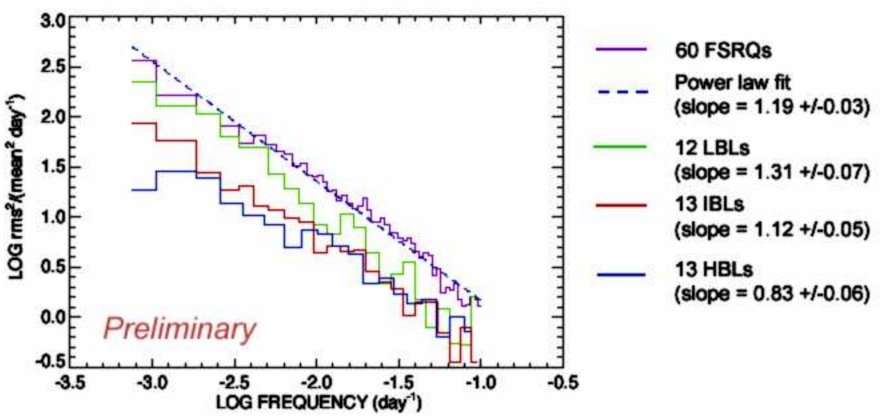
- ❑ All LC data will be public and ready for analysis.

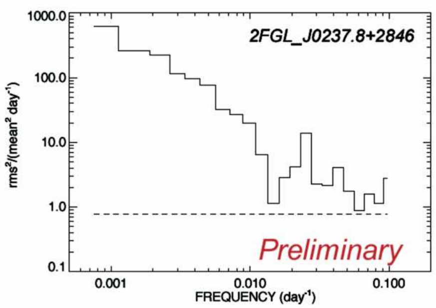


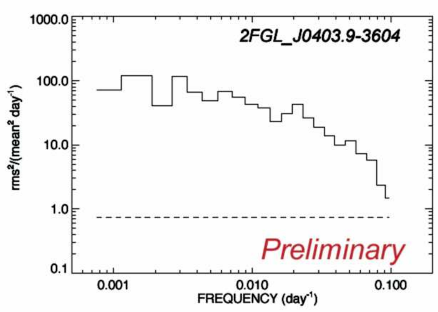
2nd list of *Fermi* LAT blazar γ-ray light curves

Adaptive-binning method interesting also for cross-correlation functions (MW variability studies) and both lowest and highest detectable fluxes assessed for the sample sources. First preliminary results:

- ❑ Cumulative flux distributions look different for the blazar classes.
- ❑ Shortest rise and decay times are similar in magnitude and evolve with different blazar classes.
- ❑ Moderate spectral variability indicative of a harder-when-brighter effect present for most FSRQs while BL Lacs do not show a uniform behavior.
- ❑ We can now get a decent PDS and power law slope for an individual source
- ❑ PDS confirm 2LAC findings with a trend to flatter distribution as the synchrotron peak moves to higher frequencies. No persistent breaks found in PDS. Break or steepening of the PDS is seen for some of the sources, however, these are associated with LCs that typically contain one or up to a few strong flares. It is not possible to say if these flares represent a persistent timescale or are just chance events.
- ❑ Mean gamma-ray PDS for blazars can be described as a power law with slope ranging 1.3-1.2 for low synchrotron peaked BL Lacs and FSRQs and 0.8 for high synchrotron peaked sources. → Decrease in fractional variability. FSRQs and LBLs show much more variability on longer timescales (months-years) than does the HBLs.



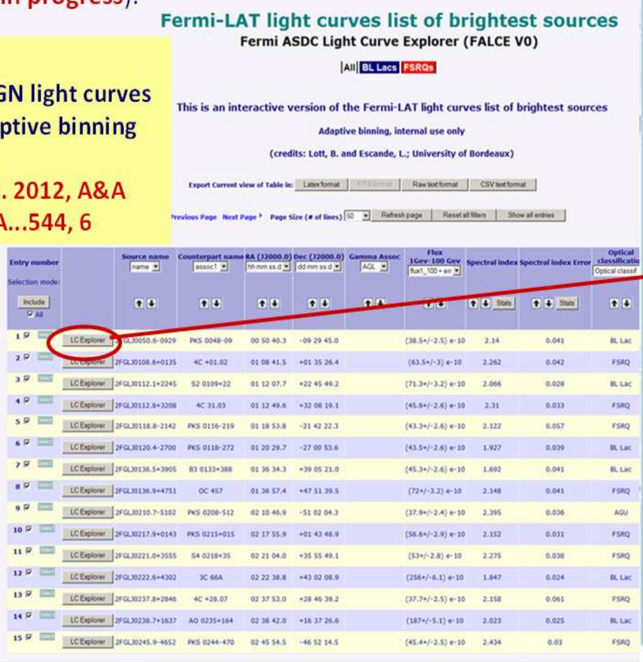


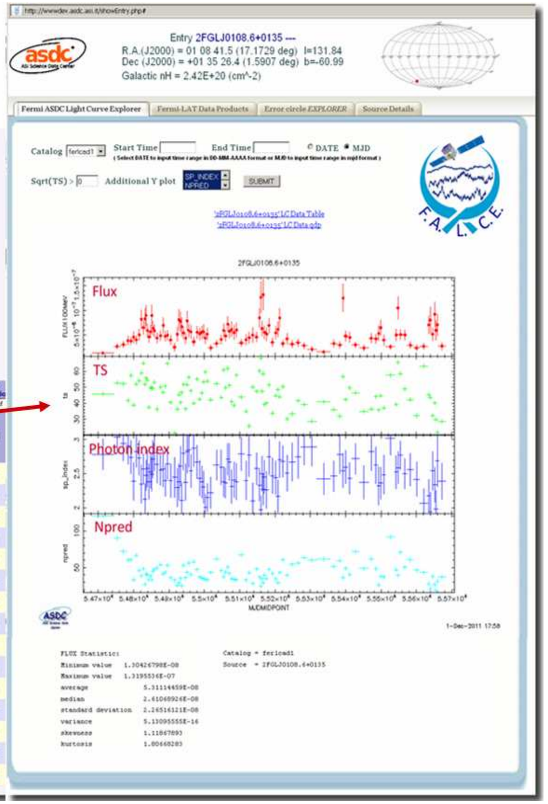


LAT blazar light curve data release

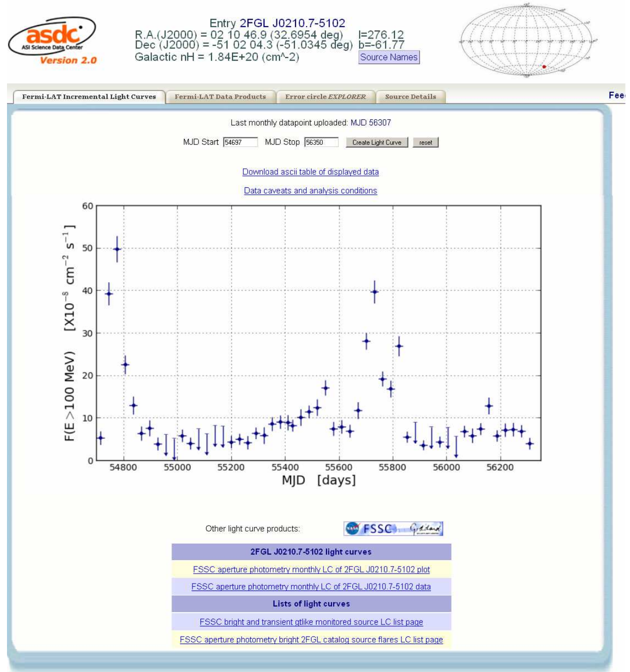
❑ Fermi ASDC Light Curve Explorer (FALCE):
1) interactive display of catalogued Fermi LAT light curves
2) on-line basic temporal analysis on the displayed light curve (work in progress).

Dataset:
bright AGN light curves with adaptive binning (ADB).
Lott et al. 2012, A&A 2012A&A...544, 6





LCs that are already online:
2FGL (variable sources)
monthly LCs ascii data:
www.asdc.asi.it/fermi2fgl/
(light curve button)



❑ www.asdc.asi.it/fermibalc/ (future address, work in progress, online at ASDC after submission of the LAT paper with the list of LCs II): Adaptive binning LCs of brightest LAT AGN/blazars. … and more:

❑ Interactive Catalogs: *Fermi* LAT BSL/0FGL, Fermi LAT BAS, Fermi LAT 1FGL, Fermi LAT 1LAC, Fermi LAT 1st Pulsar Catalog, Fermi LAT 2FGL,

❑ Online web analysis tool (data retrieval, preview and basic likelihood run): tools.asdc.asi.it/?&searchtype=fermi

LAT blazar light curve data release

Light curves at FSSC-GSFC:

- fermi.gsfc.nasa.gov/ssc/data/access/
- fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/
- fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/ap_lcs.php
- fermi.gsfc.nasa.gov/ssc/data/access/lat/2yr_catalog/ap_lcs_flares.html

…and more data:

❑ LAT Photon and Extended Data (several sets)

❑ LAT Data (high-level products only):

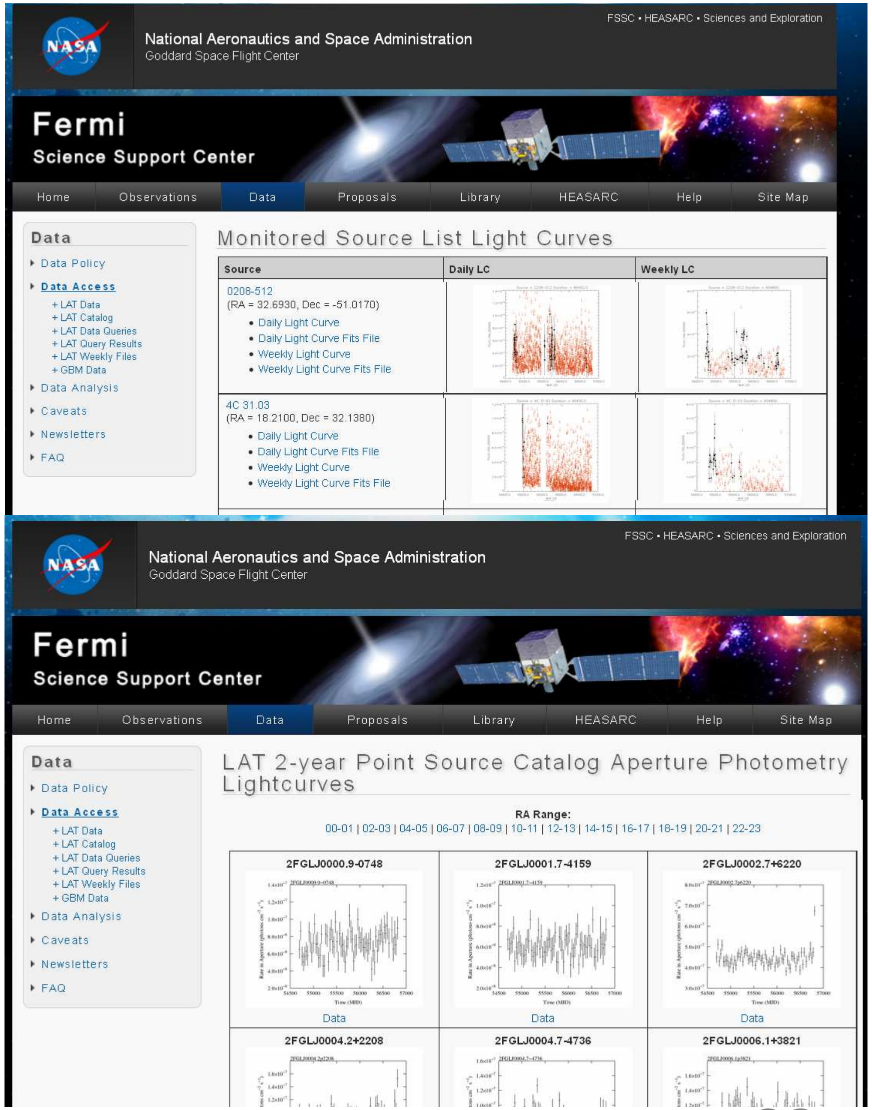
e.g., AT Monitored Source List Light Curves, LAT 2-year Point Source Catalog, Aperture Photometry Light Curves for the 2FGL Catalog, Flaring Sources in the Aperture Photometry Lightcurves, First LAT High-Energy Catalog, LAT Second Catalog of Gamma-ray Pulsars, LAT List of Detected Gamma-Ray Pulsars, LAT Pulsar Ephemerides, LAT GRB Catalog, Background Models, List of LAT GRBs announced via GCN notices, List of LAT Sources announced via ATels, etc.

❑ GBM Data:

GBM Trigger Catalog, GBM Burst Catalog, GBM Daily Data, GBM Continuous Data, GBM Earth Occultation Light Curves, GBM Pulsar Spin Histories, List of GBM GRBs announced via GCN notices etc.

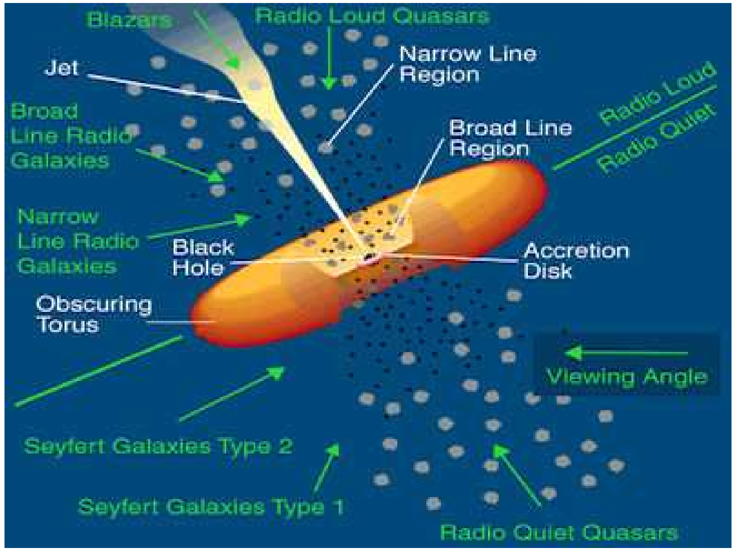
❑ Spacecraft Data: Spacecraft Pointing Files –

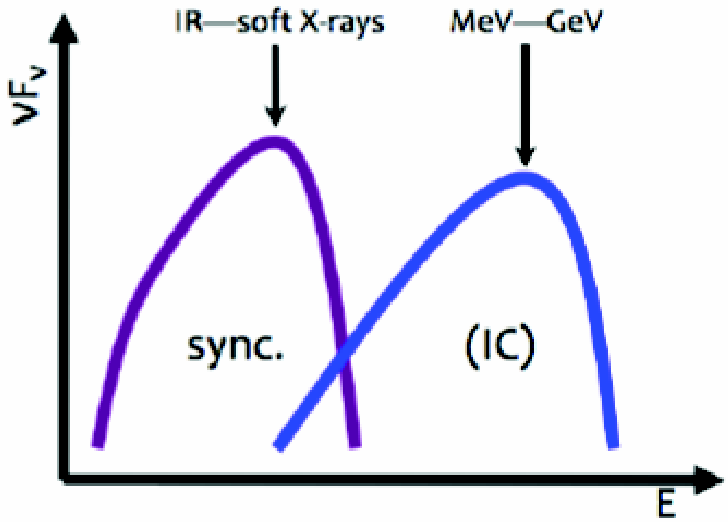
❑ Additional Data: MW Programs Supporting Fermi, Fermi Solar Flare Observations



Characteristics of LAT AGN/blazars

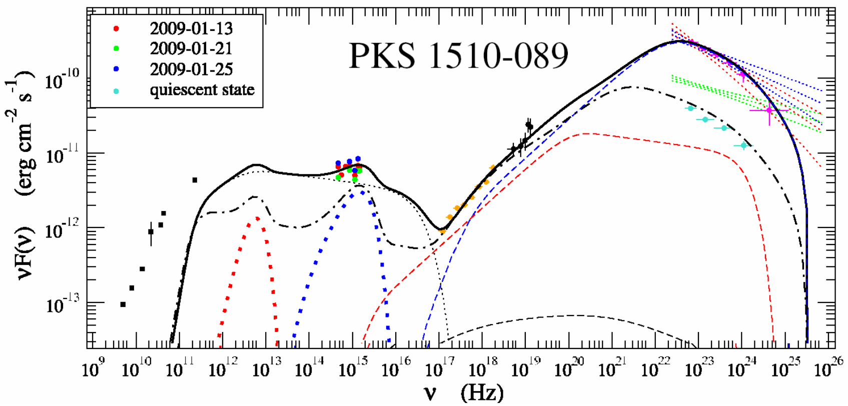
- *Fermi* LAT has discovered hundreds of new sources → blazars dominate the MeV-GeV extragalactic sky (detailed population studies, detailed spectral and variability temporal studies possible).
- Important spectral properties (correlation of photon index with blazar class,spectral breaks, relative constancy of photon index with flux, but there are exceptions: 3C 454.3, Mkn 501, etc.)
- Variability time scales were observed ranging from sub-day to several months.
- Many multifrequency studies heve been triggered by Fermi observations, providing time-resolved SEDs and interband (radio, optical, X-ray, TeV) temporal correlation.
- The emission of gamma-rays from the lobes of Cen A has been discovered and manny new non-blazars sources have been detected (Radio galaxies like M87, NRLSy1, NGC 1275, etc.).
- Gamma-ray flares from gravitationally lensed blazars discovered.
- Constraints on EBL opacity have been obtained.
- Novel features and correlations to digest, but ultimately a better understanding of gamma-ray AGNs is emerging.
- The cause of the gamma-ray spectral break is still a mystery, although several causes have been proposed.
- Large variability events might be initiated by sporadic accretion events with clues as to how AGN engine works.



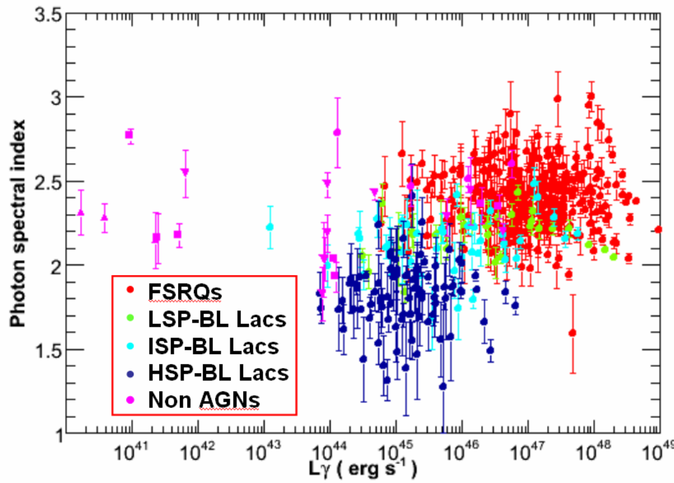


Characteristics of LAT AGN/blazars

- First *Fermi* observations provided some evidence, independent of redshift, that there is an anti-correlation between Compton dominance and the peak value for blazars a key component of the "blazar sequence". On the other hand new high-power high synchrotron peaked blazars are discovered and the meaning of instrumental bias (PSF very energy-dependent) is starting to be considered. It is certainly is possible in the future that high gamma-ray luminous and flat sources will be found as more redshifts are available (potential selection effect involving sources with unknown redshifts).
- Some cases with Evidence for large distances gamma-ray emission regions from BH.
- Gamma-ray flares appear to be correlated with 43 GHz VLBI flux of the core, while gamma-ray vs cm radio flux light curves finds strong correlations and results consistent with cospatial emission regions on pc scales.
- The location of the gamma-ray emitting region in the jet is still ambiguous, although gamma-ray variability may be the key to resolving this issue.
- *Fermi* and multi-wavelength observations and simultanous radio-to-gamma-ray SEDs are forcing us to look for models beyond the standard one-zone leptonic models.



Abdo et al. 2010 ApJ 721 1425



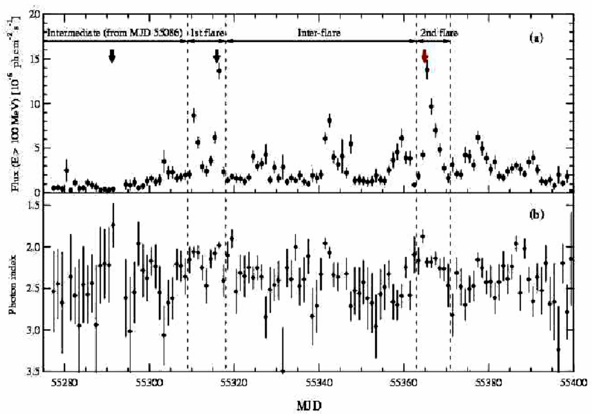
γ-ray emission site: within the BLR or outside?

NB: Following Arguments valid for FSRQ-like blazars only
(objects with radiatively efficient disk, BLR emission, no or very weak TeV emission)
NOT FOR HBLs / TeV BLLacs !!

- Close to the BH (<0.1 pc)
  - Fast variability
  - Seed photons for EC: Disk and BLR
  - Spectral curvature?

- Far from BH (1-10 pc)
  - simultaneous flares in gamma-rays and radio/mm
  - detection of VHE gamma-rays (ex: 4C+21.35)
  - synchronous optical and radio polarization variability

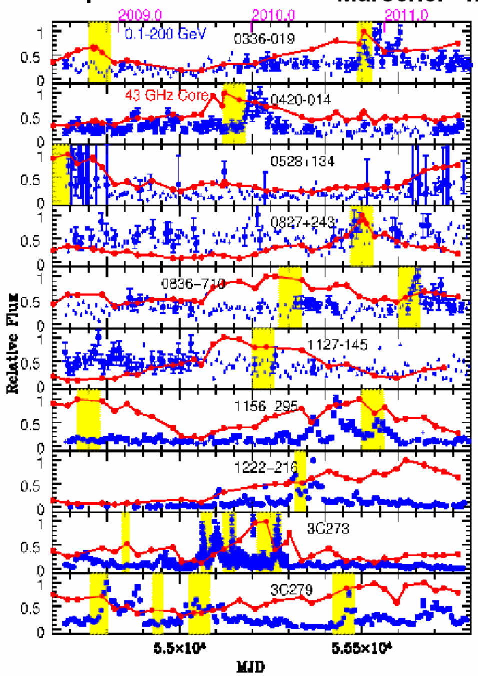
Tanaka+11



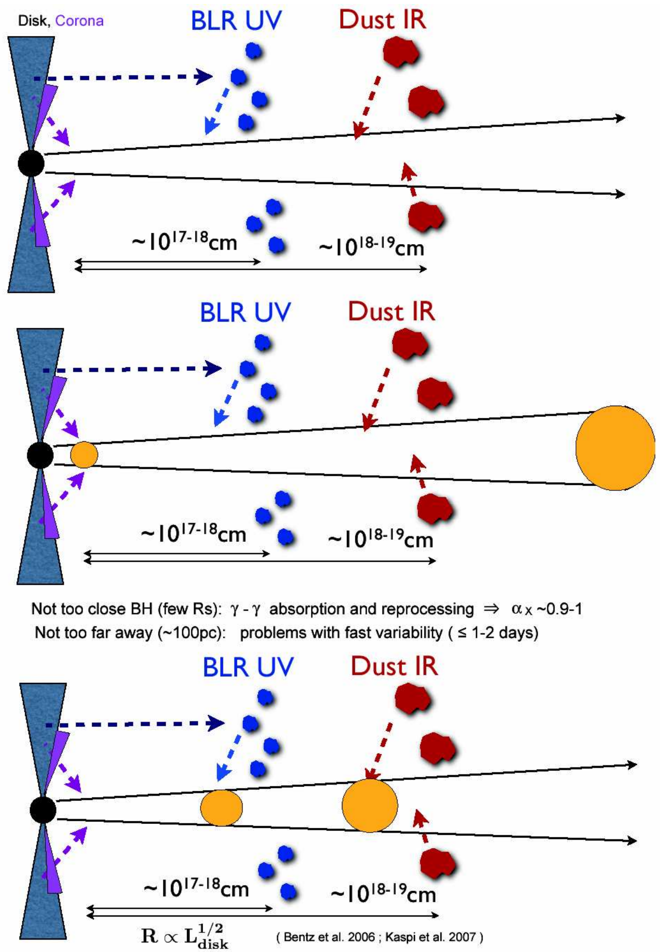
Fermi LAT γ–ray, 43 GHz VLBI "core"

times when a new superluminal knot passed the core

Marscher+12



34 γ-bright blazars and radio-galaxies
2/3 of the γ-flares associated with new superluminal knots



Not too close BH (few Rs): γ - γ absorption and reprocessing ⇒ α_X ~0.9-1
Not too far away (~100pc): problems with fast variability (≤ 1-2 days)

$R \propto L_{disk}^{1/2}$ (Bentz et al. 2006 ; Kaspi et al. 2007)

$U_{rad} \propto L/R^2 \sim$ const. $\sim 10^{-2}$erg/cm^3

External Compton (EC) onto: UV (~9-10 eV) or IR (0.1 eV) (e.g. Ghisellini et al. 2009 Sikora et al. 2009)

Basic 0th-order assumptions/approximations:
a) R ~ 10^{17} ($L_{disk,45}$)$^{1/2}$ cm b) isotropic field
c) BlackBody spectrum @9eV d) reprocessing factor η~ 10% (e.g. Ghisellini et al. 2009 Sikora et al. 2009

Radio-gamma-ray connection

- The jets of the *Fermi* LAT-detected blazars have:
  - higher-than-average apparent speeds (Lister+09, Piner+12),
  - larger-than-average apparent opening angles (Pushkarev+09)
  - more compact radio cores (Kovalev+09)
  - strong polarization near the base of the jet (Linford+11)
  - higher variability Doppler factors (Savolainen+10).

- All the above points to higher-than-average Doppler boosting in gamma-ray bright blazars.

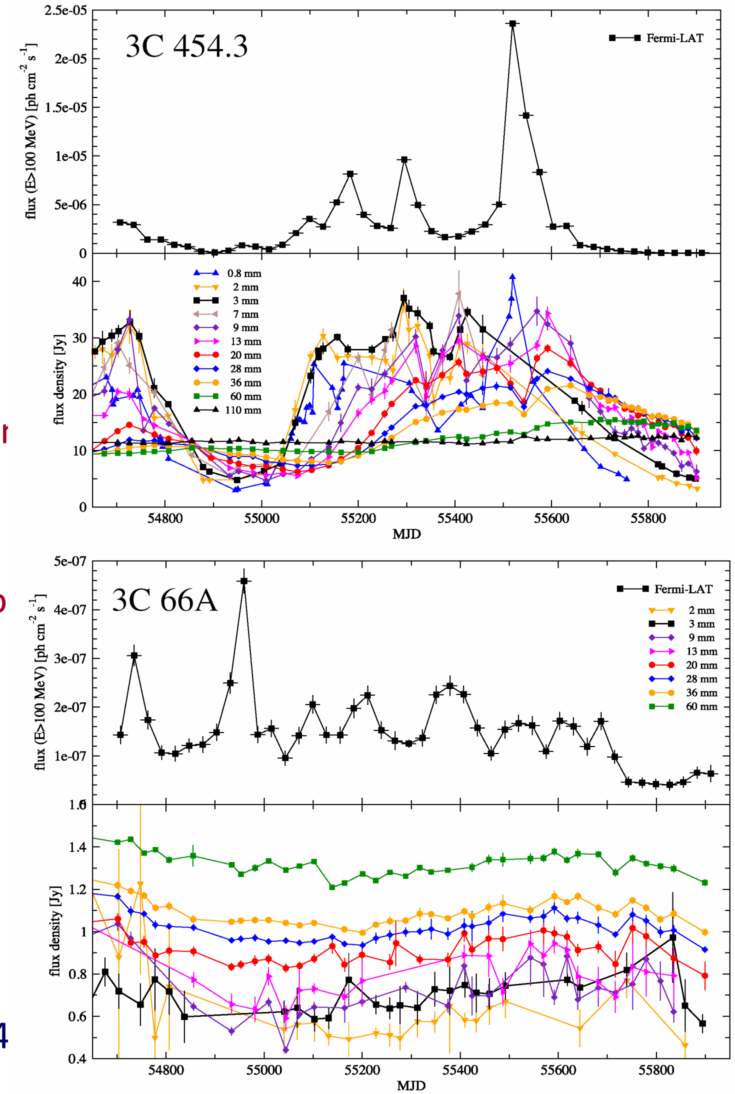
- AGN jets have been found to be in a more active radio state withir several months of the LAT-detection of their strong gamma-ray emission (Kovalev+09, Pushkarev+10).

- The gamma-ray photon flux correlates with the parsec-scale radio flux density (Kovalev+09; Arshakian +11)

- γ-ray loudness correlates with position of synchrotron peak and gamma-ray photon spectral index for BL Lacs (Lister+12, Linford+12)

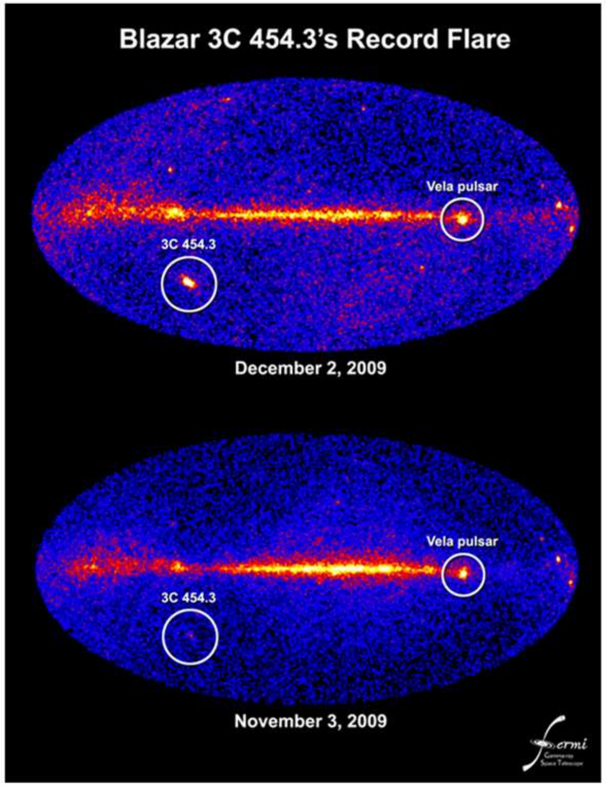
- Cross-correlation between radio (11 cm to 0.8mm, F-GAMMA program) and GeV light curves of 54 LAT-bright blazars show significant multiband (radio lagging γ-rays), average time delays decreasing from cm to mm/sub-mm bands, bulk γ-ray production region located within/upstream the 3mm core region (Fuhrmann+14

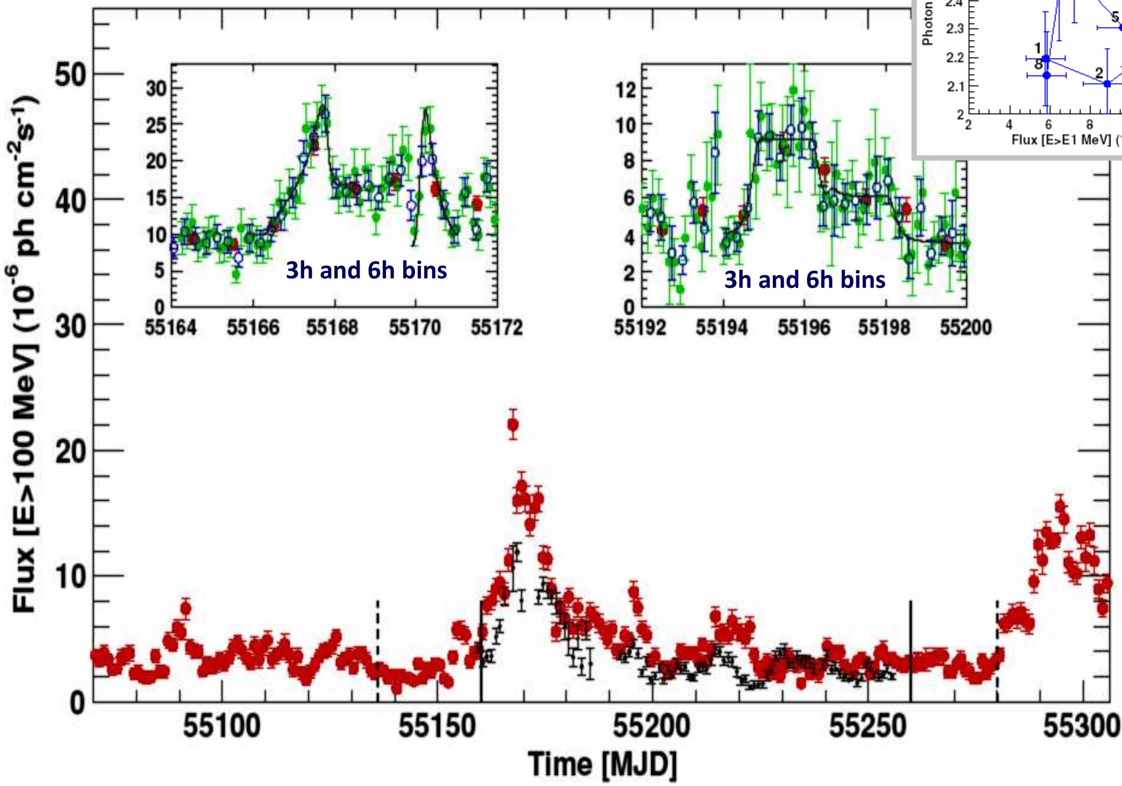
Fuhrmann, Larsson, Chiang, Angelakis et al. 2014 MNRAS **441,** 1899



Individual sources, example (1): the big outbursts of 3C 454.3 (Dec. 2009, Apr. 2010)

- Correlated spectral-temporal properties of 3C 454.3 during two very strong flaring episodes (it was the brightest object in the gamma-ray sky during the peak) studied.





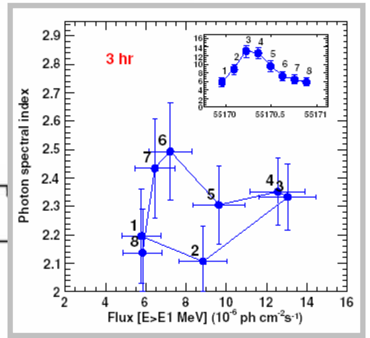


Figure 1. Light curve of the flux of 3C 454.3 in the 100 MeV–200 GeV band (red) between MJD 55,070–55,307 (2009 August 27–2010 April 21). The solid (dashed) lines mark the period over which the PSD (CWT) analysis has been conducted. The light curve of the 2008 July–August flare, shifted by 511 d, is shown for comparison (black). The insets show blow-ups of the two periods when the largest relative flux increases took place. The red, blue, and green data points in the insets correspond to daily, 6 hr, and 3 hr averaged fluxes, respectively. The fit results discussed in the text are displayed as solid curves.

Individual sources, example (1): The big outbursts of 3C 454.3

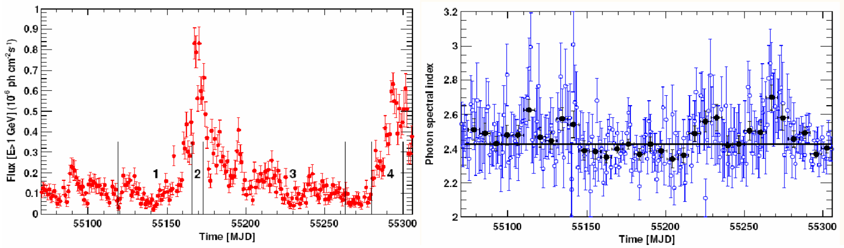
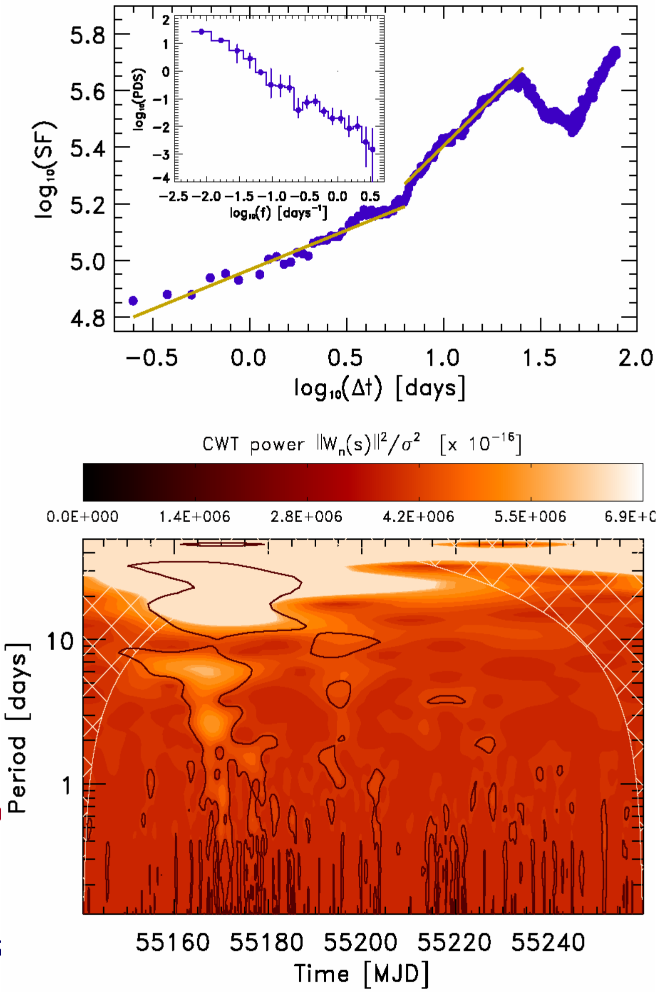


Figure 3. Top: light curve of the flux in the 1–200 GeV band. Bottom: variation of the daily (blue points) and weekly (black points) photon spectral index derived from a PL fit. The black line depicts the mean weekly spectral index.



- First-order structure function (SF), power density spectrum (PDS), global methods, and Morlet continuous wavelet transform (CWT), local method, are applied to the unprecedented-resolution gamma-ray light curve of 3C 454.3 (interval MJD 55140-55260).
- Break around 6.5 days is hinted (power-index slopes $\alpha = 1.29 \pm 0.10$ between 3 hr and 6.5 days and $\alpha = 1.64 \pm 0.10$ between 6.5 and about 26 days. PDS confirms values ($\alpha = 1.40 \pm 0.19$ and a = 1.56 ± 0.18).
- Steepening toward longer lags (flattening toward higher frequencies).
- Morlet-CWT (best tradeoff between localization and period/frequency resolution), showed only marginal features below timescales of 1 day. The
- big outburst of Dec.2009 well localized and decomposed in a chain of mino CWT power peaks. 6.5 day timescale confirmed by the major power peak still out of the finite-series cone of influence (at about MJD 55166)
- Another energetic peak in this period is found with scale of about 2.5 days

Figure 2. Top panel: SF of the 3 hr bin flux light curve for the period MJD 55,140–55,260 and corresponding PDS (inset). Bottom panel: plane contour plot of the continuous Morlet wavelet transform power density for the same light curve. Thick black contours are the 90% confidence levels of true signal features against white/red noise background, and cross-hatched regions represent the "cone of influence," where spurious edge effects become important.

Individual sources, example (2): gravitational lens PKS 1830-211

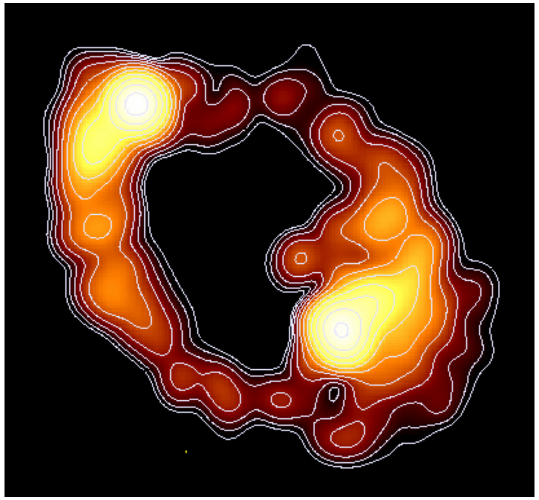
- ❑ Flat spectrum radio quasar (FSRQ) PKS 1830-211 (a.k.a. TXS 1830-210, RX J1833.6-210, MRC 1830-211) clearly a strong gravitationally lensed source. Discovered as single source in Parkes (PKS, in 1969) catalog. VLA and ATCA clearly revealed two sources (NE and SW, separated by 0.98'' and connected by an Einstein ring). NE radio image a flux about 1.5 times as bright as the SW image.

- ❑ For the first time point source neutrino flux upper limits calculations (after the LAT ATel issue) are obtained for PKS 1830-211 with the IceCube telescope.

- ❑ Molecular absorption lines revealed lensing galaxies at z = 0.886, and z = 0.19. Optical imaging shows the same lens separation from the core (0.98'') and an unusually strong radio Einstein ring (confirmed by Gemini and HST). Further galaxies identified in the field of the source. Detailed exploration hampered in the optical by its proximity to the Galactic plane (dust extinction).

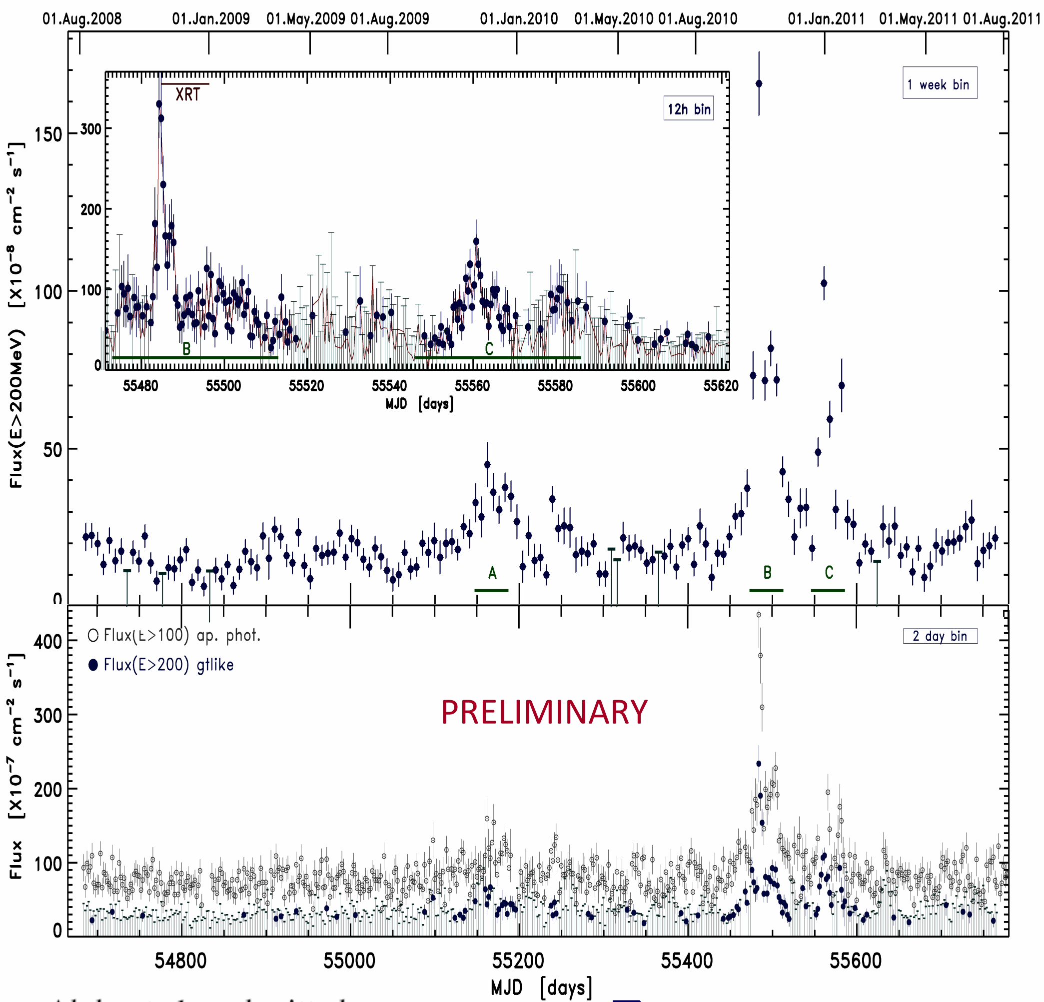
- ❑ Different paths to reach us → time delay between the photons which arrive from the two main images. Time delayed variability and flares expected. The system appears too much complex anyway to be used to measure H0.
- ❑ Radio time delays claimed: 26+/-5 days, 24+/-5 days, and a different value of 44+/-9 days (van Ommen et al. 1995 do not correctly accounting the contribution of the ring).

- ❑ PKS 1830-211 is highly variable (Fermi LAT flares, radio flares) and is also bright at hard X-rays and MeV energies (Chandra, XMM-Newton, INTEGRAL, Comptel detections, and X-ray photon index about 1). An EGRET source, AGILE source, 1FGL/2FGL LAT source too.



In 1991 PKS 1830-211 was identified as an unusually strong radio-band emitter and radio Einstein ring (gravitational lens). But it now appears that there may be two separate lensing galaxies, intervening in our line of sight. This would make PKS 1830-211 the first compound gravitational lens. PKS 1830-211 lies in a crowded and obscured sky field close to the Milky Way Galactic Centre.

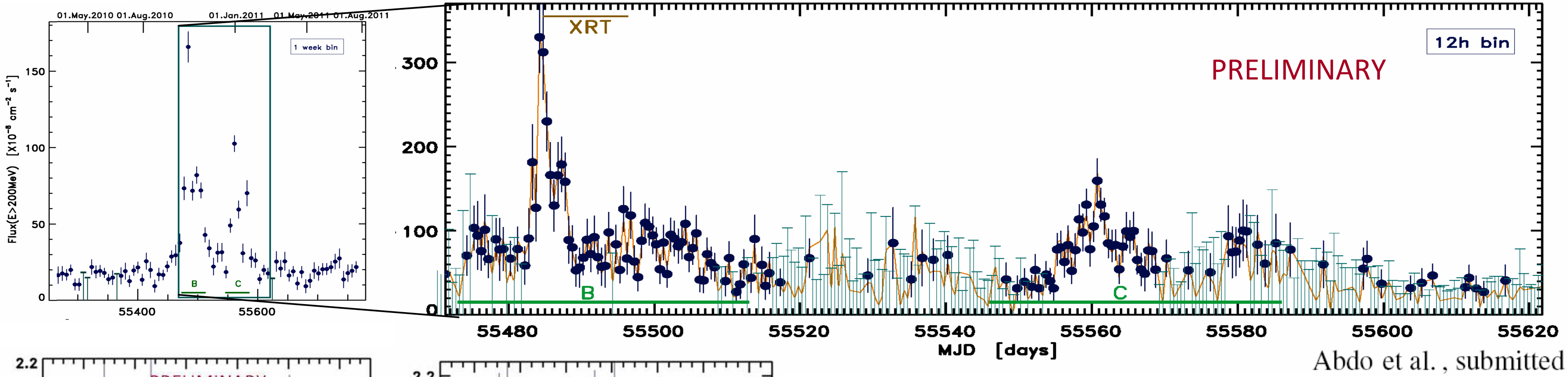
Individual sources, example (2): gravitational lens PKS 1830-211

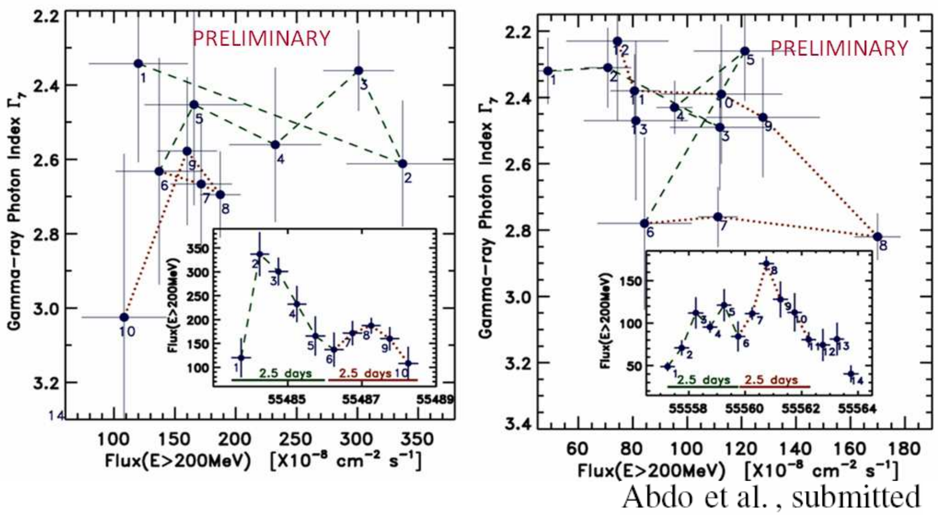


Abdo et al. , submitted

- ❑ 3-year (1085 days, 2008 Aug. 4 to 2011 July 25, MJD 54682.65 to 55767.65) LAT gamma-ray flux (E>200MeV) light curve of PKS 1830-211 in weekly and 2-day bins obtained with likelihood (gtlike) analysis. Vertical lines: 2-sigma flux upper limits (computed for bins where TS<4, Npred<3, or $\Delta F>F/2$).
- ❑ 150 day (most active phase, 2010 Oct. 2 to 2011 Mar. 1 containing the first and main outburst epoch Oct.2010 “B” and the second brightest flare epoch Dec.2010-Jan.2011 “C”) flux (E>200 MeV) light curve in 12-hour bins obtained with gtlike.
- ❑ Aperture photometry (1deg aperture) 3-year flux (E>100 MeV) light curve in 2-day bins for comparison with Barnacka et al. (2011).
- ❑ AGILE ATel on 2009 Oct. 12-13 bright activity (reported some weeks before the ``A'' phase we identified).
- ❑Main composite Oct.2010 outburst: two peaks hinted, first peak asymmetric, temporal structure characterized by two 2.5-day peaks.

Individual sources, example (2): gravitational lens PKS 1830-211

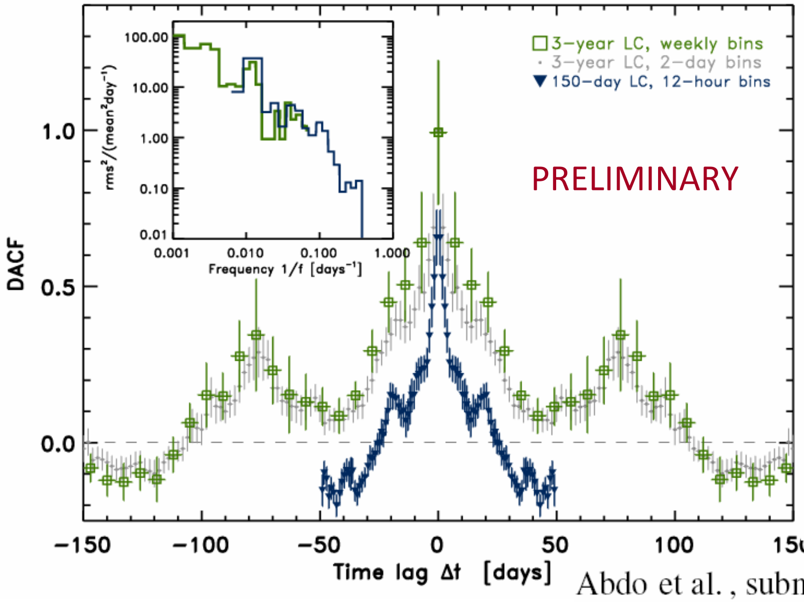




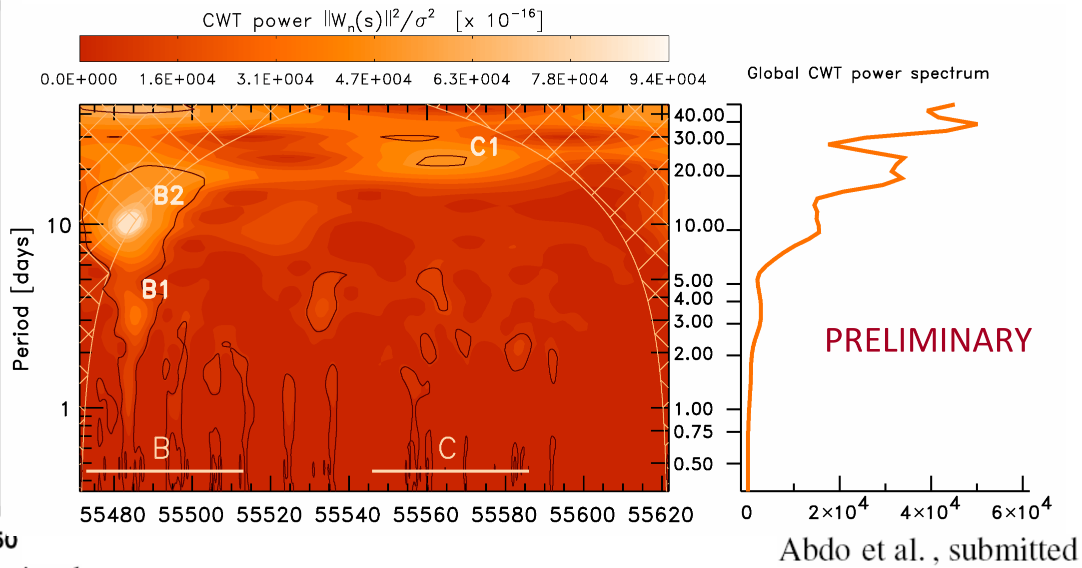
- ❑ 150-day range (2010 Oct. 2 -- 2011 March 1) likelihood flux light curve extracted with 12-hour bins, containing intervals when the main outburst of 2010 Oct. and the second largest, and double-peaked, flare of 2010 Dec.-2011 Jan occur. (12 hours → 8 Fermi orbits, bin to bin exposures roughly uniform.
- ❑ 2010 Oct. outburst: characterized by a rapid increase of a factor of about 2.6 in flux in 12 hours between 2010 Oct.14 and 15, and asymmetric temporal shape. The total peak lasts about 2.5 days, and seems to be followed by another weaker peak also lasting 2.5 days.
- ❑ Second flare 2010 Dec. 2011 Jan. 6 , displays two temporal peaks of about 2.5 days duration each. The firstpeak shows hints of a plateau while the second peak of about 2.5-day duration.

- ❑ Both flare events peaks do not show significant rotation in the ph.index-flux hysteresis diagram, (statistically constant photon index and relatively large errors on flux / ph.index w.r.t. variations.

Individual sources, example (2): gravitational lens PKS 1830-211



Abdo et al., submitted



Abdo et al., submitted

- Power Density Spectra (PDS) and Discrete Auto-Correlation Function (DACF) extracted for both the 3-year/weekly bin 150-day/12-hour bin LAT light curves. Variability behavior characterized by PDS power-law index about 1.2. DACF shows an hint for an about 20-day time signature.
- Continuous Wavelet Transform (CWT) scalogram (3D plot of the 2D CWT transform power density spectrum) obtained for the 150-day/12-hour bin LAT light curve. Morlet, complex valued, mother function. B epoch (main outburst) is decomposed in two main temporal-localized components.
- Most CWT power in scales (y-axis 1/f, f=frequency) range 8 to 30 days. Bulk of the power is localized along the light curve and released in range about 2010 Oct.6 - 26. Characteristic scale of this outburst is 10 days. Resolved component of 3 days at Oct.17 (agreement with 2.5-day sub-peaks observed).
- Second brightest flare with defined power peak having timescale about 21 days (2010 Dec. 30 - 2011 Jan. 4).

Individual sources, example (2): gravitational lens PKS 1830-211

- A strong evidence of lensing-induced following-up flares is not confirmed. No following-up gamma-ray flares from the second lens image for both the ``B'' outburst and the ``C'' second brightest flare found. Gtlike flux (bin x bin spectral fit) light curve (12-hour, 2-day and 1-week bins over 3 years) extracted using the same event class (Pass-6) and analyzed with different methods (PDS, DACF, CWT). Minor variability on longer timescales also found.

- Time delay of 26^{+5}_{-4} days (Lovell98), 24^{+5}_{-4} days (Wiklind01), the main outburst peak of 2010 Oct. 14-15 showed no delayed event. The same for the 44+/-9 days time delay (by VanOmmen95). Magnification ratio in radio bands is 1.5.

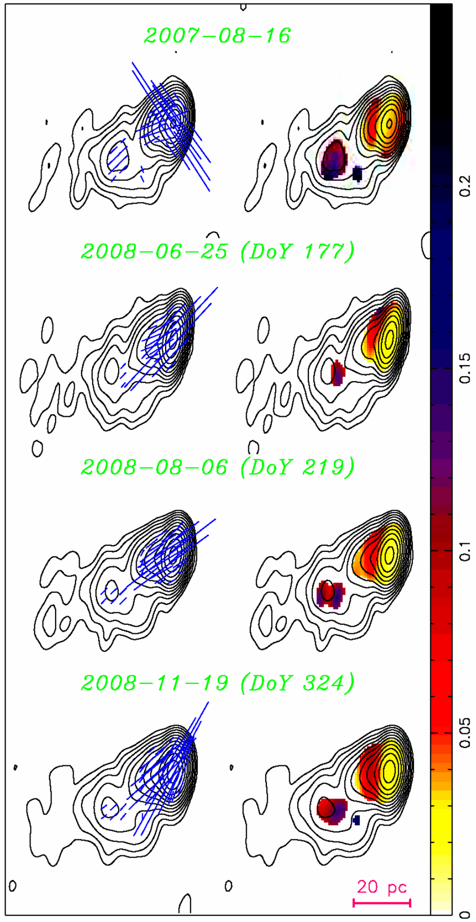
- Delayed flare does not exist in gamma-rays or magnification ratio in gamma-rays is much smaller, or there is a time or energy variable magnification ratio too given by the complex lens system, intrinsic inner structure and ambient. Besides microlensing effects and the general need for a refined lens modeling of PKS 1830-211, different absorption, spatially distinct radio- and gamma-ray emission regions of different sizes, and the emerging (ALMA observations) of an energy-dependent inner structure of the source are hypotheses to be taken into account.

- Barnacka et al. (2011) claimed a 27.1+/-0.6 days time delayed signal (using 2-day bin flux (E>300 MeV) LC extracted through aperture photometry using Pass-6 events and IRFs. Aperture photometry technique and LAT data selection differs from that used for our maximum likelihood analysis. In addition they used a reduced time range (LC stops at 2010 October 13).

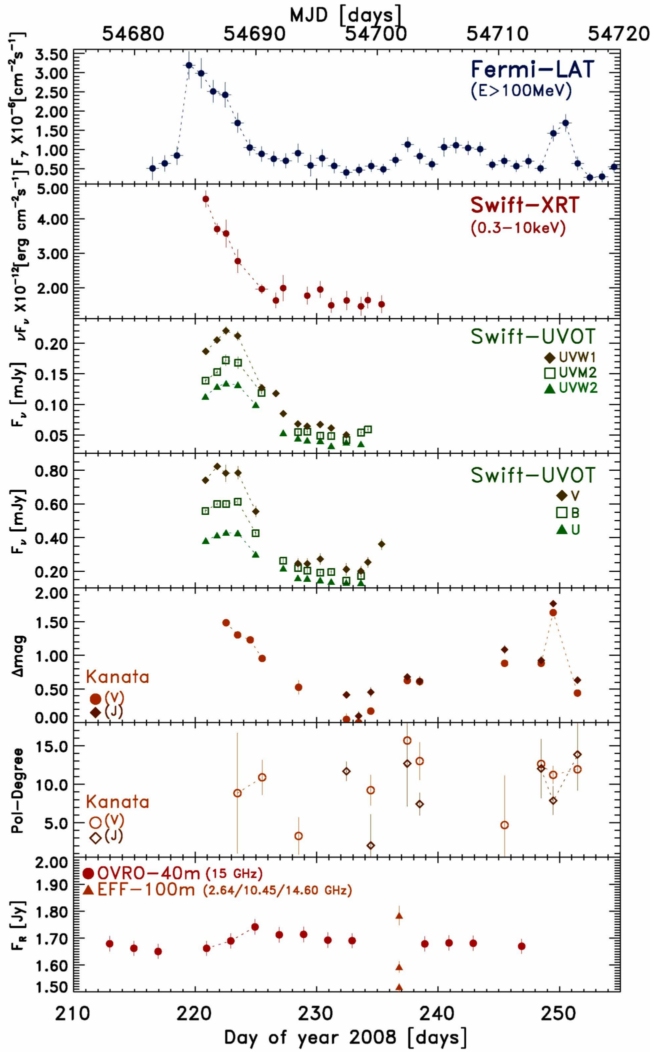
- Signal feature at 53.4-day timescale: precession period of the spacecraft orbit → systematics by effective area variation in Pass-6 data/IRFs (27.1+/-0.5 day delay claimed is the first harmonic of that). On the other hand LAT observations of PKS 1830-211 ap.photometry LCs) appears not affected by moon gamma-ray emission (sidereal period of 27.32 days), also in data before October 2010.

Individual sources, example (3): new flaring gamma-ray blazar PKS 1502+106

- A new and luminous gamma-ray blazar (not seen by EGRET). New gamma-ray source to be identified and variability shown → multifrequency campaign and study needed.

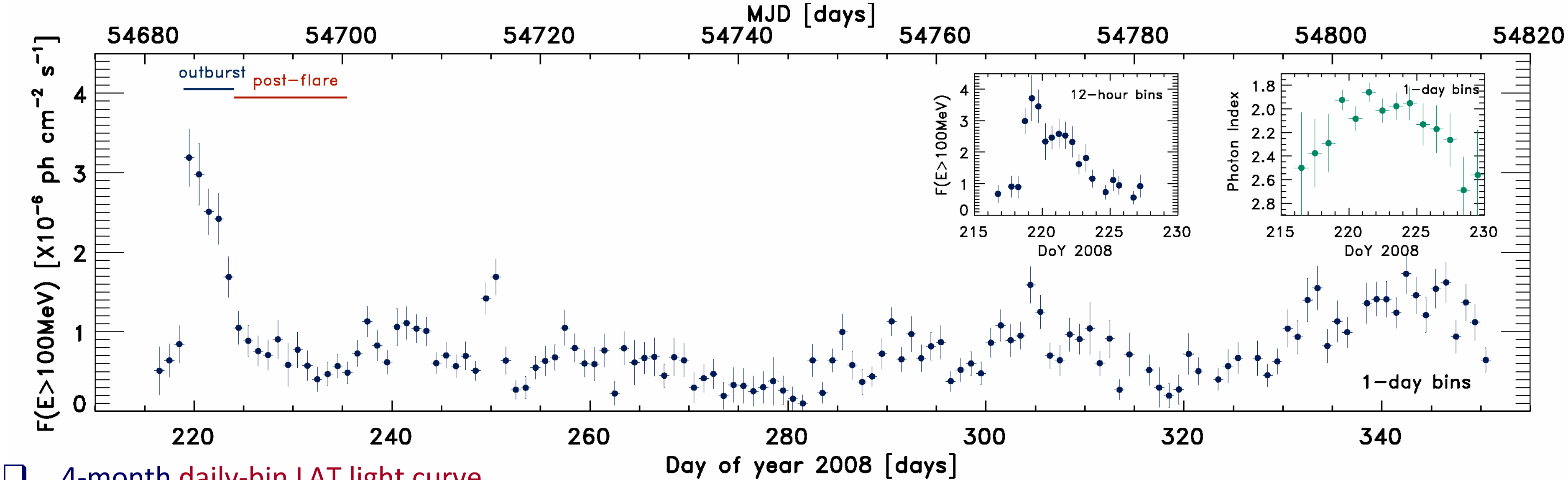


- Swift follow up for 16 days.
- Ground based radio-optical snapshots (VLBI structure and radio-mm spectra) and monitoring (radio-optical flux).
- 4-days time lag between GeV and UV-optical flare peak.
- Marked gamma-ray bolometric dominance, ERC SED modeling (energy dissipation within BLR). Asymmetric gamma-ray outburst observed simultaneously from optical to X-ray bands. SSC appears to dominate from radio to X-rays.
- Possible radio counterpart of the gamma-ray outburst assumed only if a delay of >3months is considered.
- Rotation of the electric vector position angle observed by VLBA from one year before the outburst could represent a slow field ordering and alignment with respect to the jet axis, likely a precursor feature of the ejection of a superluminal radio knot and the high-energy outburst.

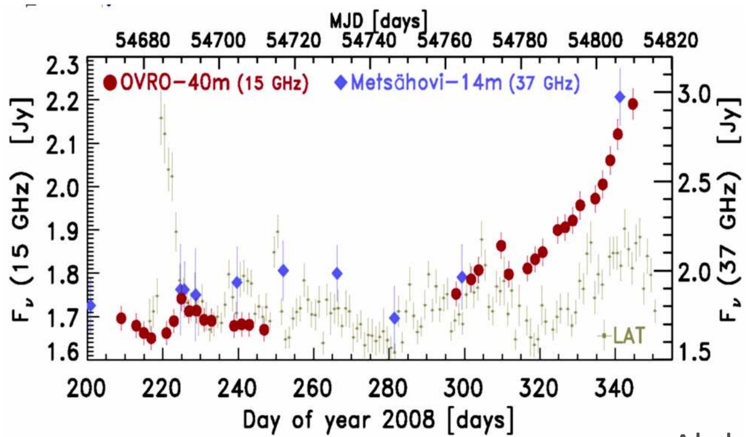


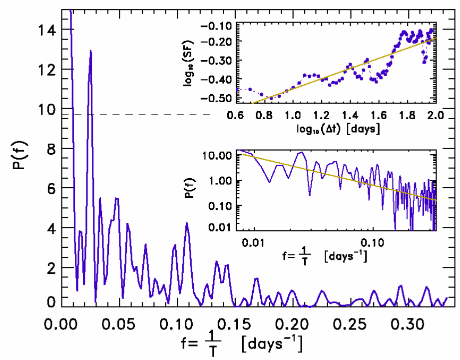
Abdo et al. 2010, ApJ, 710, 810

Individual sources, example (3): new flaring gamma-ray blazar PKS 1502+106



- 4-month daily-bin LAT light curve obtained with no gaps after the outburst (1/f^(1.3) variability).
- Gamma-ray-radio connection well investigated: 3 MOJAVE VLBA mapping with Fermi on flight. OVRO-40m daily simultaneous monitoring at 15 GHz. Metsahovi-14m weekly monitoring at 37 GHz. Effelsberg 100m single dish and RATAN 600-ring tel., radio-mm simultaneous multi-band snapshots.





Abdo et al. 2010, ApJ, 710, 810

Individual sources, example (4): PKS 1510-08 in the MW context

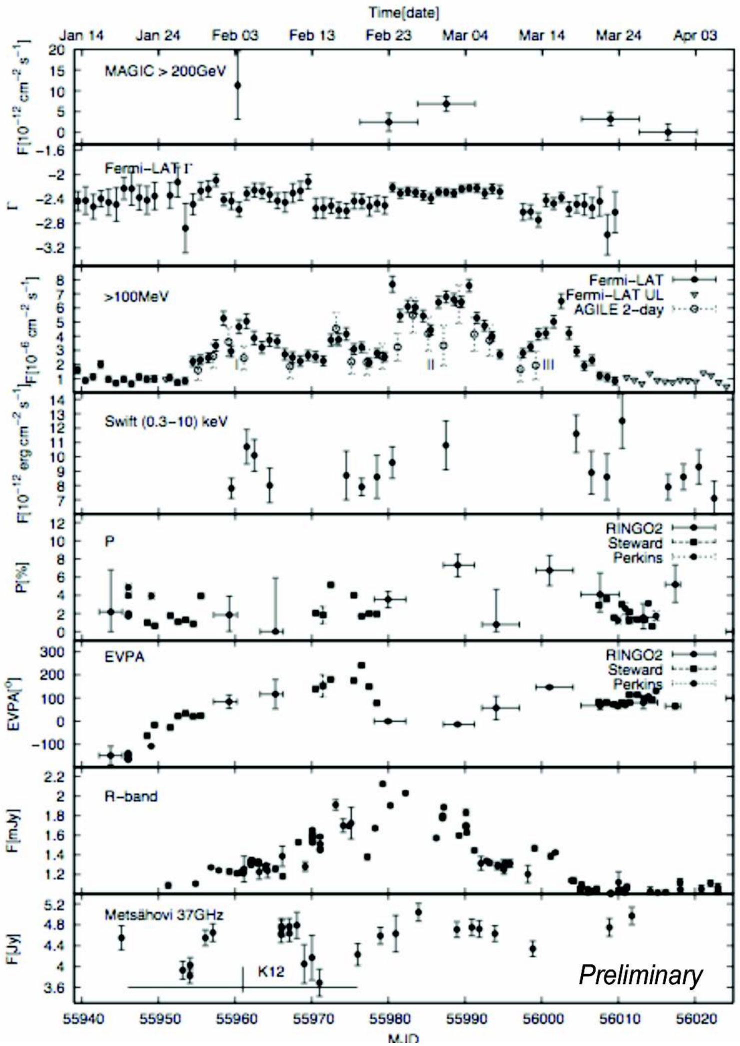
VHE (>200GeV)

HE (>100MeV)

X-rays (2-10 kev)

Optical

Radio 37 GHz

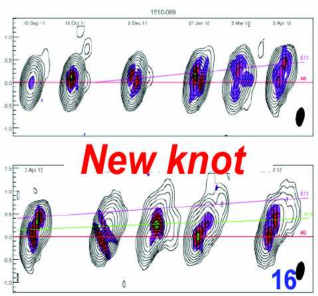


no significant variability

3 distinct flares

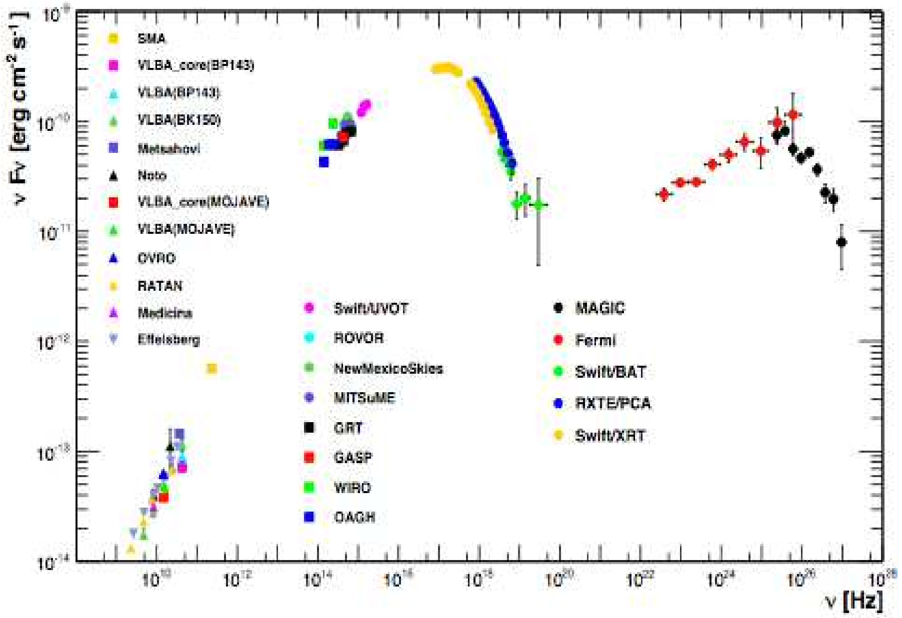
modest variability

3 distinct EVPA Rotations >180°



- ❑ The GeV and TeV spectra of PKS 1510-08 connect smoothly --> suggests radiation originates from a single emission region located far from the central engine.
- ❑ The GeV 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. 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 GeV and 37 GHz light curves + ejection of a new component from the 43 GHz VLBA core support this emission scenario.

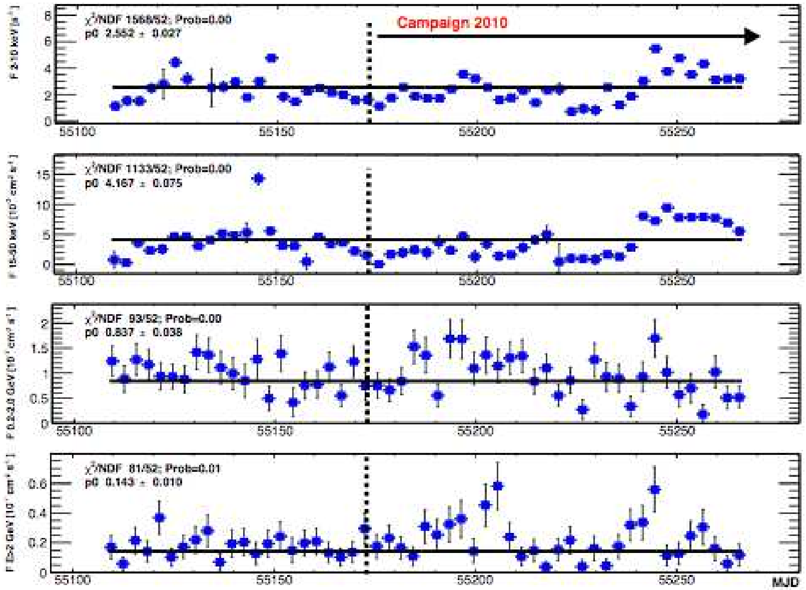
Individual sources, example (5): GeV-TeV Connection in Mkn 421



Abdo et al 2011, ApJ 736, 131,22

Extensive multi-wavelenght campaing on MKN 421

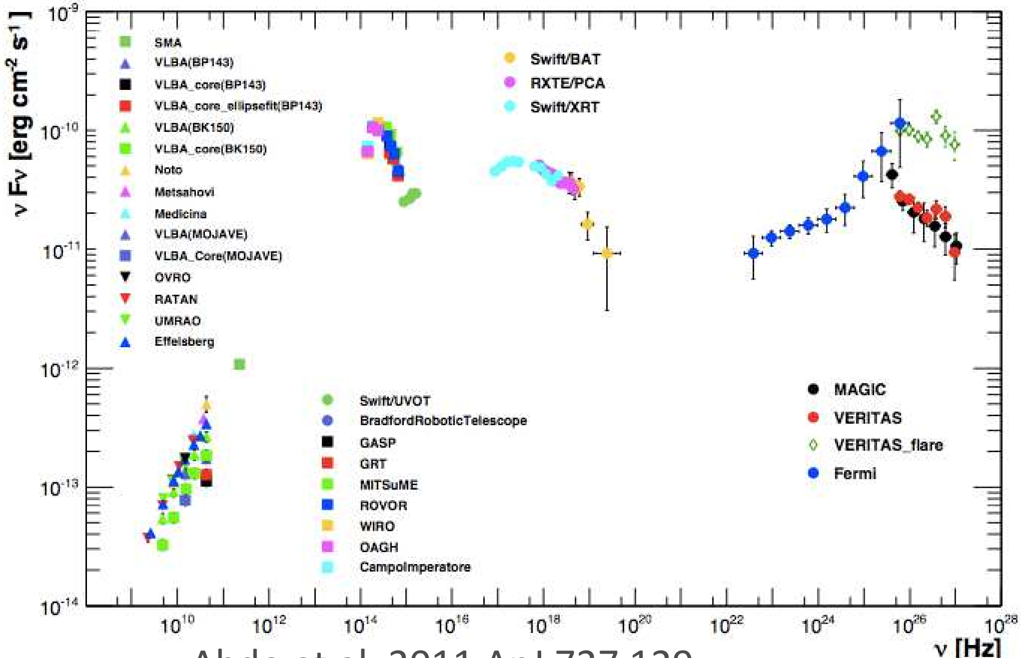
- ❒SED emerging from this is the most complete and accurate representation of the low/quiescent state of Mrk421.
- ❒Two scenarios are proposed: Hardonic and Leptonic



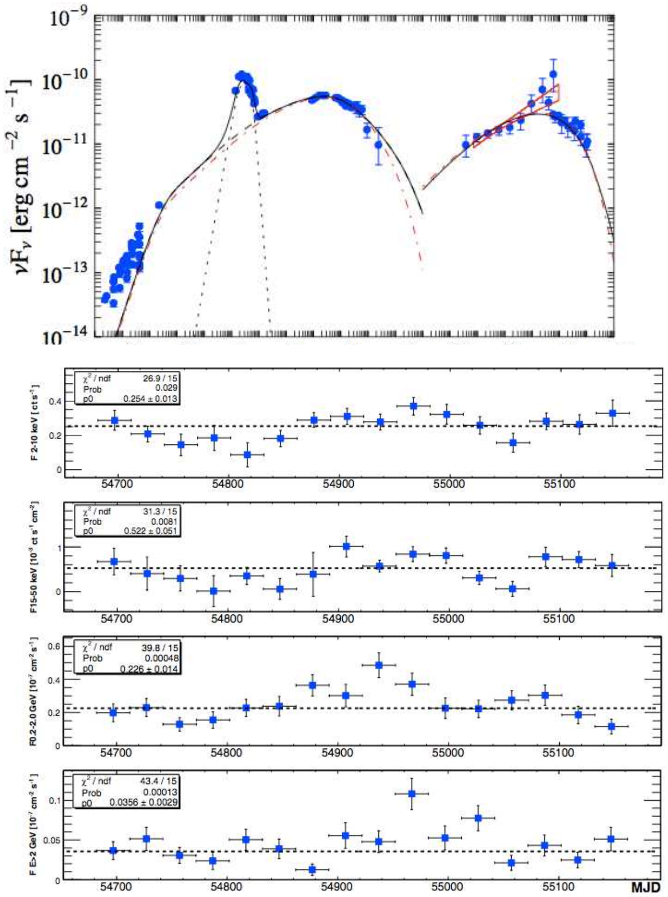
Multi-frequency light curves (X-ray:RXTE/ASM, Soft-Gamma:Swift-BAT, Gamma-ray:Fermi-LAT)

❒No indication of a correlated activity between X-ray and Gamma-ray

Individual sources, example (6): GeV-TeV Connection in Mkn 501



Abdo et al. 2011 ApJ 727 129



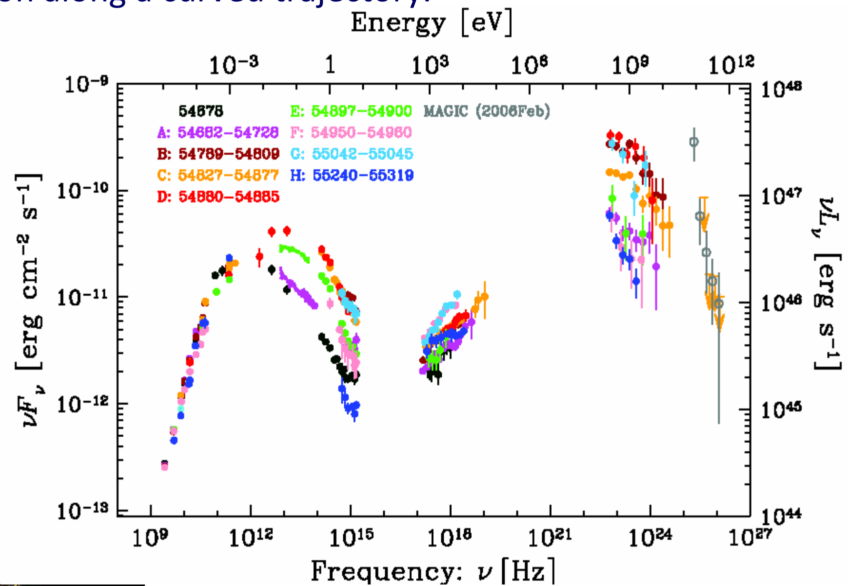
❐Modeled with 1-zone SSC in the low phase

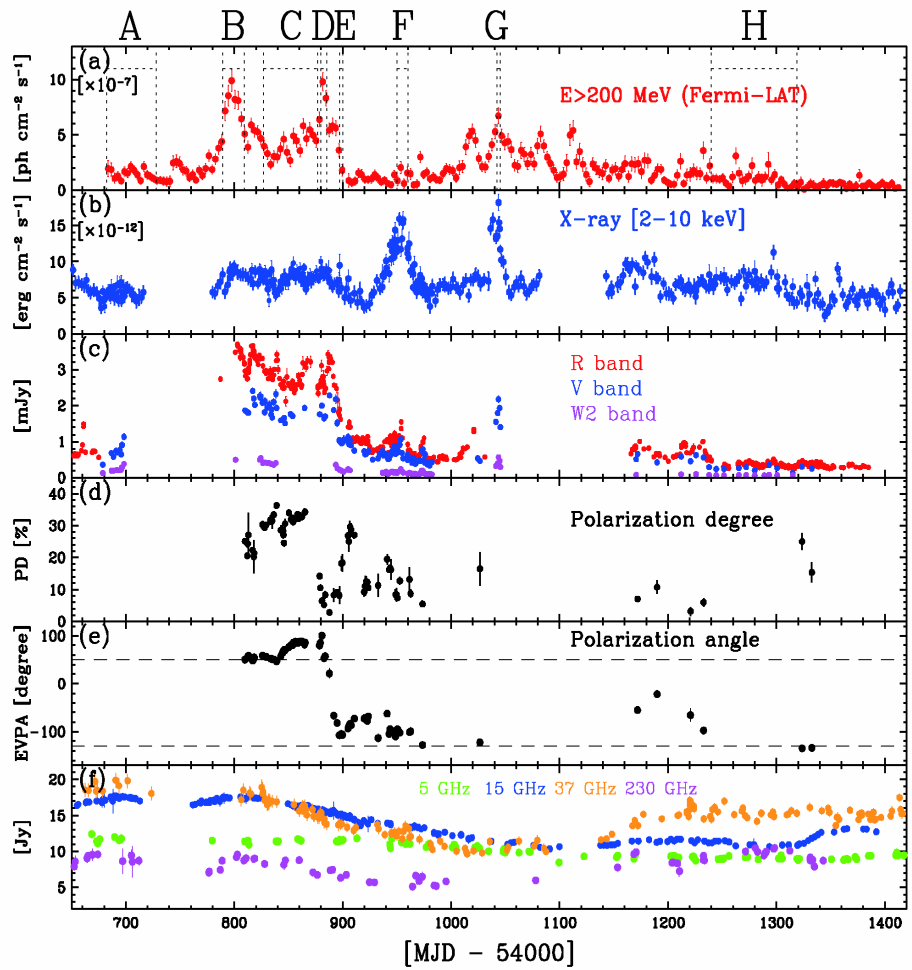
❐The epoch of enhanched gamma-ray activity may be more difficult to explain with a single SSC

Multi-frequency light curves (X-ray:RXTE/ASM, Soft-Gamma:Swift-BAT, Gamma-ray:Fermi-LAT)

Individual sources, example (7): flares of 3C 279

- ❑ 2-year multi-wavelength campaigns.
- ❑ Discovery of a change in the optical polarization associated with a LAT gamma-ray flare in 3C 279.
- ❑ Optical emission delayed with respect to gamma-ray emission (about 10 days).
- ❑ Pair of (almost "orphan") flares in X-rays separated by 90 days, with only weak gamma-ray/optical counterparts.
- ❑ SED peak frequency variations (mid-/far-infrared and mm/sub-mm bands).
- ❑ ERC SED modeling (dusty torus too).
- ❑ Polarization swing involving propagation of the emitting region along a curved trajectory.





▪Abdo et al. 2010, Nature 463, 919
▪Hayashida et al. 2012 ApJ 754 114

Conclusions

❑ The high duty cycle and sky-survey capabilities of the Fermi LAT have allowed to follow up many AGN in flaring states and to continuously monitor gamma-ray source variability over almost 6-years.

❑ In AGN/blazar field gamma-rays are are signatures of extreme events (energetics of AGN) and probe of extreme systems (acceleration mechanisms) and mediums (extragalactic background light).

❑ Data are public, and MW data, observing campaigns, follow-up and monitoring are very important. (there are plan to release also more high-level data like LCs, spectra, online tools).

❑ Incrementing the number of objects (*Fermi* 1FGL/1LAC/2FGL/2LAC/1FHL/3FGL/3LAC... Catalogs) trough the almost-continuous all-sky survey leads to draw a better picture of the AGN/blazar (and other objects like pulsars and Galactic sources) populations and demography, with the advantage of possible serendipitous discoveries.

❑ Correlated variability studies at different energy bands (MW variability analysis), especially simultaneous, promise substantial progresses in gaining insights in the intrinsic AGN/blazar physics.

→ Next future for Fermi, major upgrades:

❑ Larger acceptance, better Point Spread Function at high energies and a wider energy range (going also below 100MeV) thanks to the next revolution represented by the Pass 8 full data reprocessing and new analysis will provide a dramatic improvement in Fermi LAT capability for time-domain high-energy GeV astronomy.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