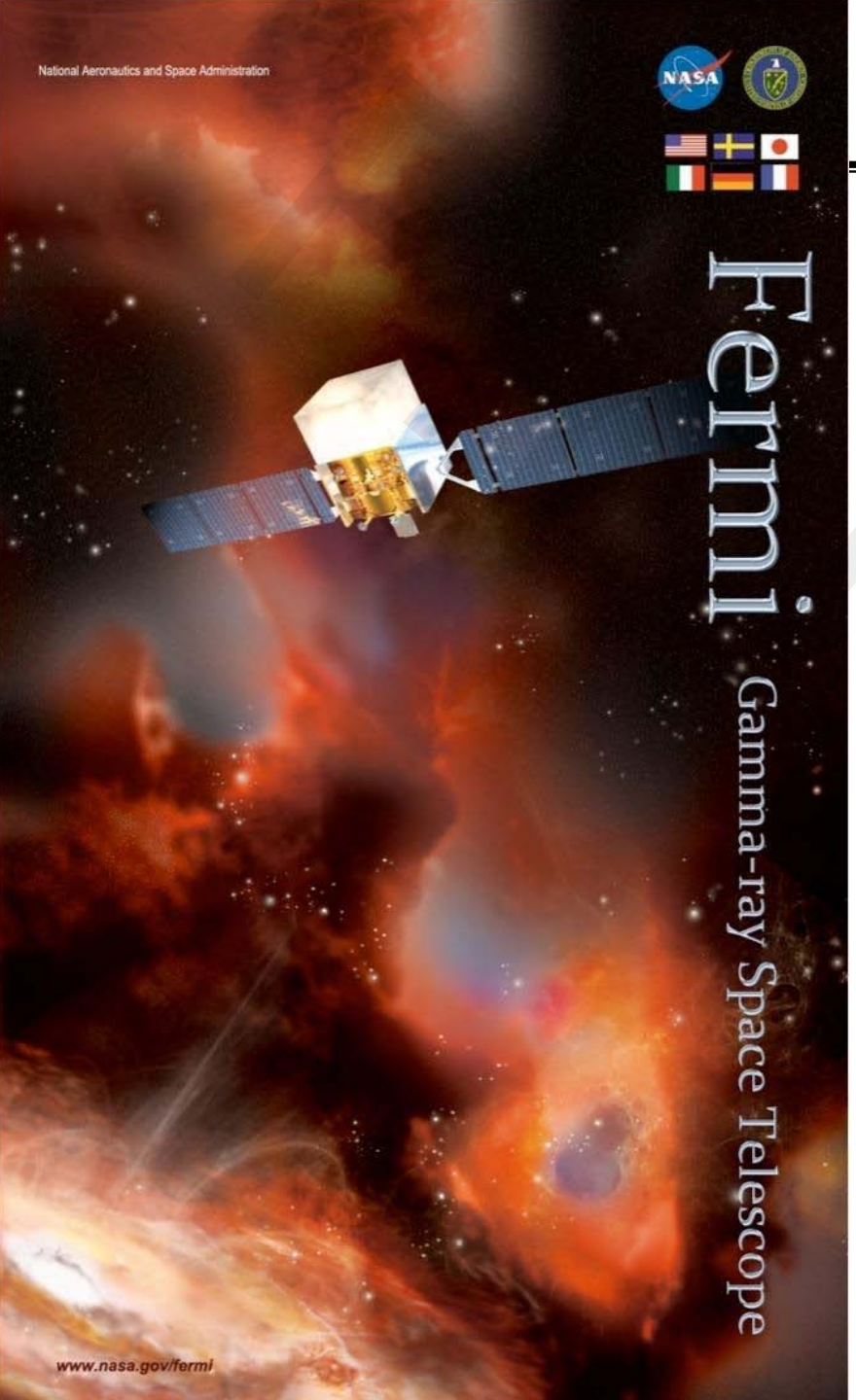
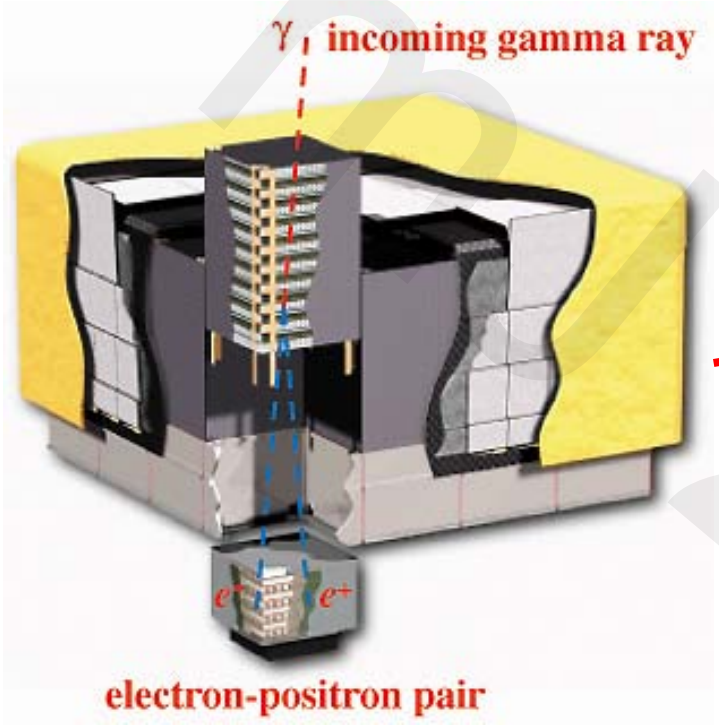


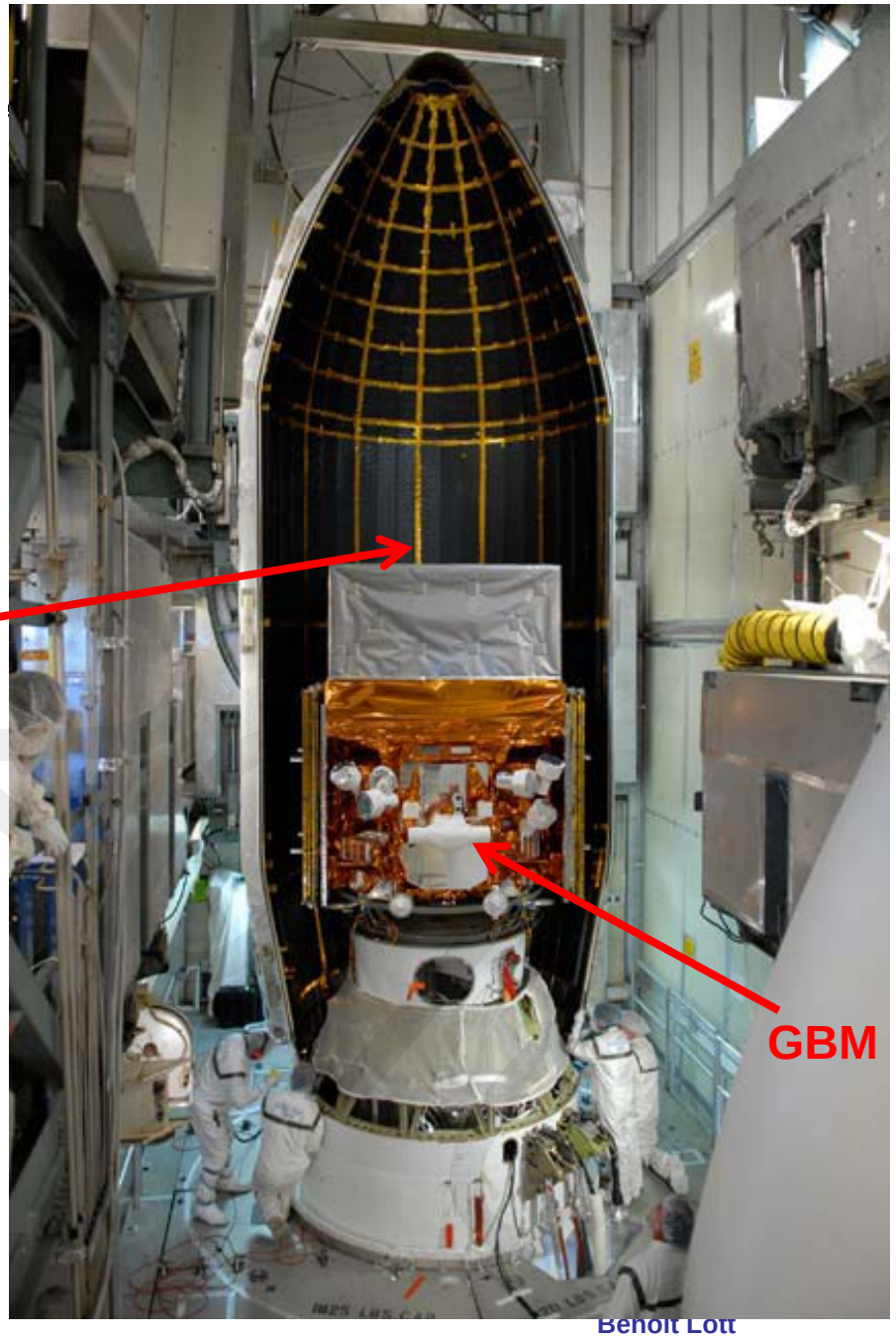
Blazars with the Fermi-LAT: General properties

Benoît Lott
CEN Bordeaux-Gradignan
lott@cenbg.in2p3.fr

on behalf of the *Fermi*-LAT collaboration

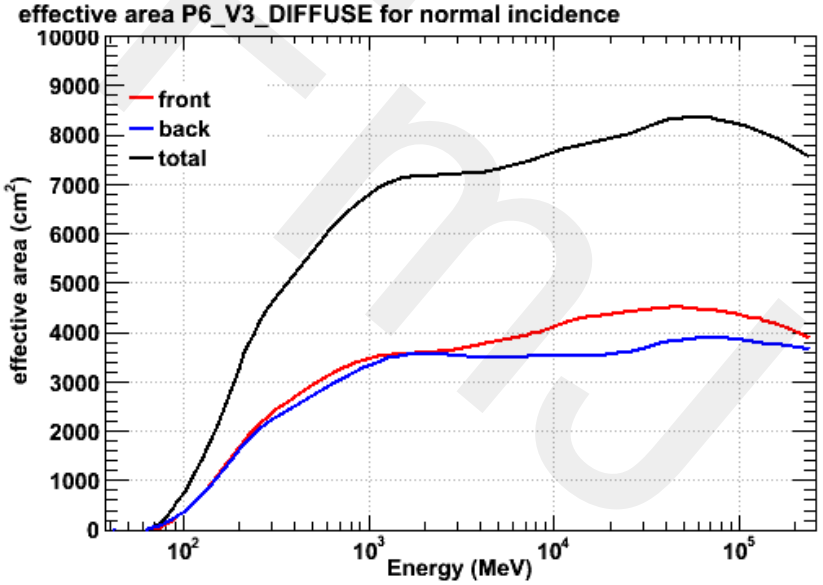
The Large Area Space Telescope

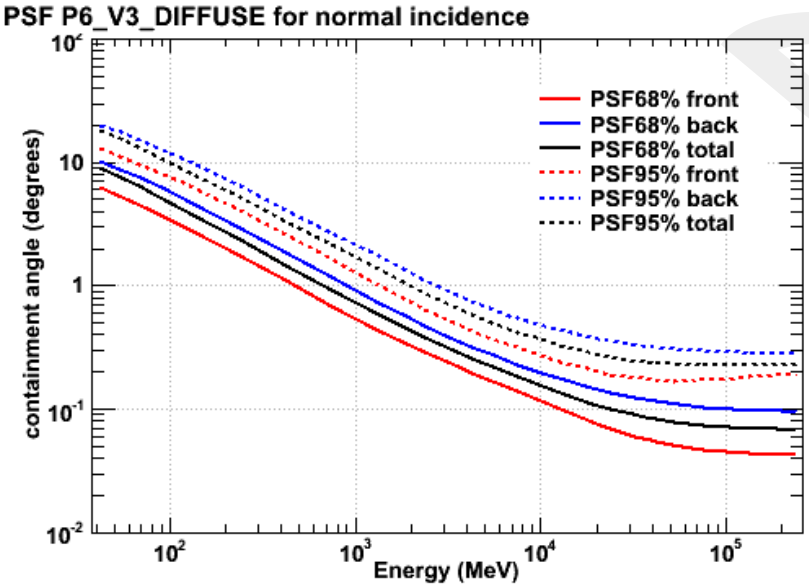




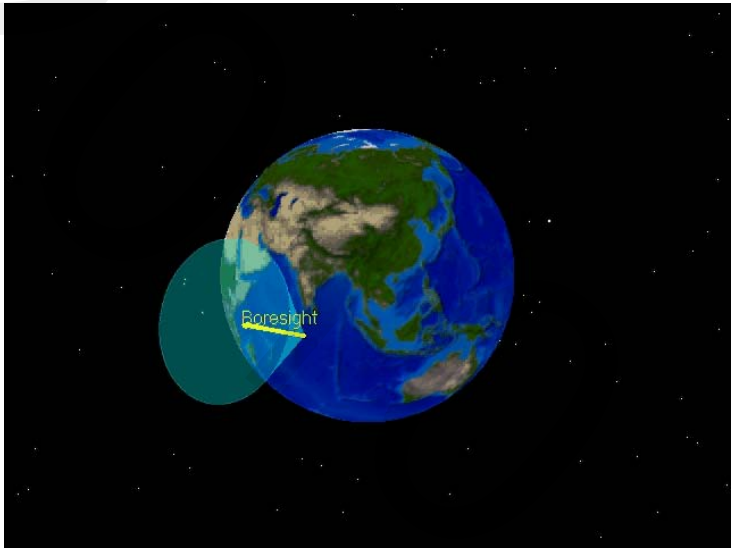
PI: Peter Michelson, Stanford

LAT performance

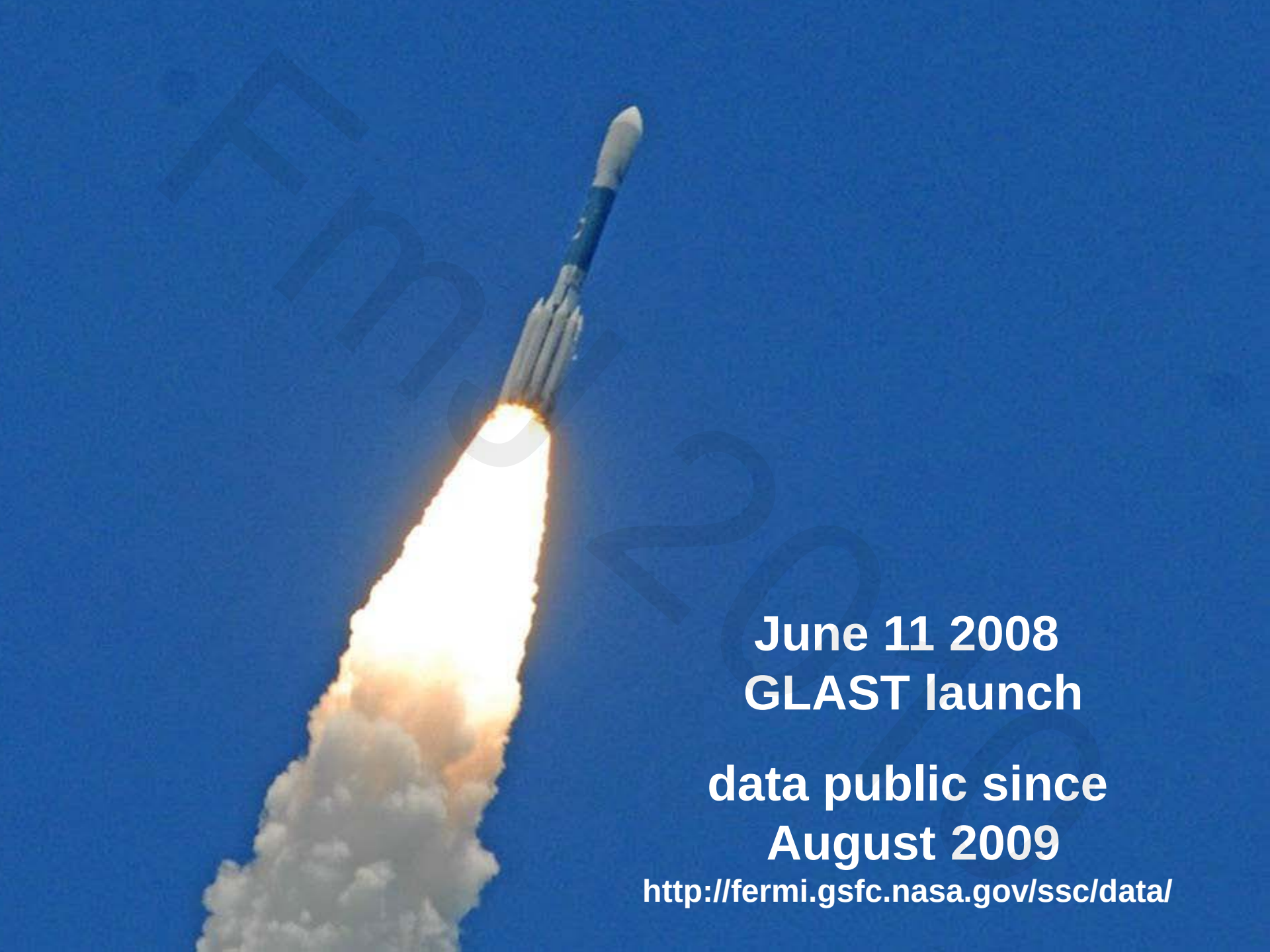




- energy range: 20 - 300 GeV
- large FOV: 2.4 sr
- Aeff:~8000 cm^2 at 1 GeV
- PSF: $\theta_{68\%}$~0.8° at 1 GeV
- altitude: 565 km
- orbital period: 91 min
- inclination: 25.6°
- whole sky covered in 2 orbits



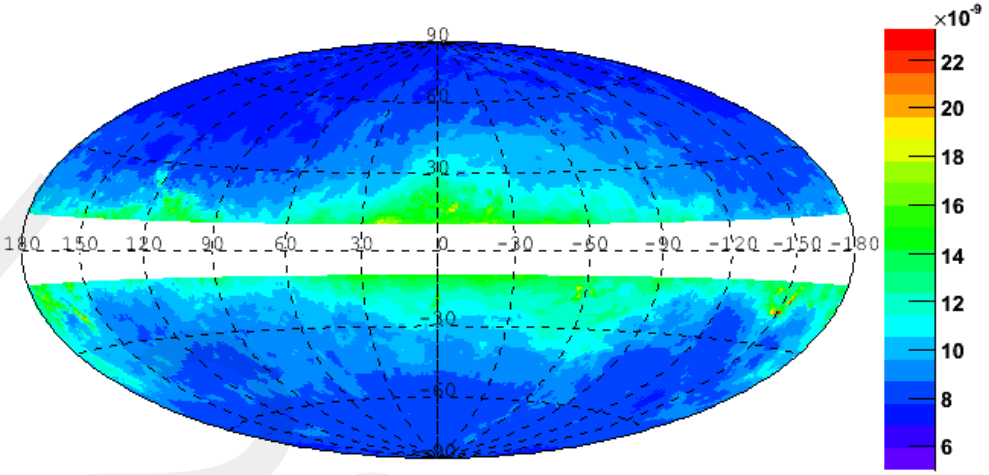
http://www-glast.slac.stanford.edu/software/IS/glast_lat_performance.htm


June 11 2008
GLAST launch
data public since
August 2009
http://fermi.gsfc.nasa.gov/ssc/data/

Assets for blazar science

- unprecedented sensitivity
- fairly uniform at high galactic latitude
- sky scanned every 3 hours in survey mode
- alerts issued shortly after transient or new flaring sources are detected

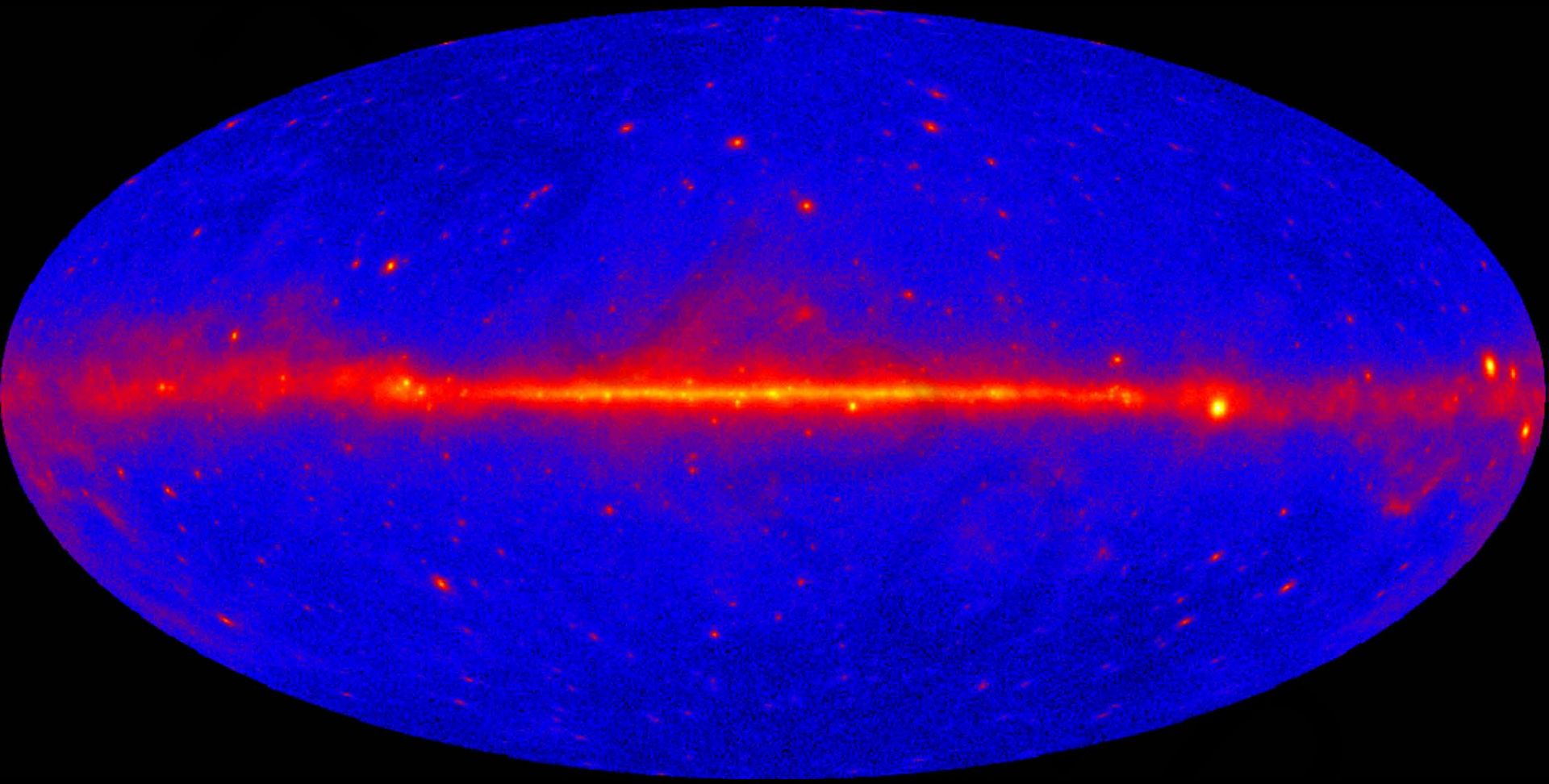
TS=25 sensitivity map (1 month, photon index=2.2)



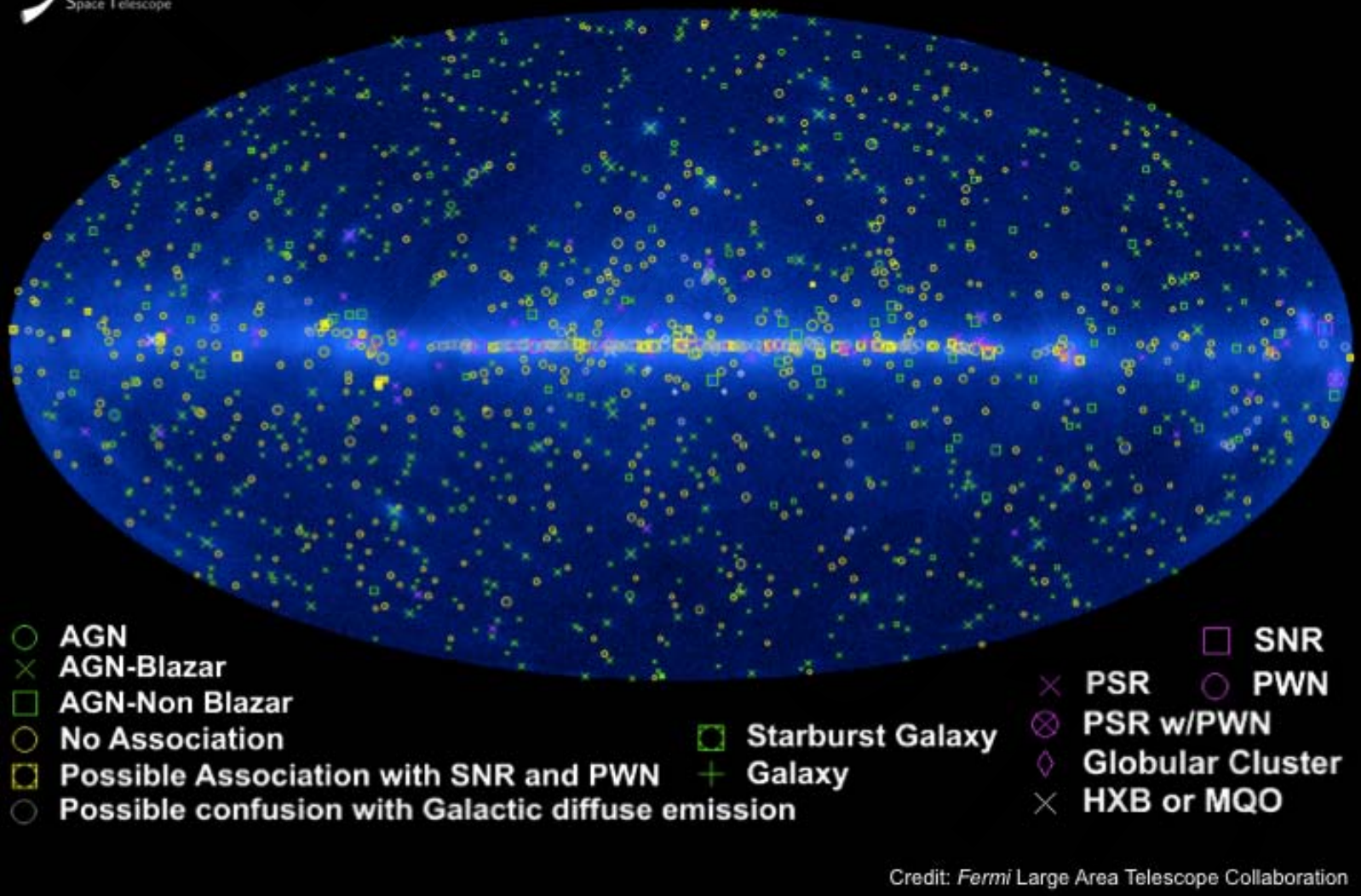
Flux(E>100 MeV) ph $cm^{-2}s^{-1}$

- continuous survey allows for source monitoring and variability studies on time scales ranging from months down to a few hours
- covers the little-explored 10-100 GeV domain
  - new spectral features at high energy discovered
  - identification of potential candidates of TeV sources (several discoveries)

1 year sky map



The Fermi LAT 1FGL Source Catalog



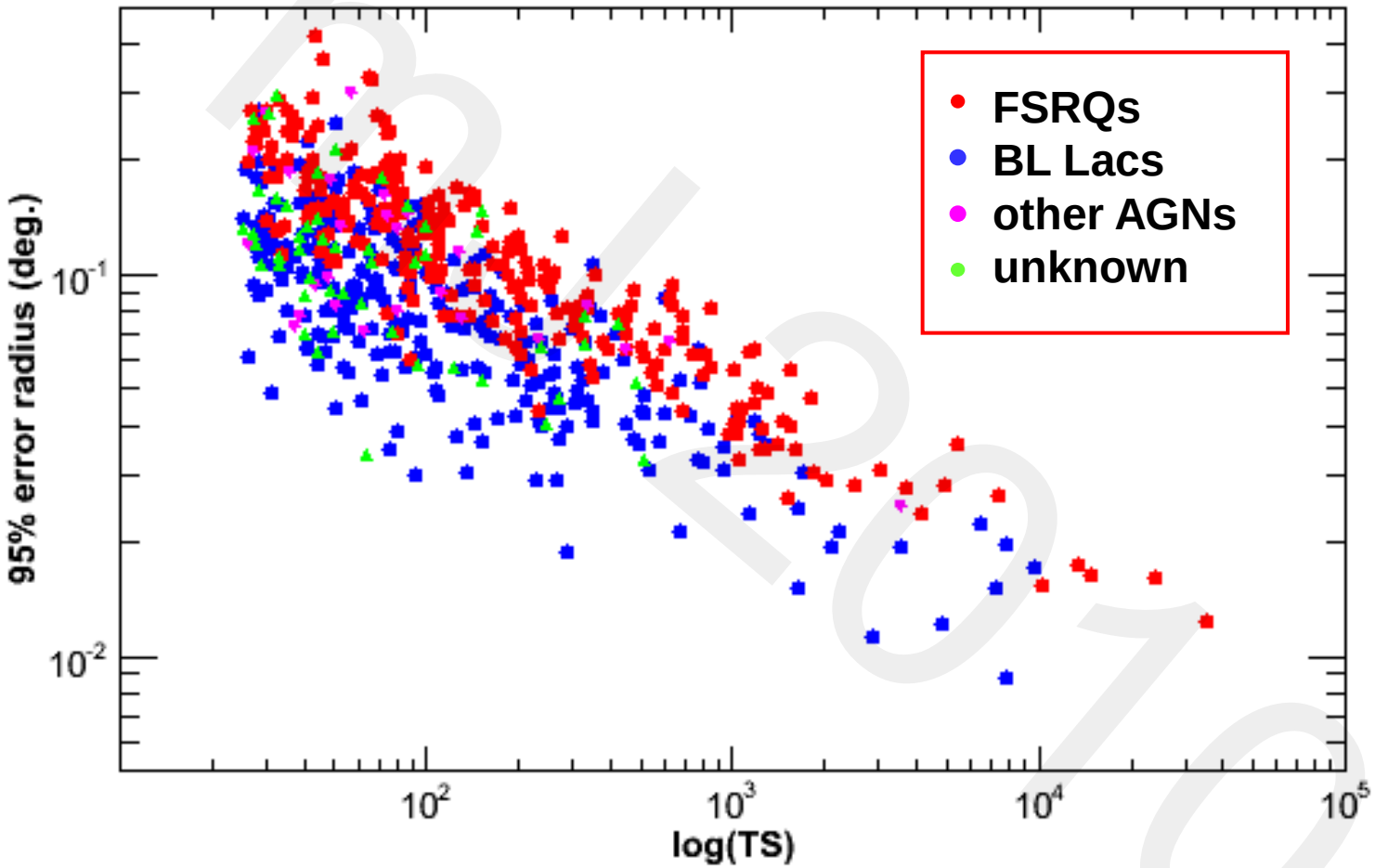
Credit: *Fermi* Large Area Telescope Collaboration

1451 sources with TS>25

The Fermi collaboration, 2010, ApJS, 188, 405, arXiv: 1002.2280

Populations

Position accuracy



mean 95% error radius for |b|>10° 1FGL sources: 0.15°

Associations

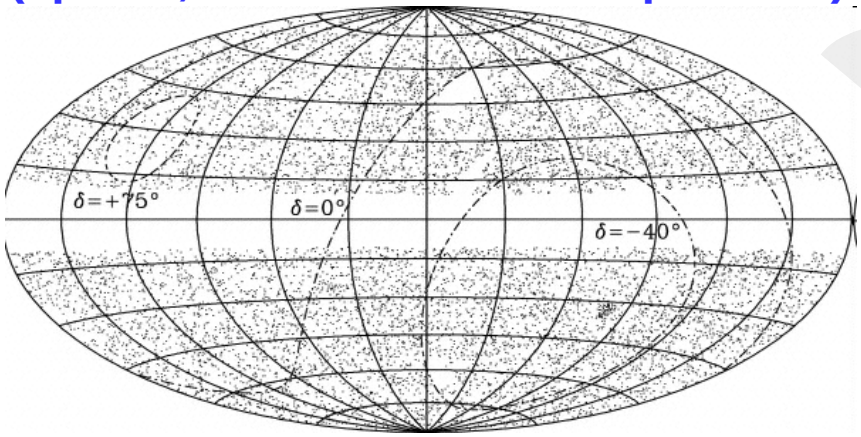
1FGL: **1049 sources with TS>25, |b|>10°**

Bayesian approach based on spatial coincidence (Mattox et al., 01)

CRATES-CGRaBS

(Healey et al. 08)

8.4 GHz survey of bright, flat-spectrum (α >-0.5) radio sources (11000 sources) + selected sources (1627) with high Figure-of-Merit (spatial, radio and X spectrum)

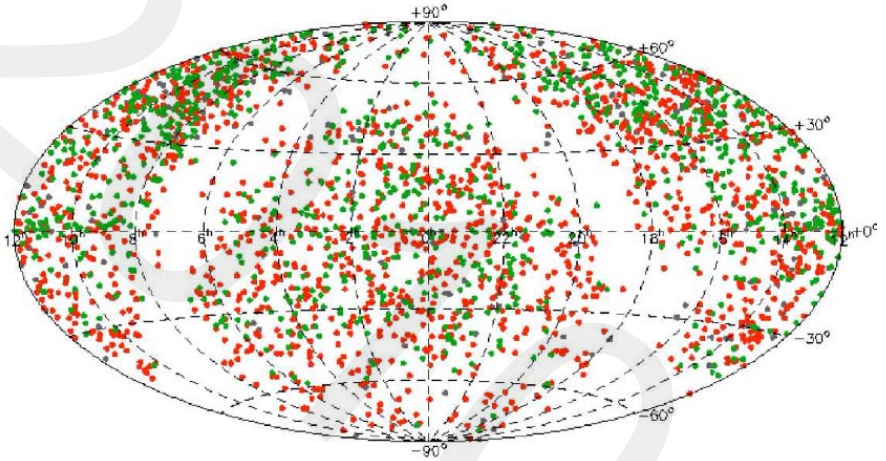


galactic

BZCat

(Massaro et al. 08)

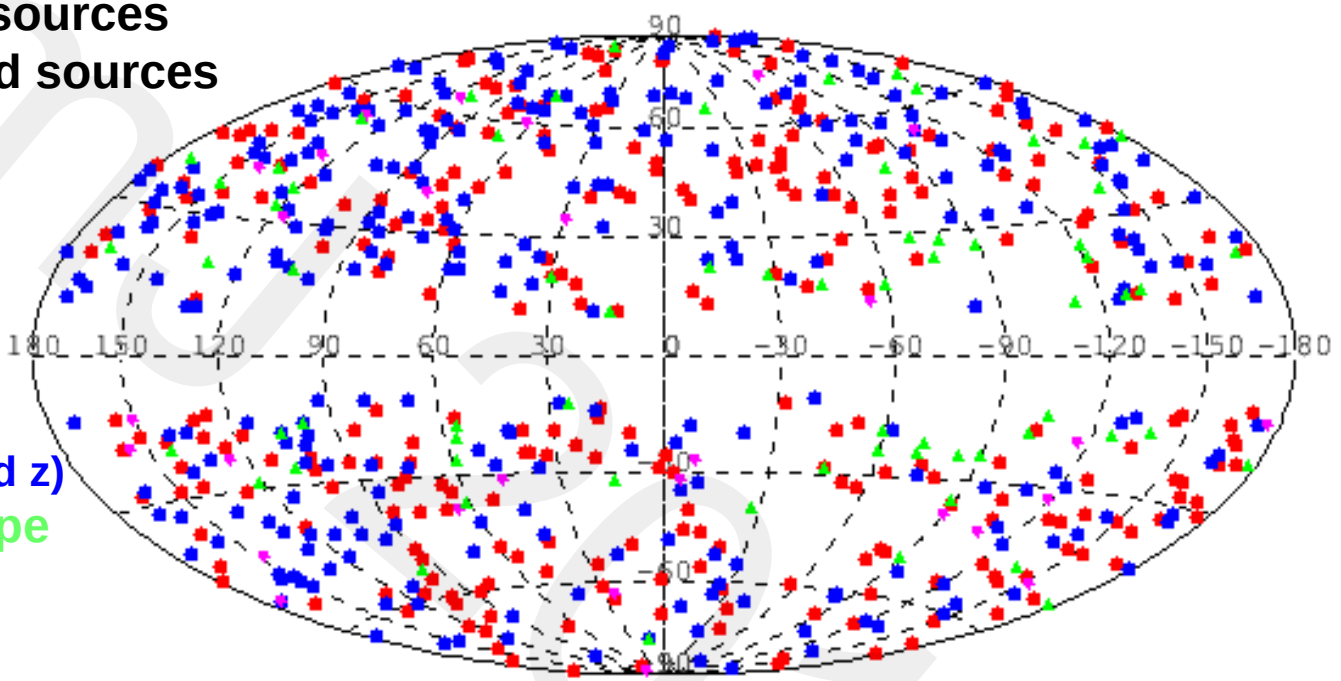
Compilation of 2500 known blazars, without any other conditions



celestial

The First LAT AGN catalog (1LAC)

- 11 month data set
- 1079 TS>25, |b|>10° sources
- 1LAC: 709 associated sources
- 663 high-confidence (P_{assoc}>80%) AGNs



- Census :
  - 281 FSRQs
  - 291 BLLacs (~141 with measured z)
  - 61 of unknown type
  - 30 other AGNs

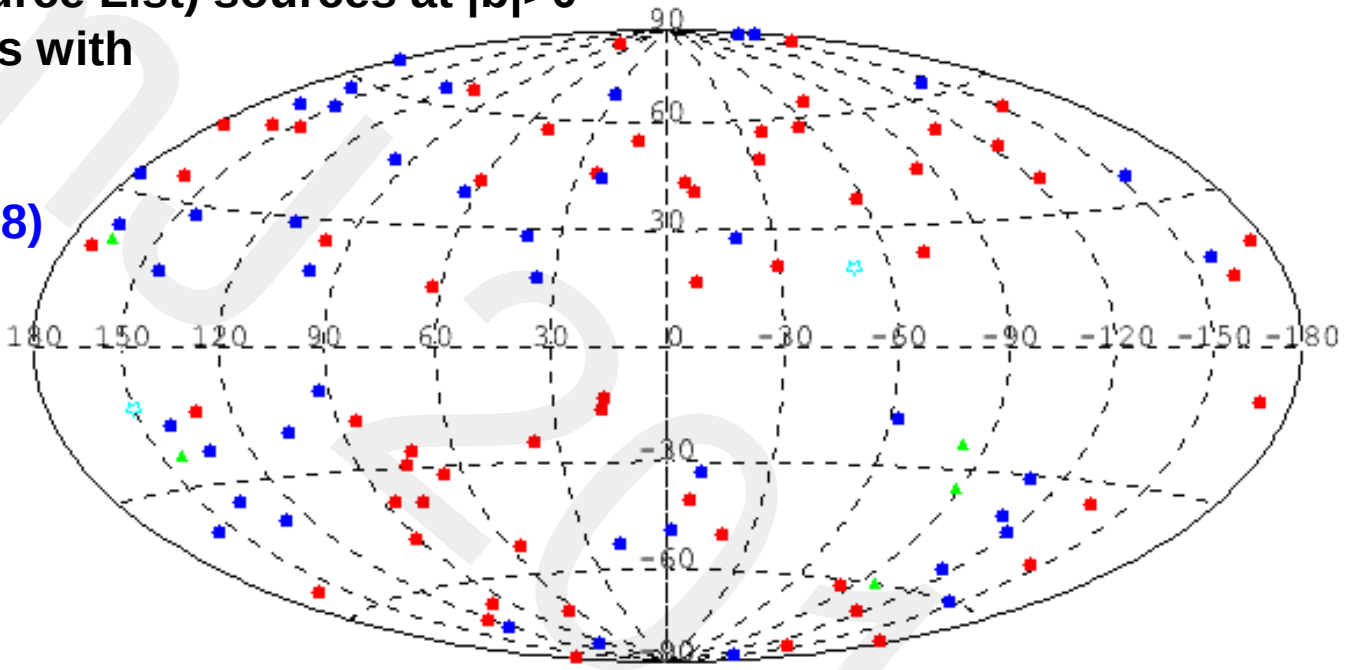
- « Clean sample »: 599 sources
- 109 « affiliations » (104 1LAC sources)

The First Catalog of Active Galactic Nuclei Detected by the Fermi LAT
Abdo, A. A. et al. 2010, ApJ, 715, 429

The LAT Bright AGN Sample (LBAS)

- 3-month dataset, TS>100

- 132 0FGL (Bright Source List) sources at |b|>0°
- 116 AGN associations with
  - CGRaBS-CRATES (Healey+ 08)
  - BZCat (Massaro+ 08)



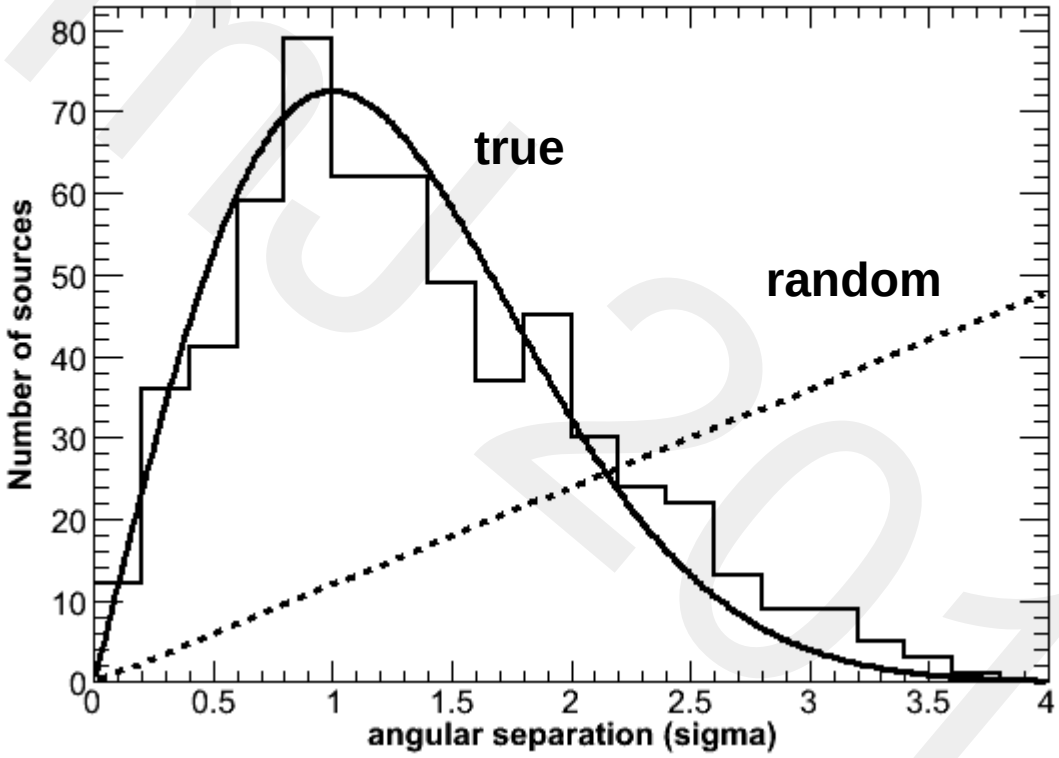
- 106 high-confidence associations:
- 58 FSRQs
- 42 BLLacs (40%)
  10 HSPs
- 2 Radio Galaxies
  Cen A, NGC1275
- 4 of Unknown type

Abdo A. A. et al. 2009 ApJ 700, 597

EGRET sources: only 30%

Angular separation

Bayesian approach to determine possible counterparts from an existing catalog of sources detected at other wavelengths (typically radio)

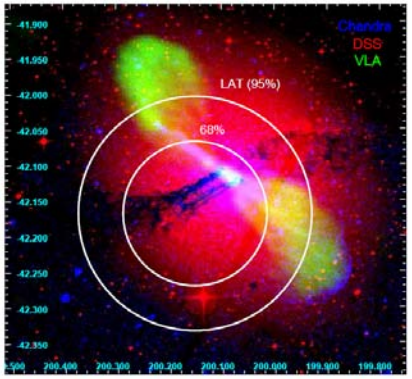


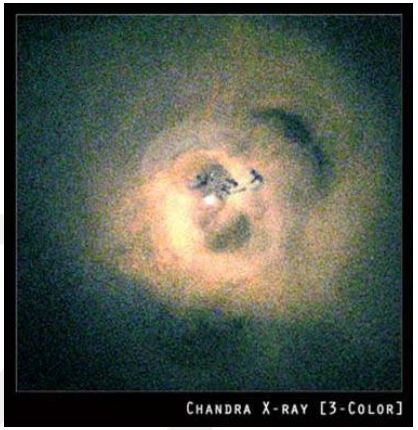
Distance between LAT source and AGN counterpart normalized to the 68% containment radius
11 spurious associations expected in 1LAC clean sample

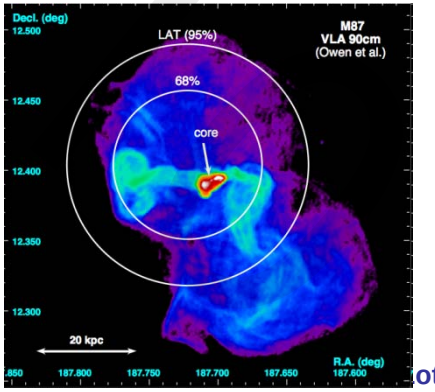
Other AGNs

- Cen A
- NGC 1275
- M 87
- 3 other radio galaxies
  - –NGC 1218 = 3C 7, PKS 0625-35, NGC6251
- 2 steep-spectrum radio quasars:
  - –3C 207, 3C 380
- 5 narrow-line radio galaxies (NLRGs):
  - –4C +15.05,PKS 1106+023,
    CGRaBS J1330+5202, 4C +15.54,
    CGRaBSJ2250-2806
- 4 Radio-loud narrow-line Seyfert 1
  - –PMN J0948+0022,B2 0321+33B,
    PKS 1502+036, PKS 2004−447

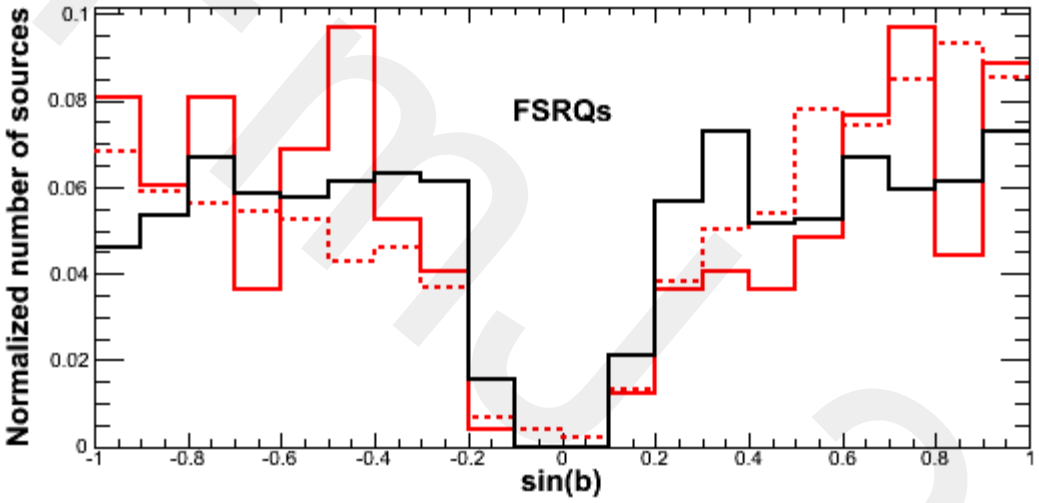
See T. Cheung's talk

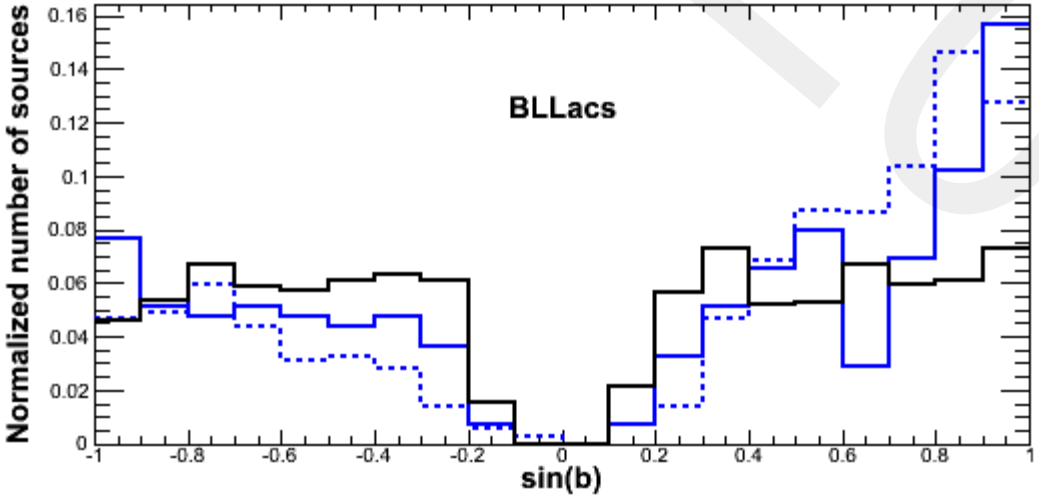






Galactic latitude distributions





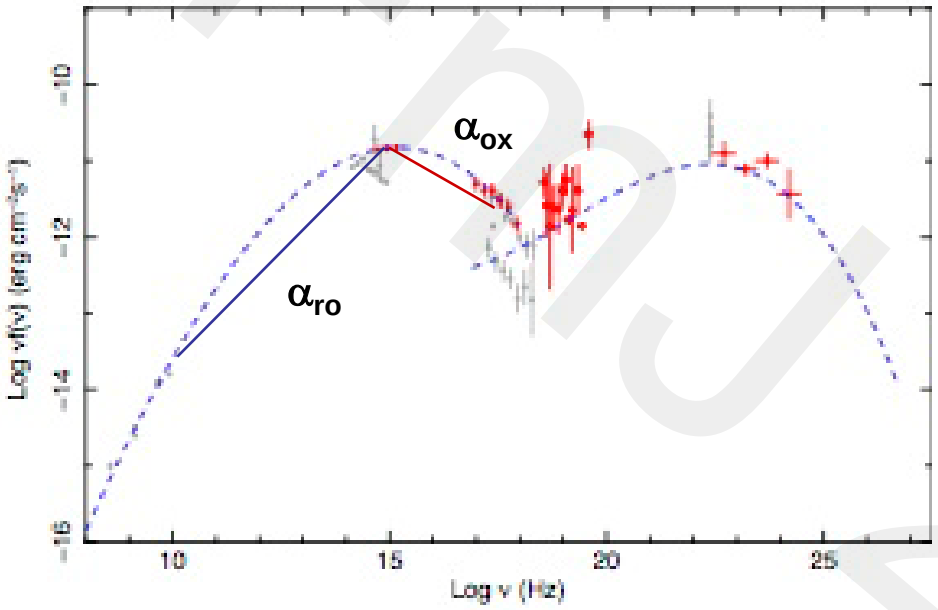
LAT sources
LAT blazars
BZCat blazars

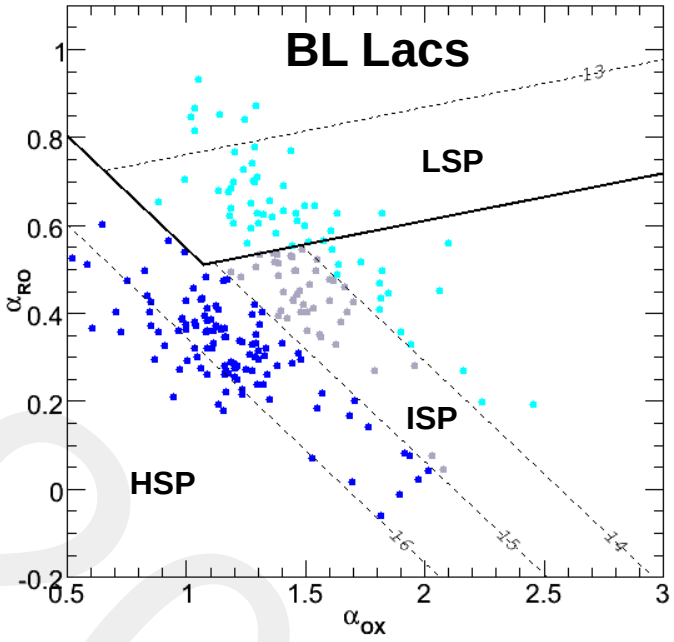
Differences between Northern and Southern Hemispheres
FSRQs: 4%
BL Lacs: 18%

Incompleteness of parent catalogs

SED-based classification

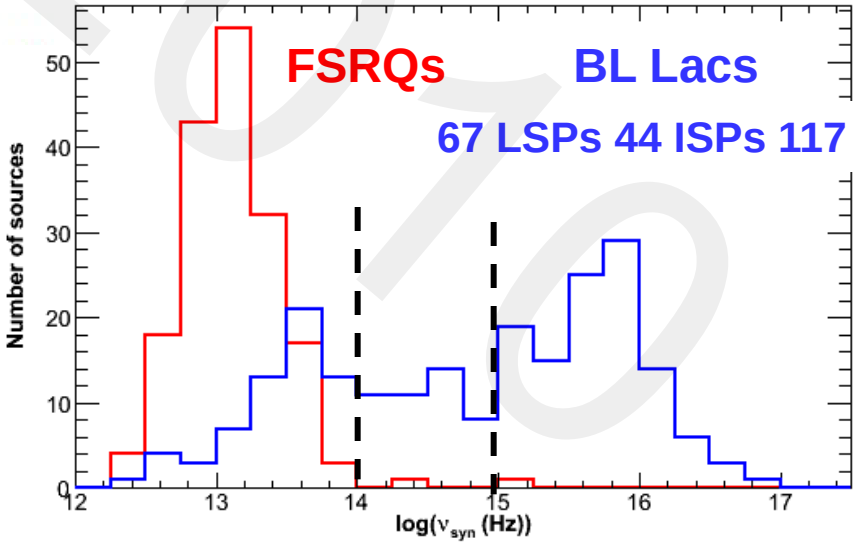
Abdo, A. A. et al. 2010, ApJ, 716, 30



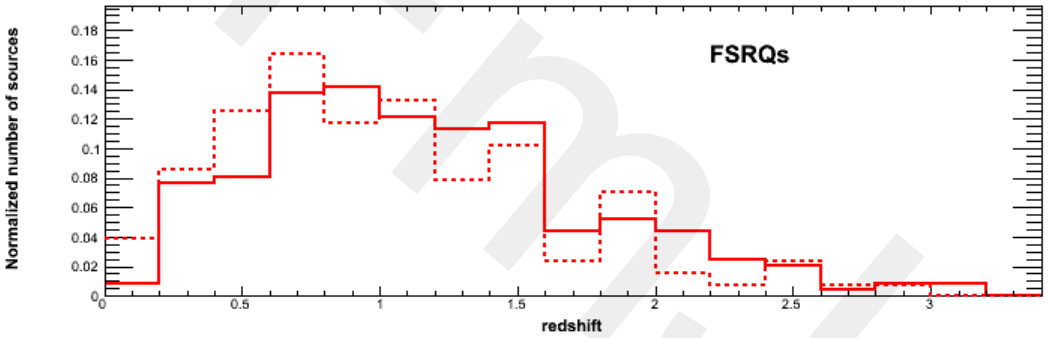


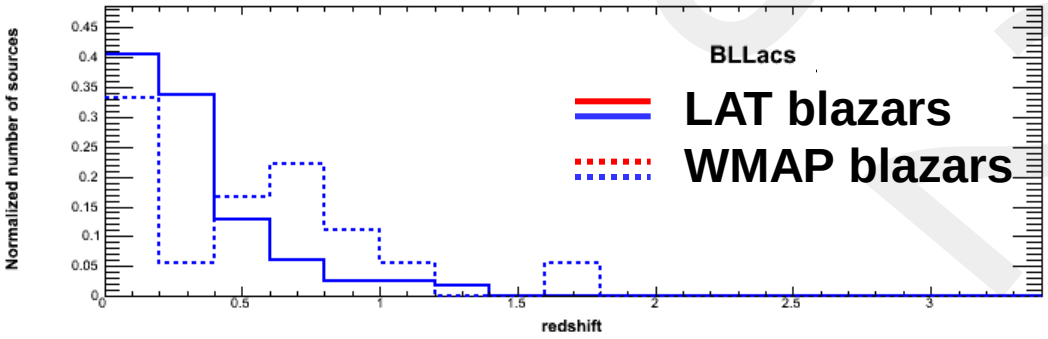
- **relation with ν_{syn} estimated from α_{ox}, α_{ro}**
- **subclasses assigned from ν_{syn} LSP, ISP, HSP: low-, intermediate-, high-synchrotron peaked blazars, resp.**
  - **LSP: $\log(\nu_{syn}) < 14$**
  - **ISP: $14 < \log(\nu_{syn}) < 15$**
  - **HSP: $\log(\nu_{syn}) > 15$**

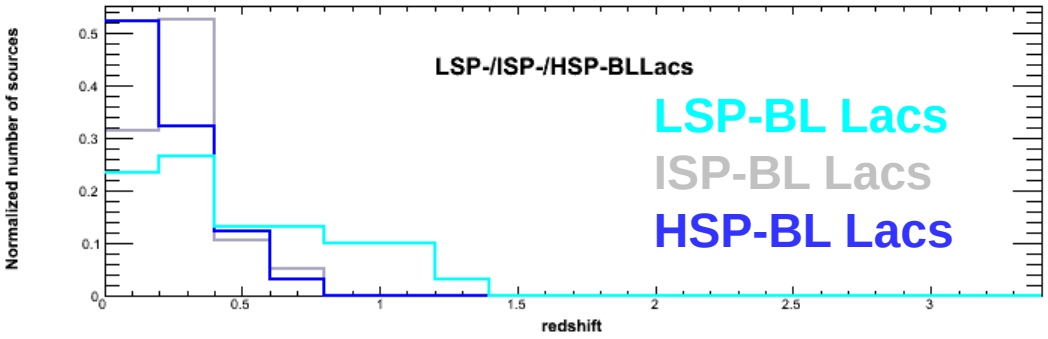
with ν_{syn} in Hz



Redshift distributions



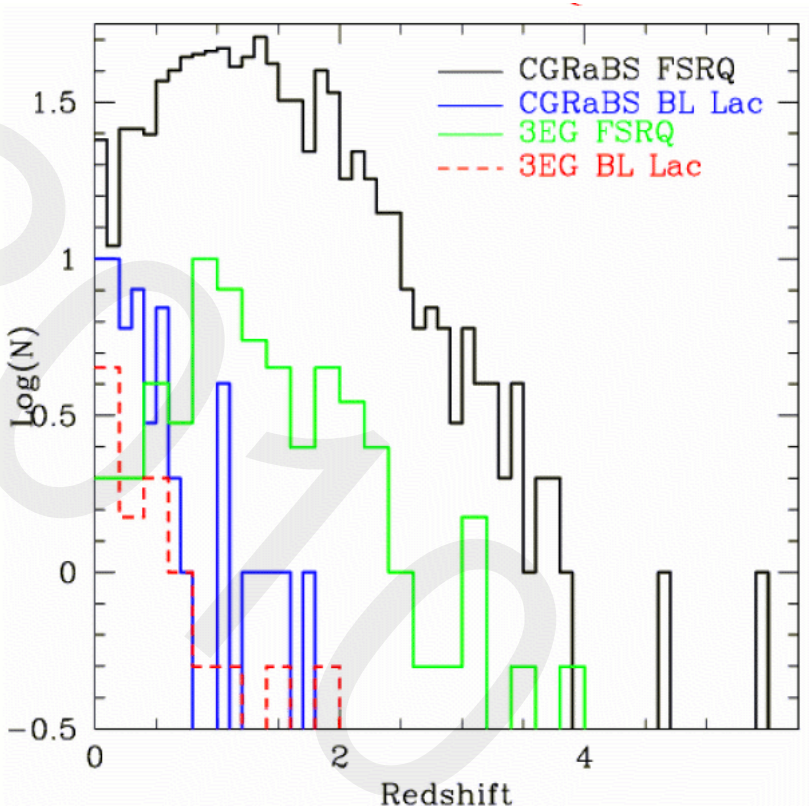




Distributions similar to LBAS

z_{max} for FSRQs: 3.1

(BAT: 40% of FSRQs are at z>2)



Comparison with other bands

EGRET sources
``positionally coincident'': separation < quadratic sum of 95% error radii.

63 AGNs correspond to 3EG sources (51 identifications and 4 associations).
11 identified EGRET AGNs without 1LAC counterparts.
45 1LAC sources in the revised EGRET catalog
22 sources in the high-energy EGRET catalog.
75 1LAC sources have counterparts in **one of the 3 EGRET catalogs**.
(All EGRET AGNs with significance >10σ)

AGILE sources
All 11 blazars

Total of 77 1LAC sources cataloged by other GeV instruments:
49 FSRQs, 21 BL Lacs, four AGNs of other types, and three AGNs of unknown types.

Hard X-ray sources
4th IBIS catalog (17-100 keV) : 291 sources at |b|>10°
54-month Palermo BAT catalog (14-150 keV) : 736 sources at |b|>10°

50 1LAC associated with known hard X-ray sources.
27 FSRQs, 16 BL Lacs, and 7 AGNs of other types

GeV-TeV connection in 1LAC

- **28/32 TeV AGNs in 1LAC**
- **3 more than in the initial « Fermi observations of TeV-selected AGN » based on 5.5-month data**
- **their hard spectra facilitates the detection by the LAT**

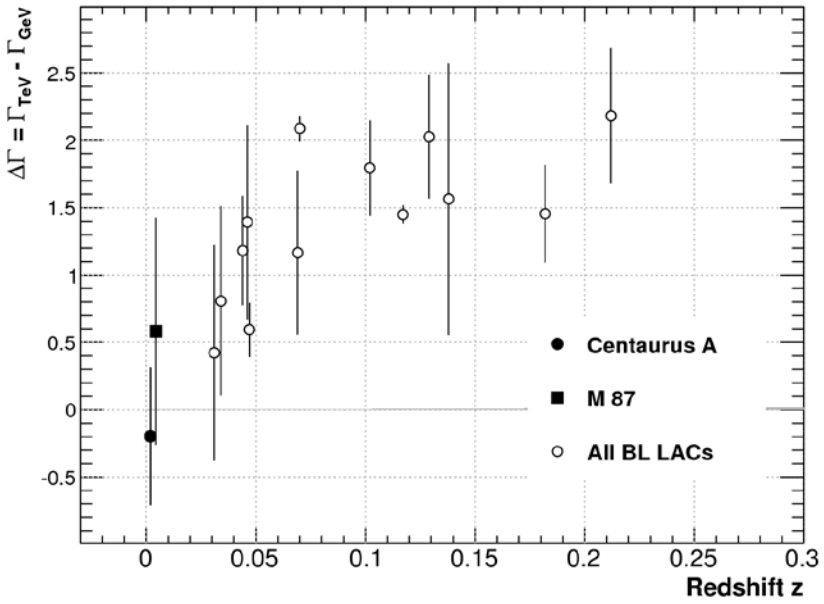


Table 5. Positional coincidences of 1LAC sources with TeV sources

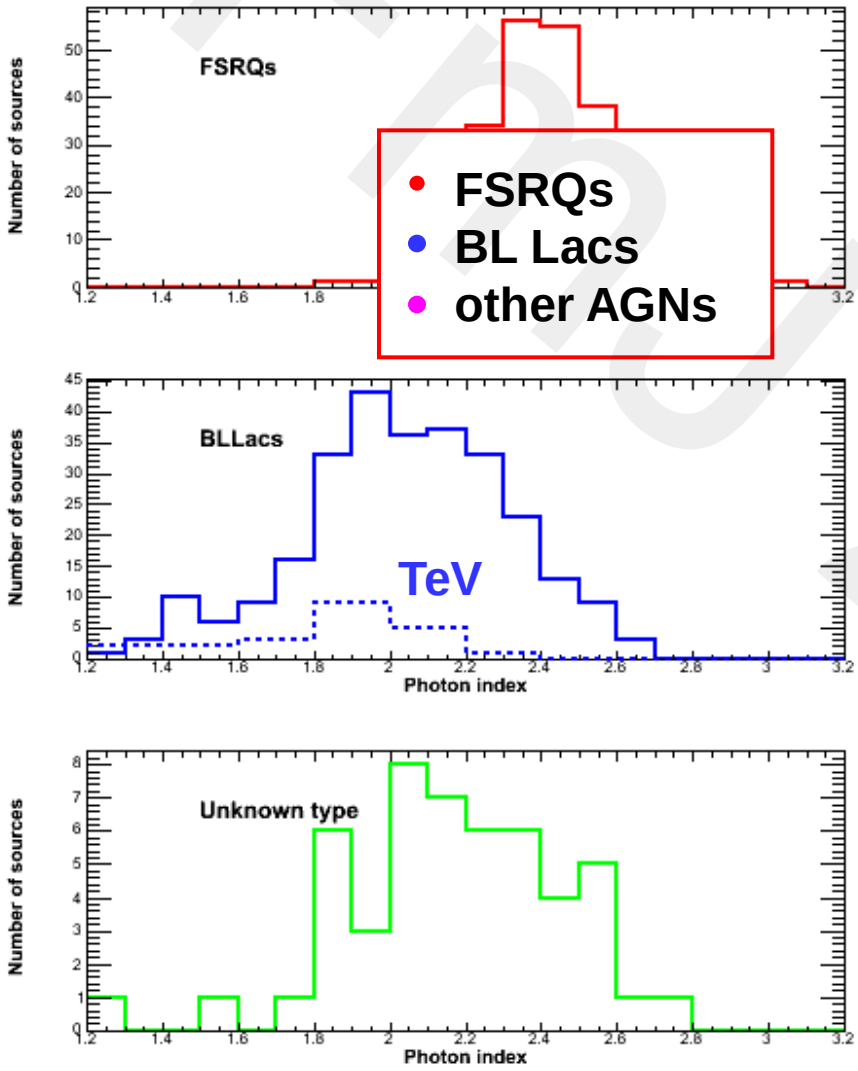
LAT Source	TeV Association	RA[a]	DEC[a]
1FGL J0222.6+4302	3C 66A	35.8000	43.0117
1FGL J0319.7+1847	RBS 0413	49.9658	18.7594
1FGL J0416.8+0107	1ES 0414+009	64.2184	1.0901
1FGL J0449.5−4350	PKS 0447−437	72.3529	−43.8358
1FGL J0507.9+6738	1ES 0502+675	76.9842	67.6233
1FGL J0521.7+2114[b]	VER J0521+211[b]	80.4792	21.1900
1FGL J0710.6+5911	RGB J0710+591	107.6254	59.1390
1FGL J0721.9+7120	S5 0716+714	110.4725	71.3433
1FGL J0809.5+5219	1ES 0806+524	122.4550	52.3161
1FGL J1015.1+4927	1ES 1011+496	153.7671	49.4336
1FGL J1103.7−2329	1ES 1101−232	165.9083	−23.4919
1FGL J1104.4+3812	Mkn 421	166.1138	38.2089
1FGL J1136.6+7009	Mkn 180	174.1100	70.1575
1FGL J1221.3+3008	1ES 1218+304	185.3413	30.1769
1FGL J1230.8+1223	M 87	187.7058	12.3911
1FGL J1221.5+2814	W Com	185.3821	28.2331
1FGL J1256.2−0547	3C 279	194.0463	−5.7894
1FGL J1325.6−4300	Cen A	201.3667	−43.0183
1FGL J1426.9+2347	PKS 1424+240	216.7516	23.8000
1FGL J1428.7+4239	H 1426+428	217.1358	42.6725
1FGL J1555.7+1111	PG 1553+113	238.9292	11.1900
1FGL J1653.9+3945	Mkn 501	253.4675	39.7600
1FGL J2000.0+6508	1ES 1959+650	299.9996	65.1486
1FGL J2009.5−4849	PKS 2005−489	302.3721	−48.8219
1FGL J2158.8−3013	PKS 2155−304	329.7196	−30.2217
1FGL J2202.8+4216	BL Lac	330.6804	42.2778
1FGL J2347.1+5142[b]	1ES 2344+514[b]	356.7700	51.7050
1FGL J2359.0−3035	H 2356−309	359.7875	−30.6228

[a]J2000 coordinate, in degrees, from TeVCat (http://tevcat.uchicago.edu/).

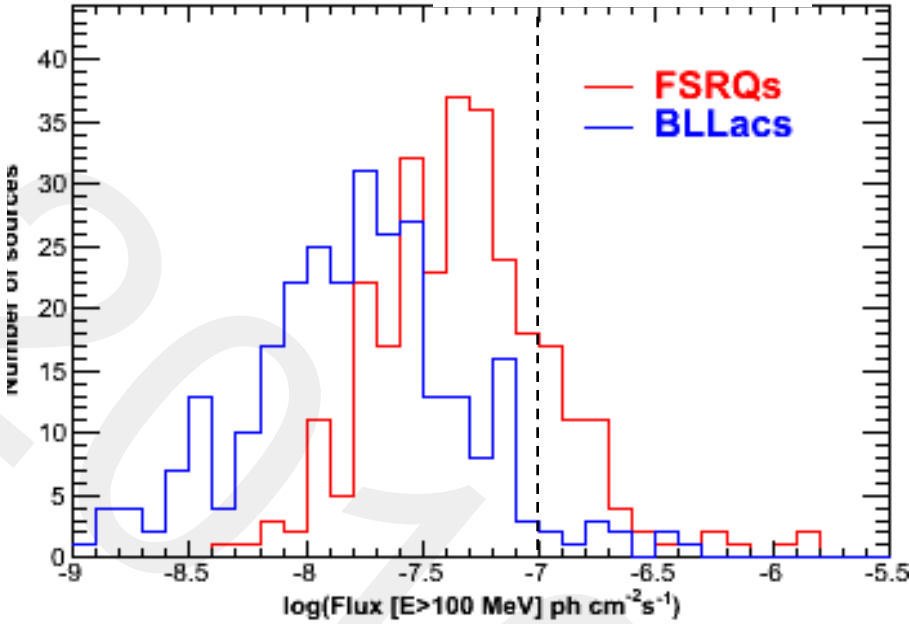
[b]This source is at low Galactic latitude ($|b| < 10°$) and is thus not formally in the 1LAC but appears in Table 2.

Spectral/flux/luminosity properties in the γ-ray band

Photon index – Flux distributions



3EG flux limit



Mean/Peak Flux distributions

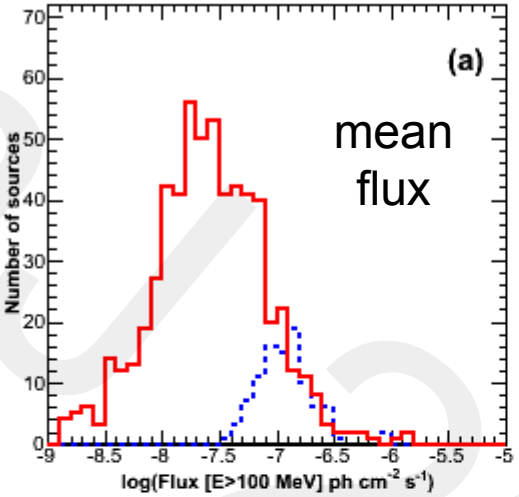
Fermi
EGRET

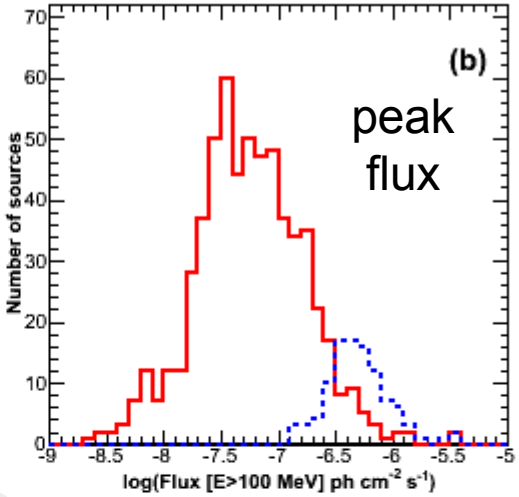
EGRET mean flux
« 1234 VP»

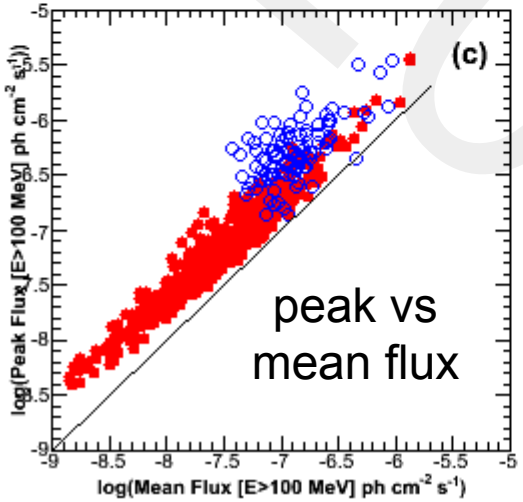
EGRET peak flux:
maximum in 2-w VPs

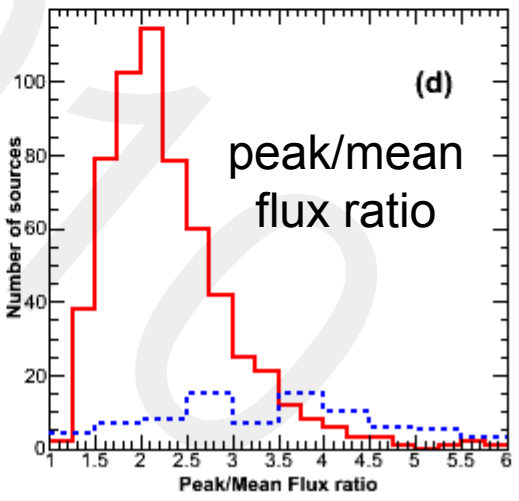
Fermi mean flux:
11-m averaged

Fermi peak flux:
maximum in 1-m periods

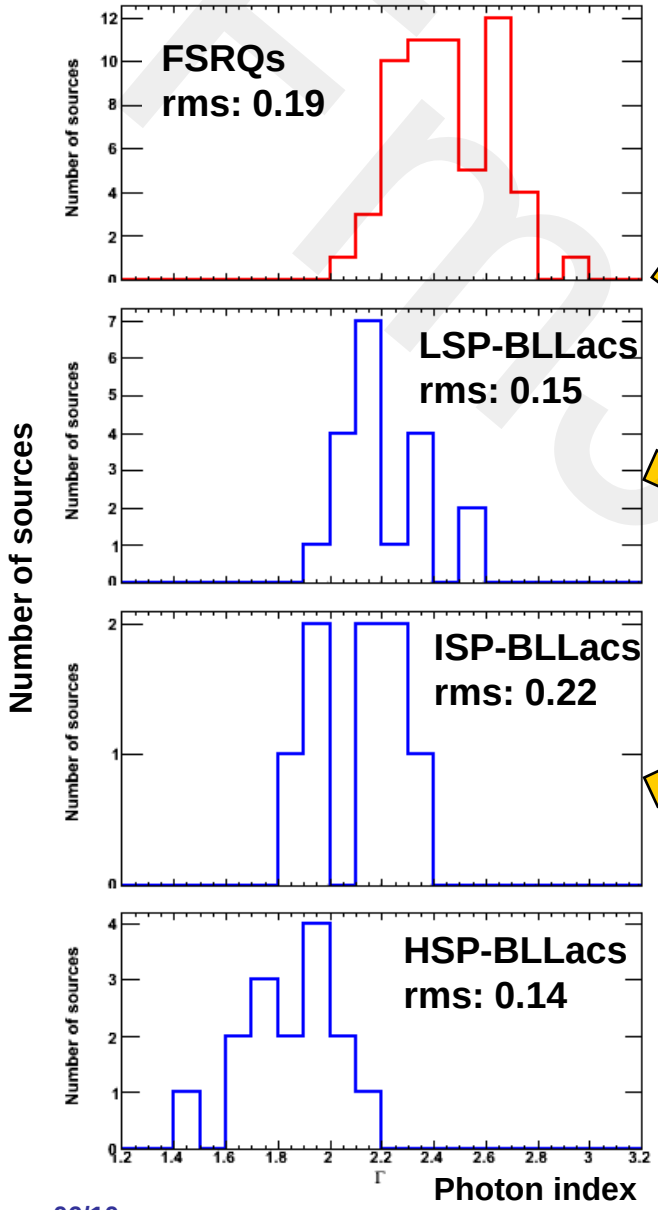




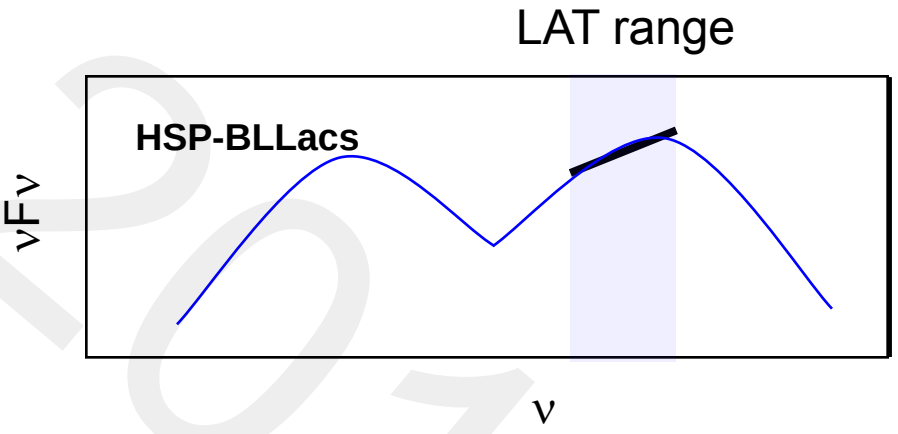




Photon index distributions in LBAS

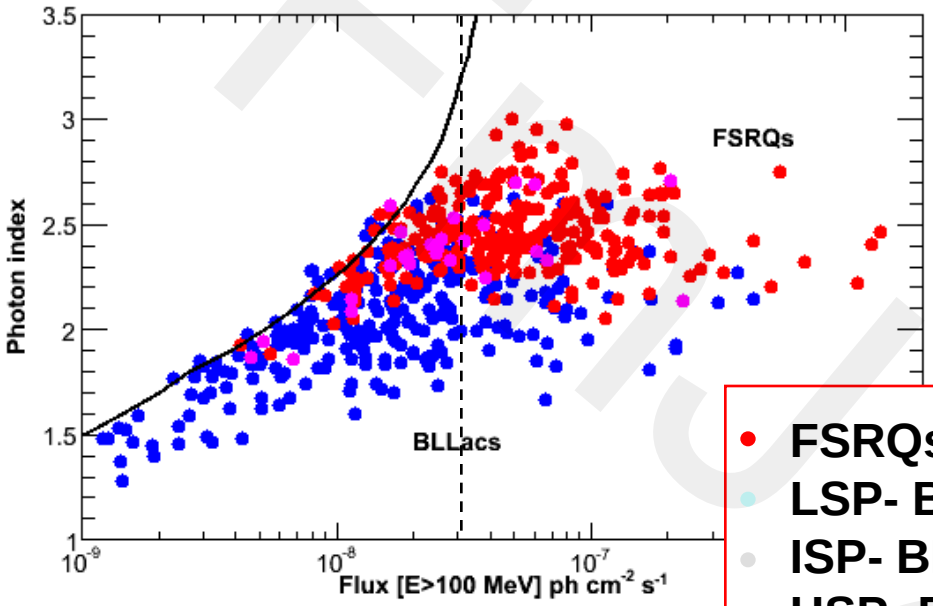


Photon index determined with the first 6-month data set

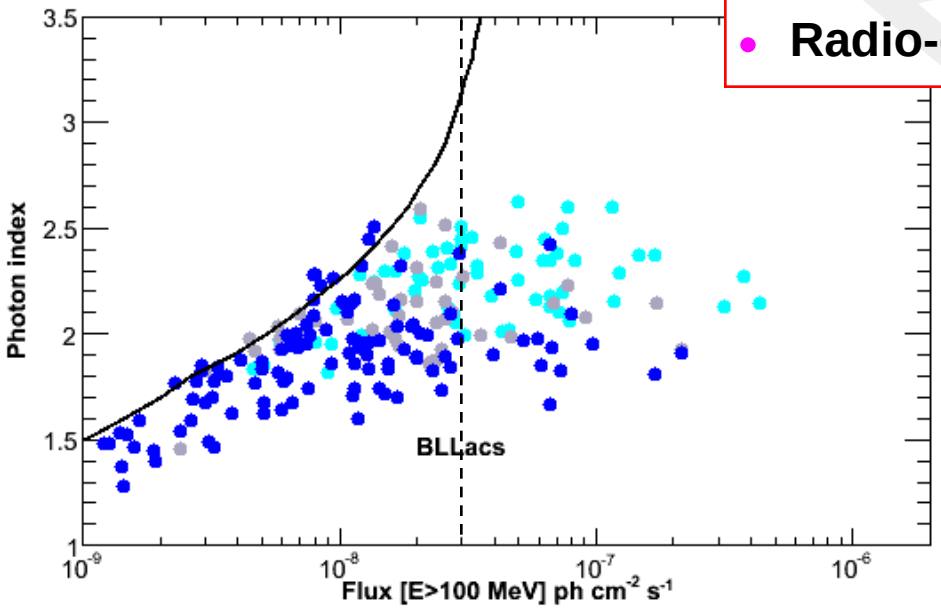


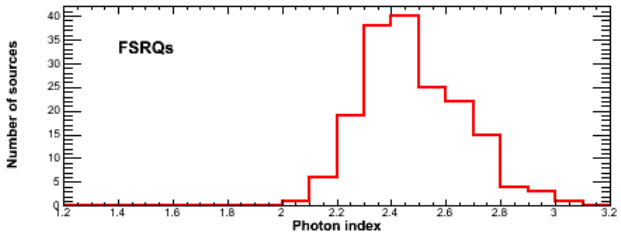
- **Strong correlation between photon index and blazar class**
- **Narrow distributions point to a small numbers of parameters driving the blazar SEDs**

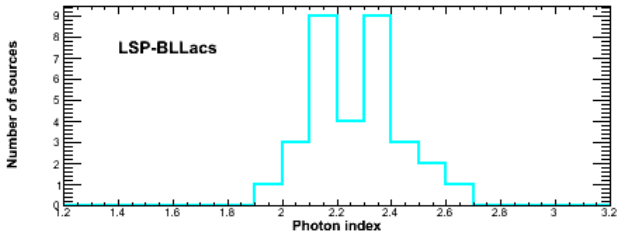
Photon index distributions

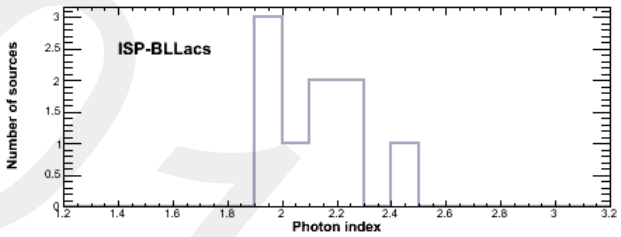


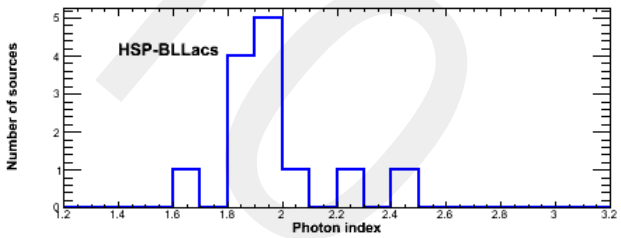
- FSRQs
- LSP- BL Lacs
- ISP- BL Lacs
- HSP- BL Lacs
- Radio-galaxies







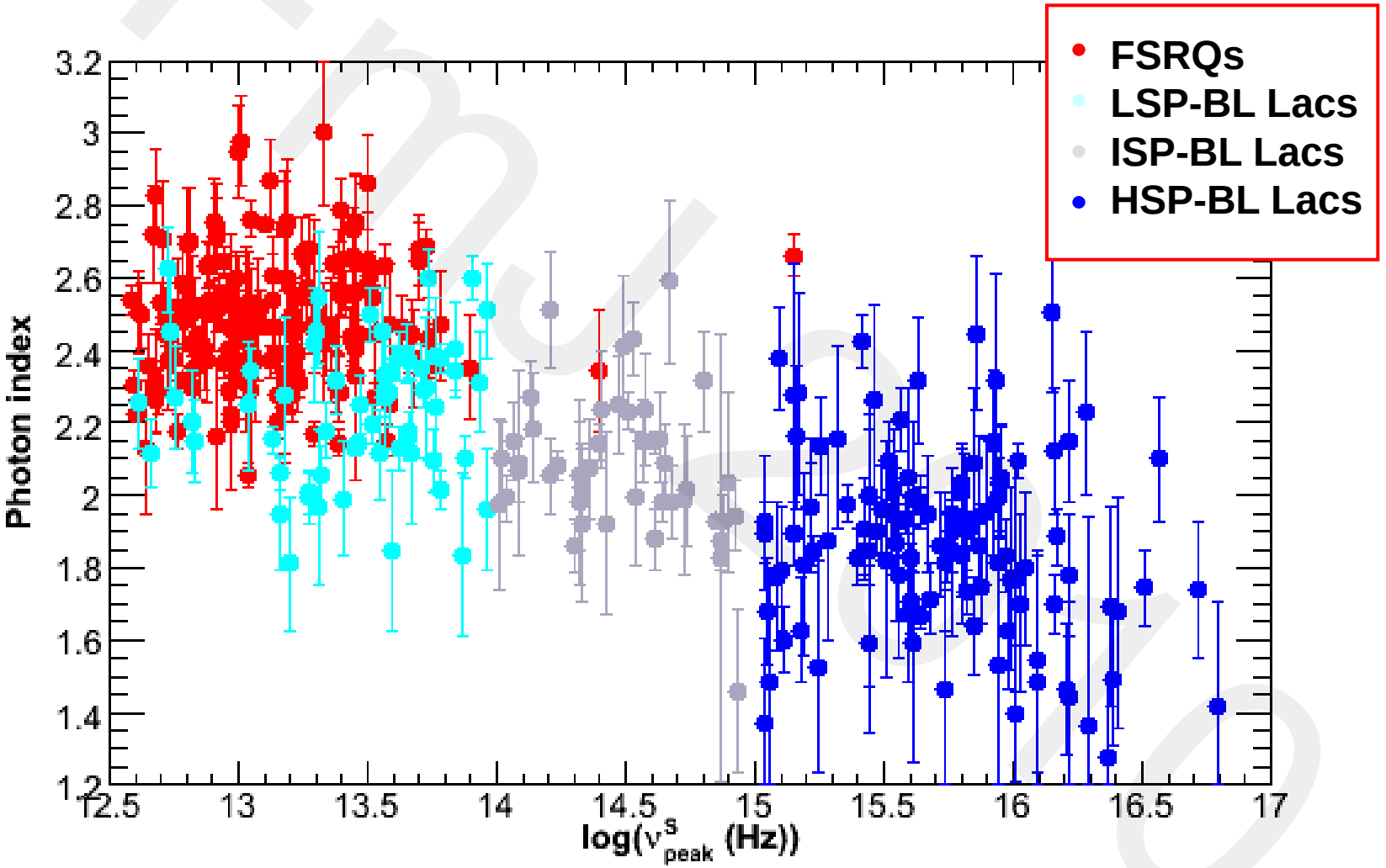




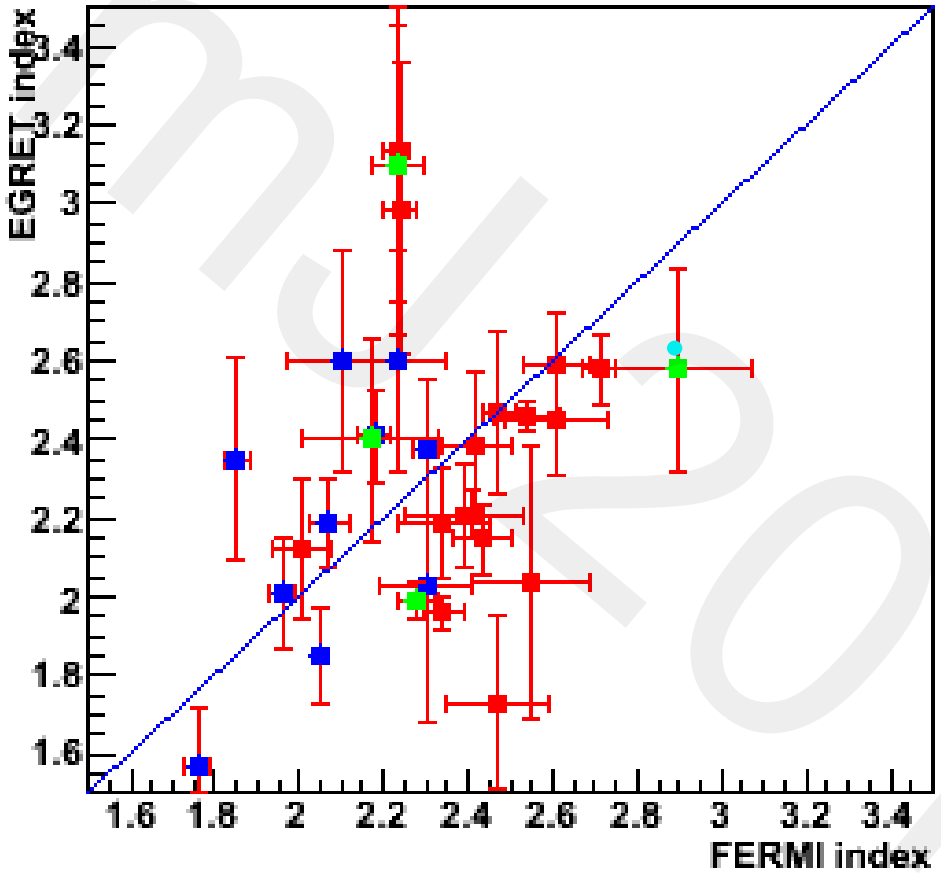
$F > 3 \times 10^{-8}$ ph cm^{-2}s^{-1}

Benoit Lott

Photon index vs ν_{peak}



EGRET vs FERMI photon index



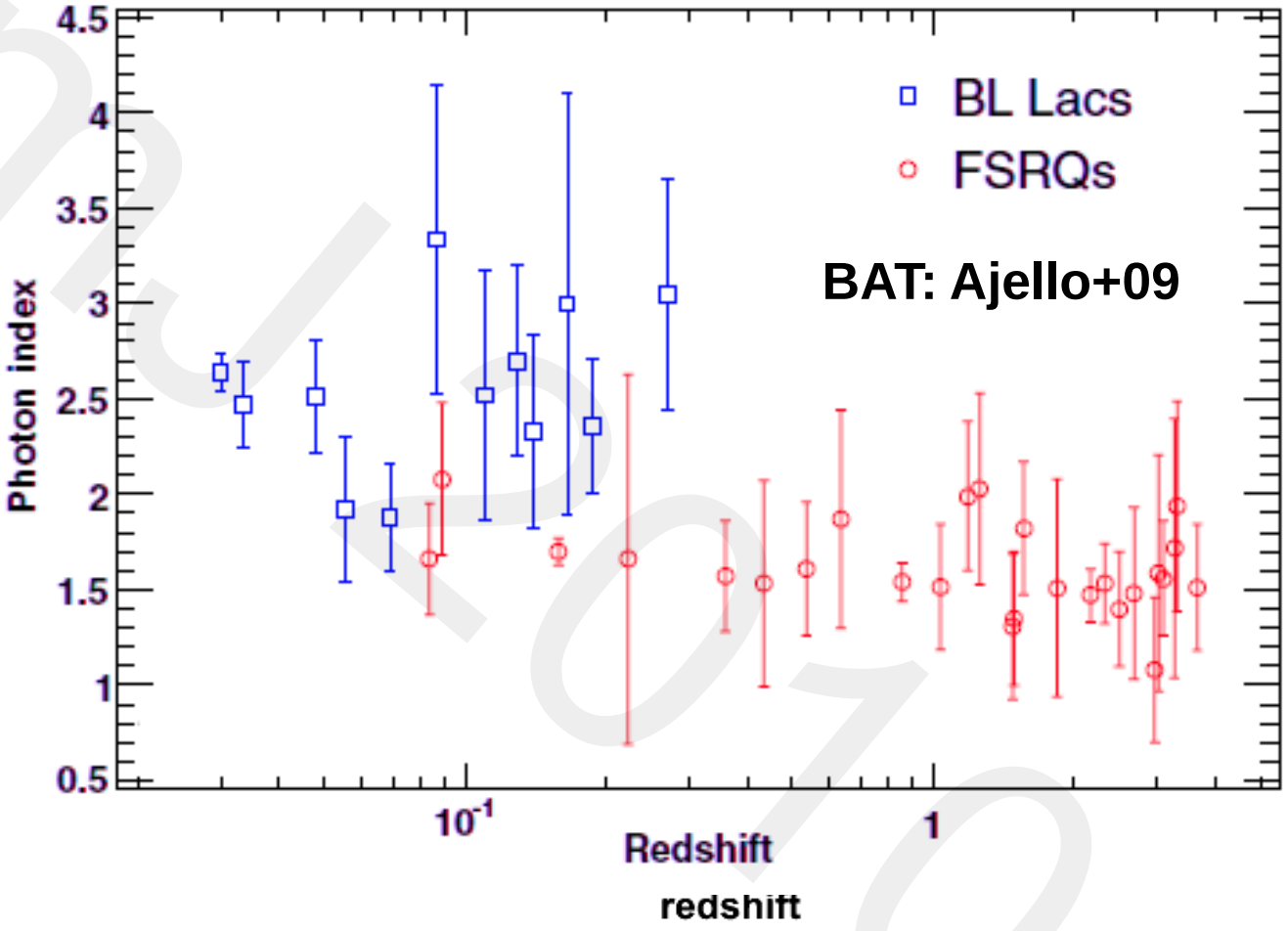
FSRQ
BLLac
Uncertain
Radio galaxies

Only weak correlation observed

Photon index vs redshift

No evolution of pho
index vs z for FSRQ

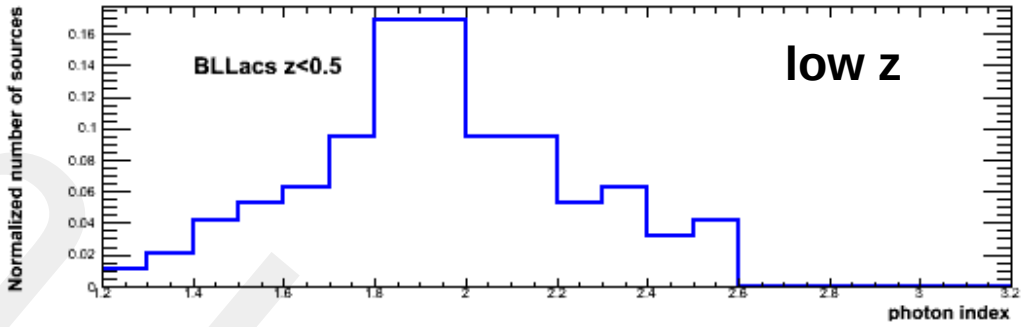
Strong evolution fo
BLLacs but just du
different subclasse
(LSP, ISP, HSP)
having different
redshift distributio

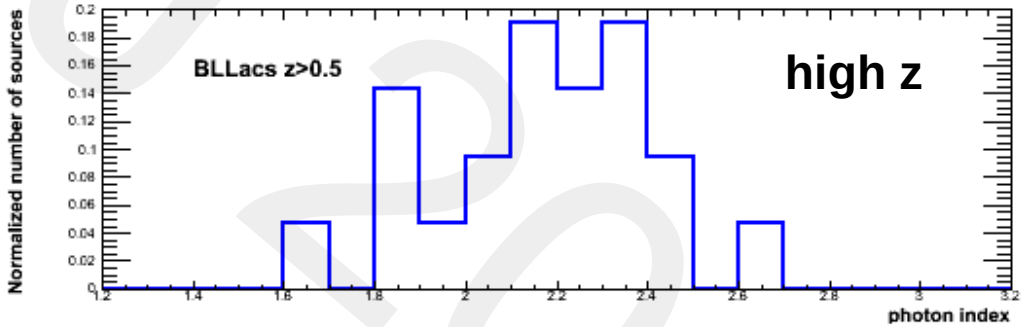


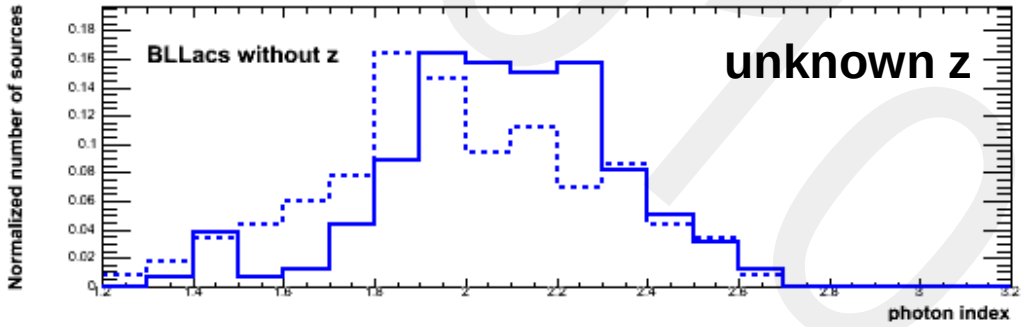
Photon index for BLLacs

BL Lacs with unknown redshifts (~50%) have photon indices as the high redshift ones

→mostly LSPs



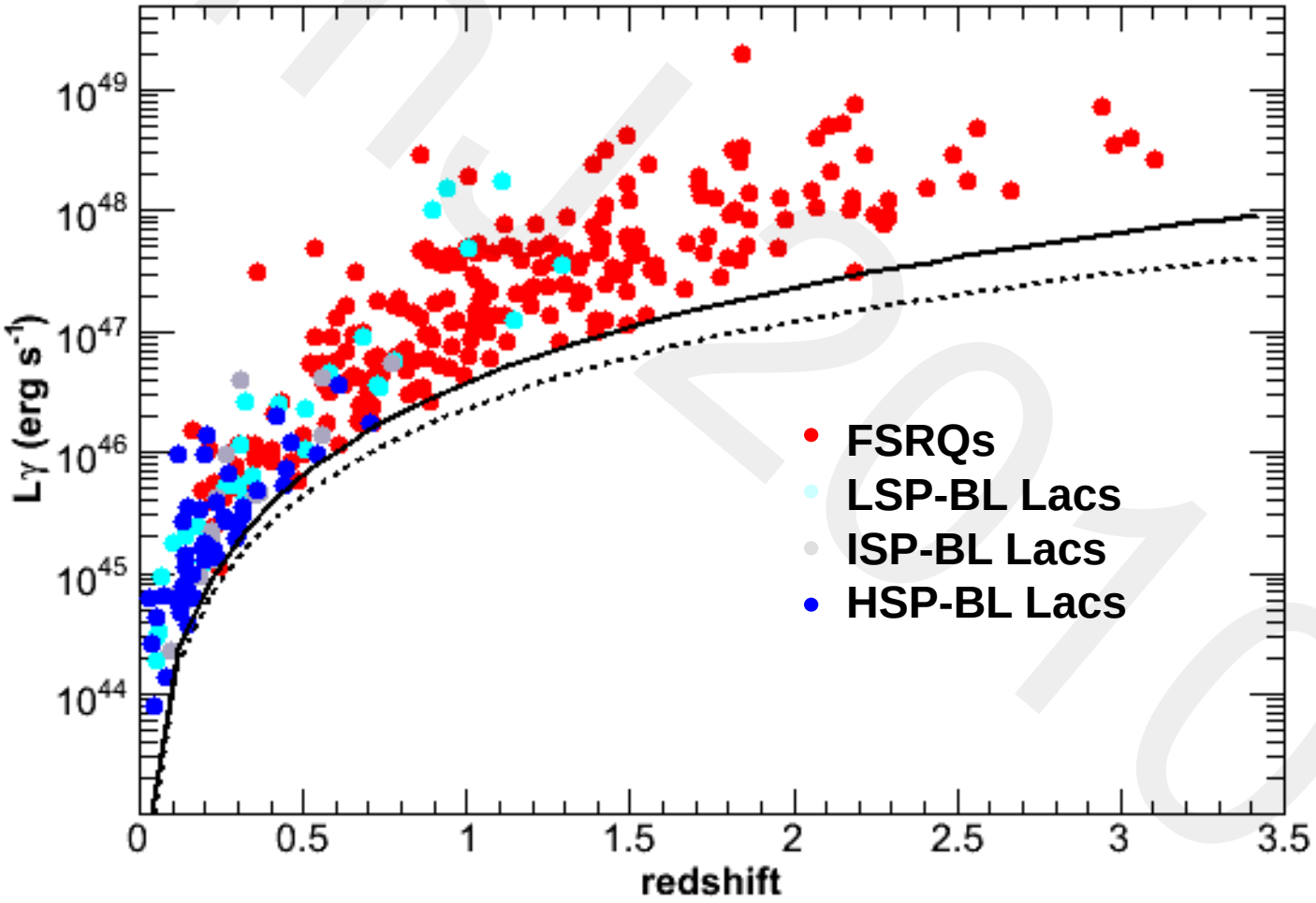




Luminosity vs redshift

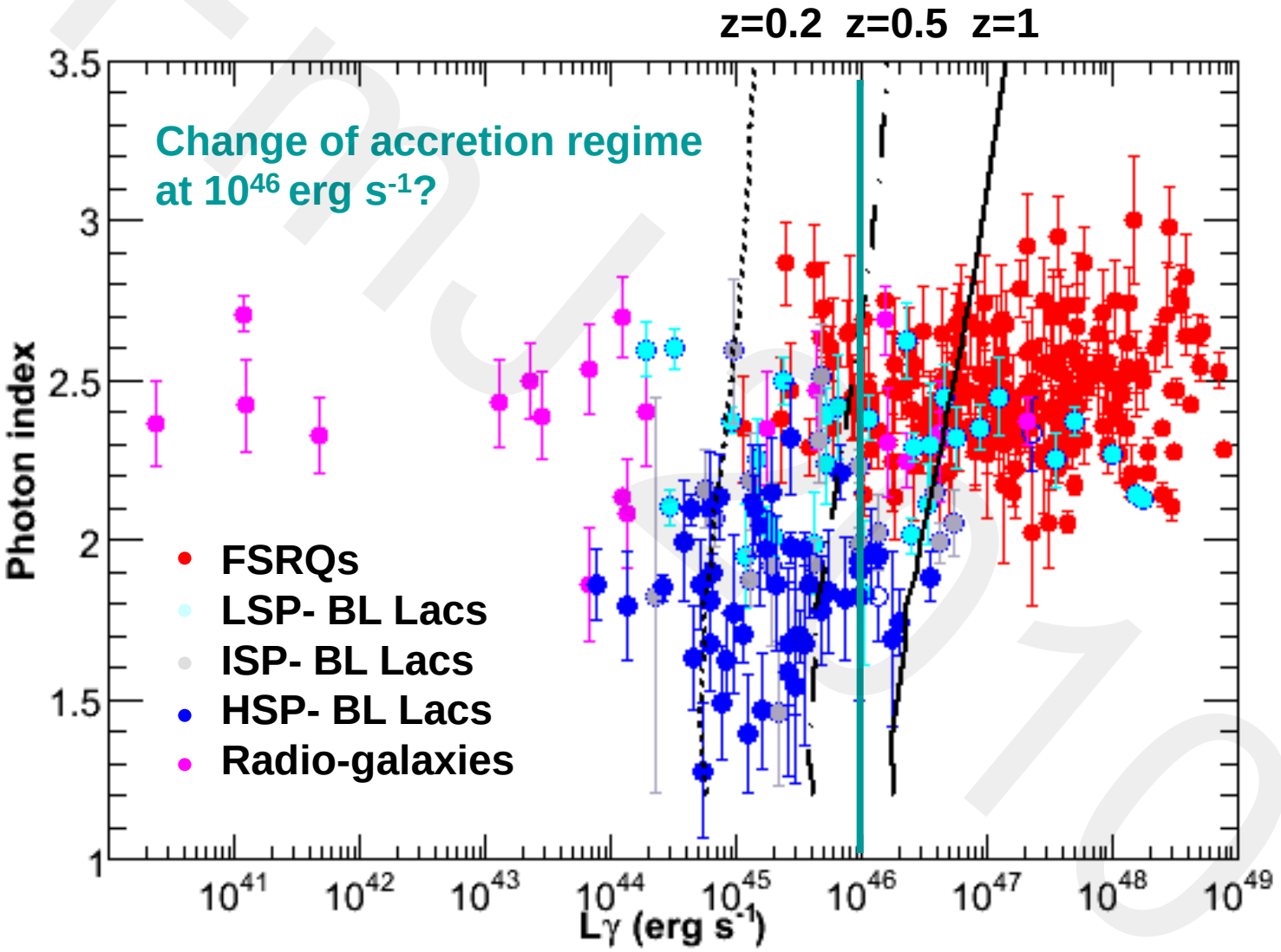
$$L_\gamma = 4\pi d_L^2 \frac{S(E_1, E_2)}{(1+z)^{2-\Gamma}}$$

d_L: luminosity distance
$S(E_1,E_2)$: energy flux between E_1(100 MeV) and E_2 (100 GeV)



index=2.2
index=1.8

Photon index vs luminosity



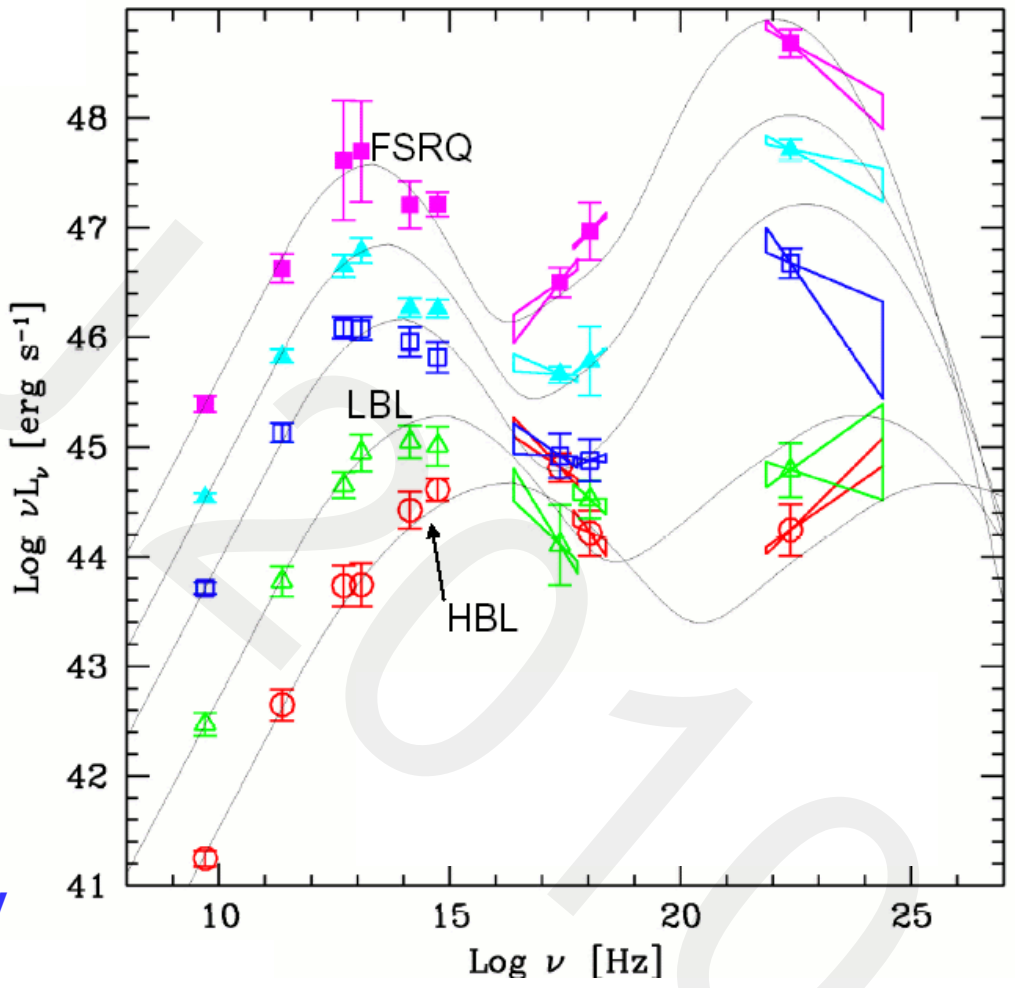
Blazar Sequence: « Grand Unification » (?)

Donato+ (2002) Fossati+(1998)

Average SEDs of blazars binned according to radio luminosity

126 blazars in total
28 with a spectral index measured by EGRET

- $\nu_{peak} \propto L^{-1}$
- $\nu_{HE} / \nu_{LE} = cst$
- $L_{HE} \propto L_{radio}$



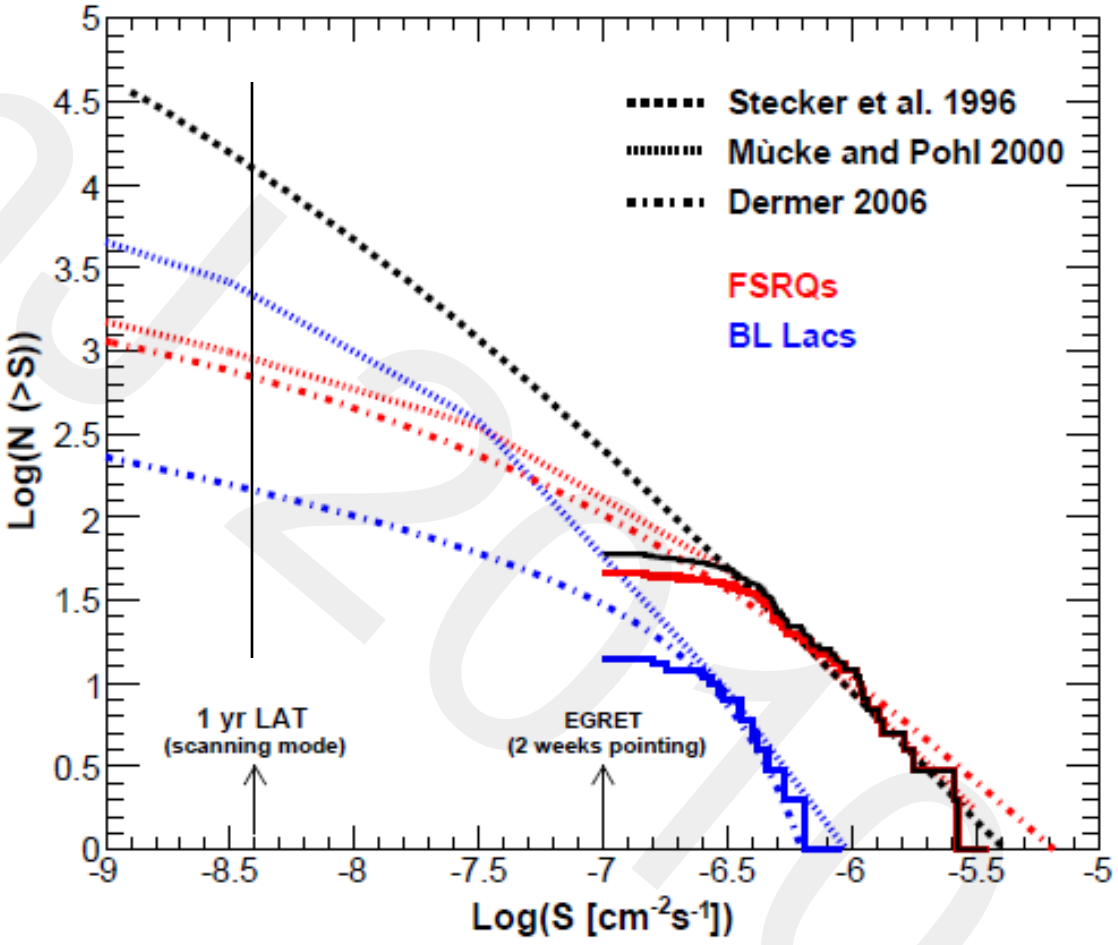
Hypothesis:
Results of reduced accretion rate leading to an evolutionary link between classes:
FSRQ →LSP BLLacs →HSP BLLacs
(Ghisellini et al., Boettcher and Dermer, Cavaliere and D'Elia)

Comparison with pre-launch predictions

Predictions assumed same flux limit for BL Lacs and FSRQs…

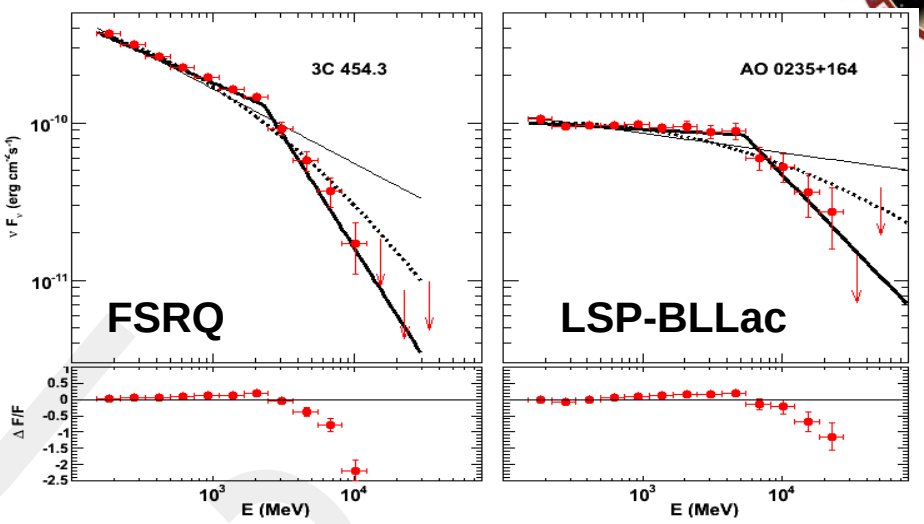
Reality is different

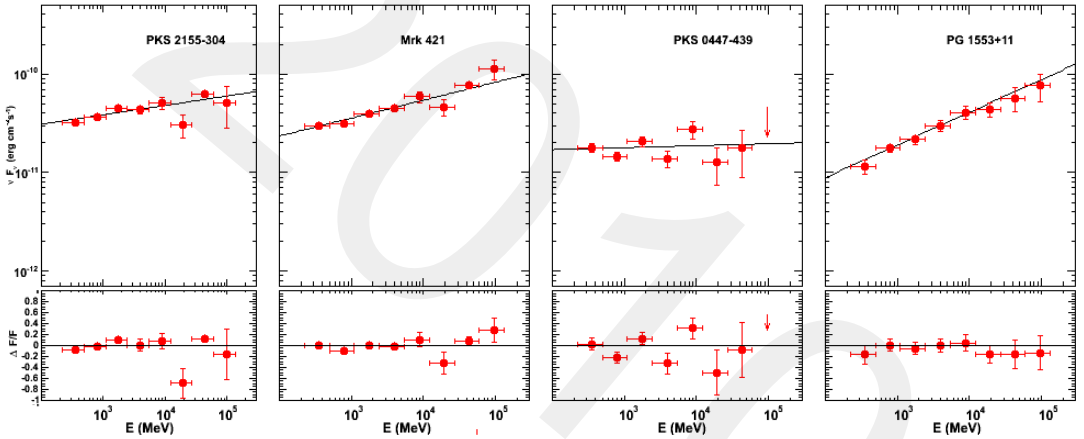
Overpredictions of FSRQ numbers



Non-power law spectra

- General feature in FSRQs and many LSP-BLLacs
- Absent in HSP-BLLacs
- Broken power law model seems to be favored
- $\Delta\Gamma \sim 1.0 > 0.5 \rightarrow$ not from radiative cooling
- Possible explanations:
  - feature in the underlying particle distribution
  - Klein-Nishina effect
  - Superposition of EC disk+BLR
  - γ–γ absorption effect
    - internal
    - external (He II)
- Implications for EBL studies and blazar contribution to extragalactic diffuse emission





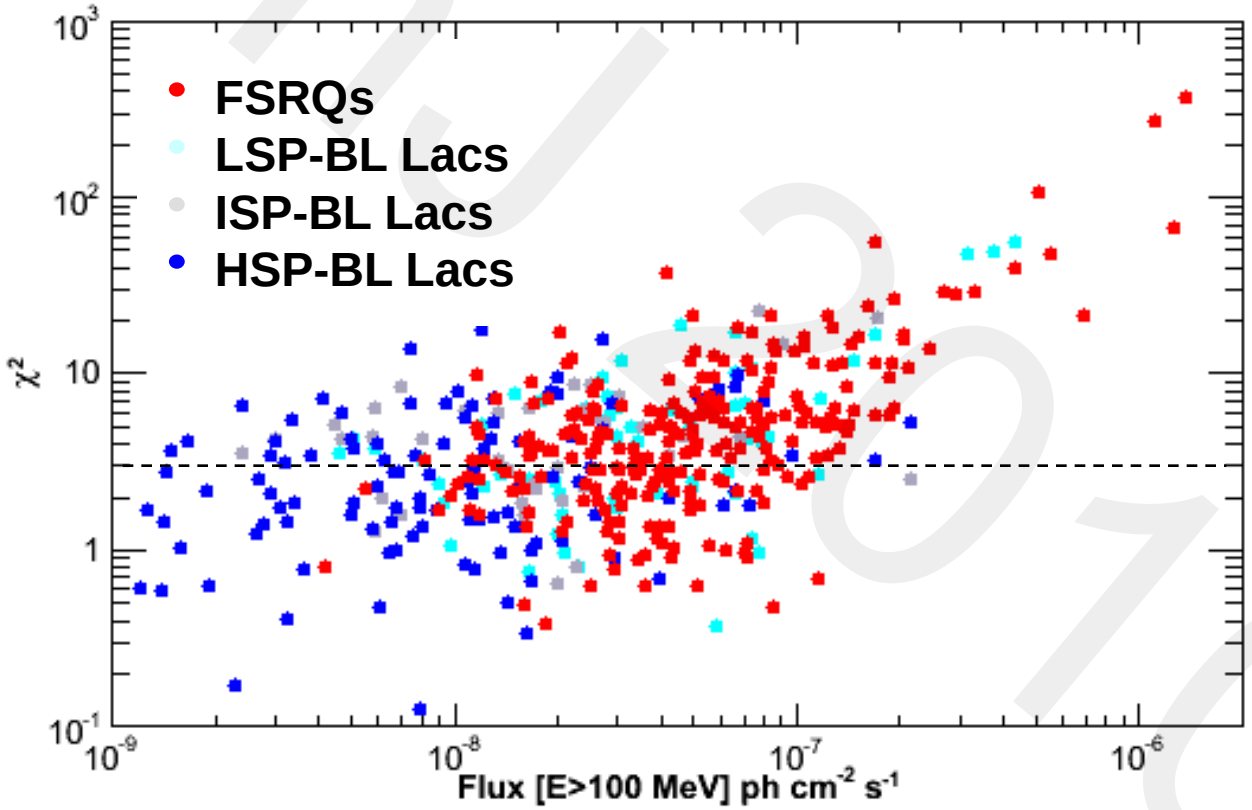
HSB-BLLacs

A. A. Abdo et al. 2010, ApJ 710, 1271

Curved spectra

Curvature index: chi-square of fit of 5-band photon fluxes with a power-law model

$$C = \sum_i \frac{(F_\mathrm{i} - F_\mathrm{i}^{PL})^2}{\sigma_\mathrm{i}^2 + (f_{i,rel} F_\mathrm{i})^2}$$



Relative constancy of photon index

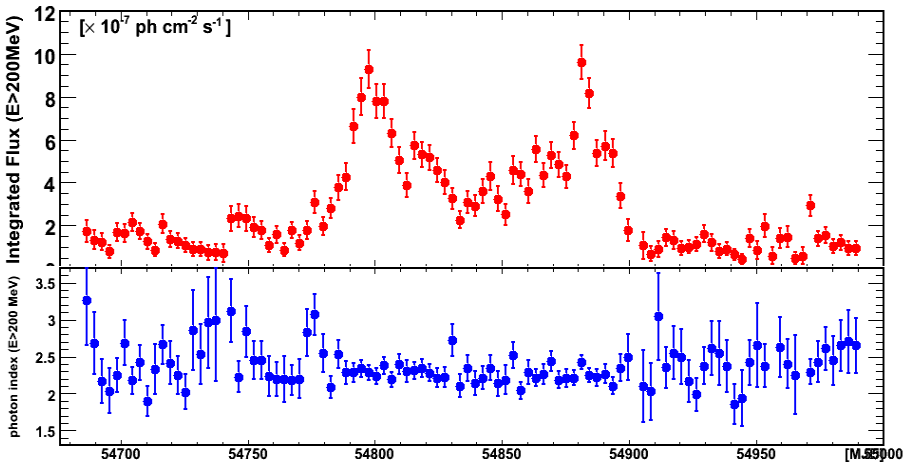
Weekly light curves

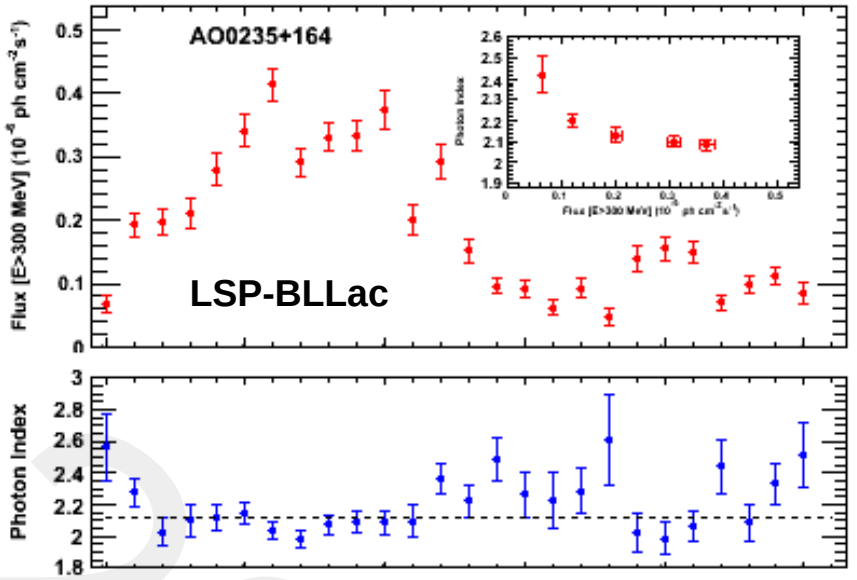
Slight « harder when brighter » effect observed

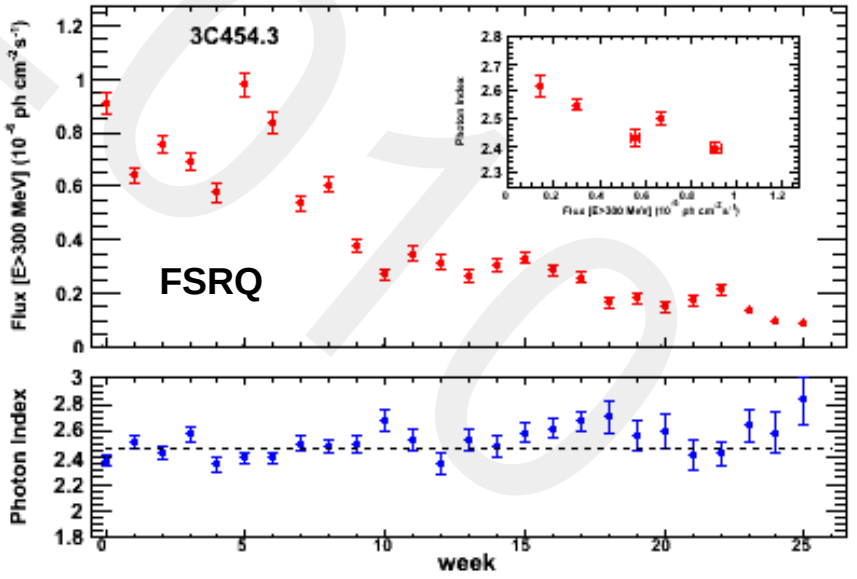
Typically, $\Delta\Gamma$ <0.3 in time

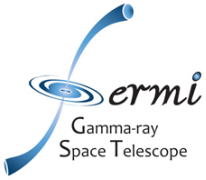
Process stabilizing the spectral shape at work?

Continous injection of particles?

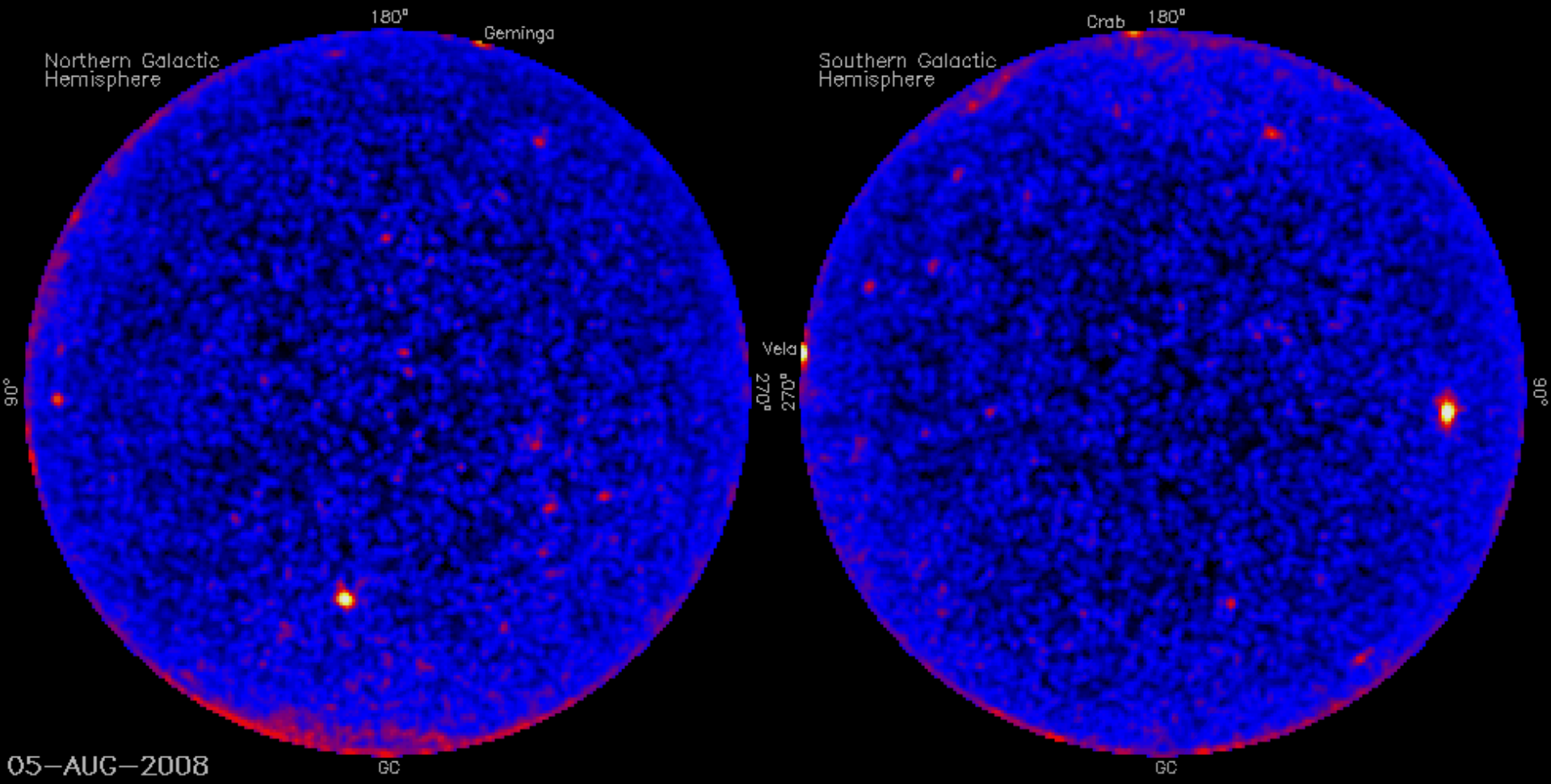




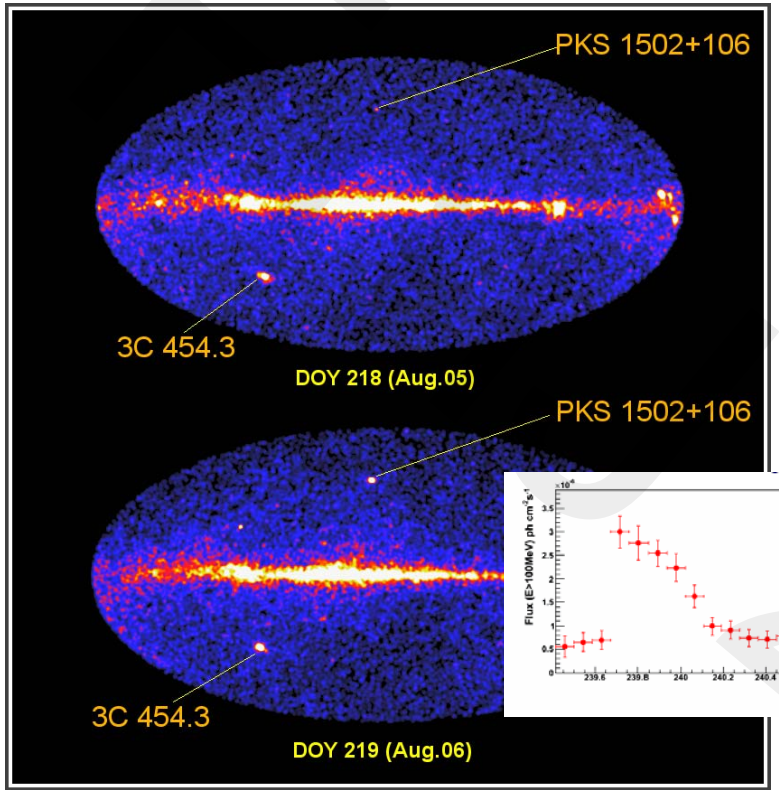


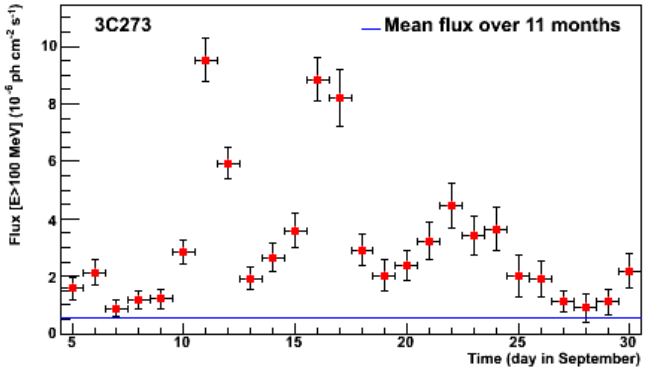


Temporal properties in the γ-ray band


Northern Galactic
Hemisphere
180°
Geminga
90°
GC
Vela
270°
Southern Galactic
Hemisphere
Crab
180°
90°
GC
05–AUG–2008

The variable sky





>80 Astronomers telegrams

> 70 for AGNs

(alert threshold:

F[E>100 MeV]~10^{-6} ph cm^{-2} s^{-1})

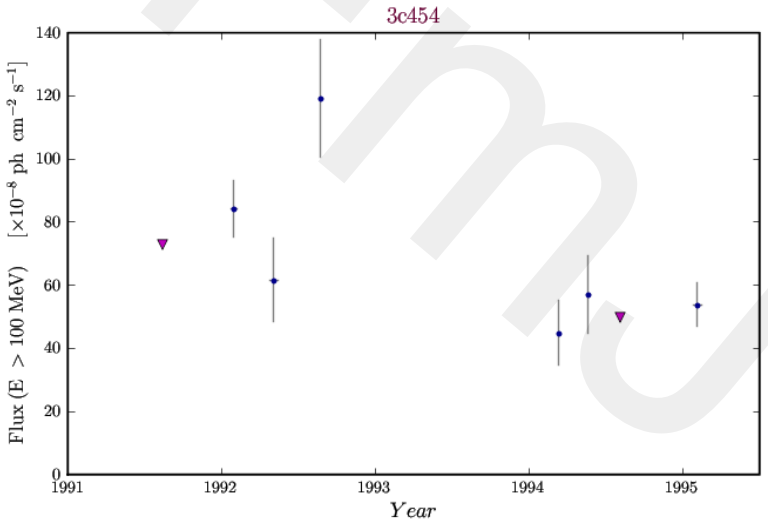
- **Discovery of new gamma-ray blazars: PKS 1502+106, PKS 1454-354**
- **Flares from known gamma-ray blazars: 3C454.3, PKS 1510-089,3C273, AO 0235+164, PSK 0208-512, 3C66A, PKS 0537-441**
- **Galactic plane transients: J0910-5041, 3EG J0903-3531**

http://www-glast.stanford.edu/cgi-bin/pub_rapid

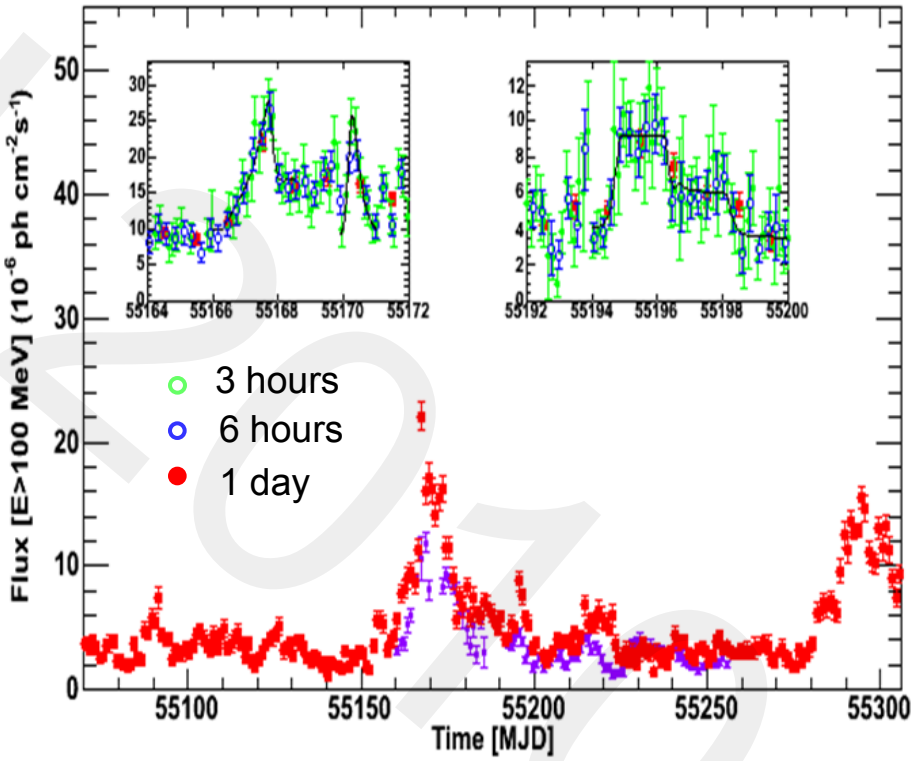
Flare Advocates issue alerts and feed the Fermi blog

Source monitoring

Ex: 3C454.3



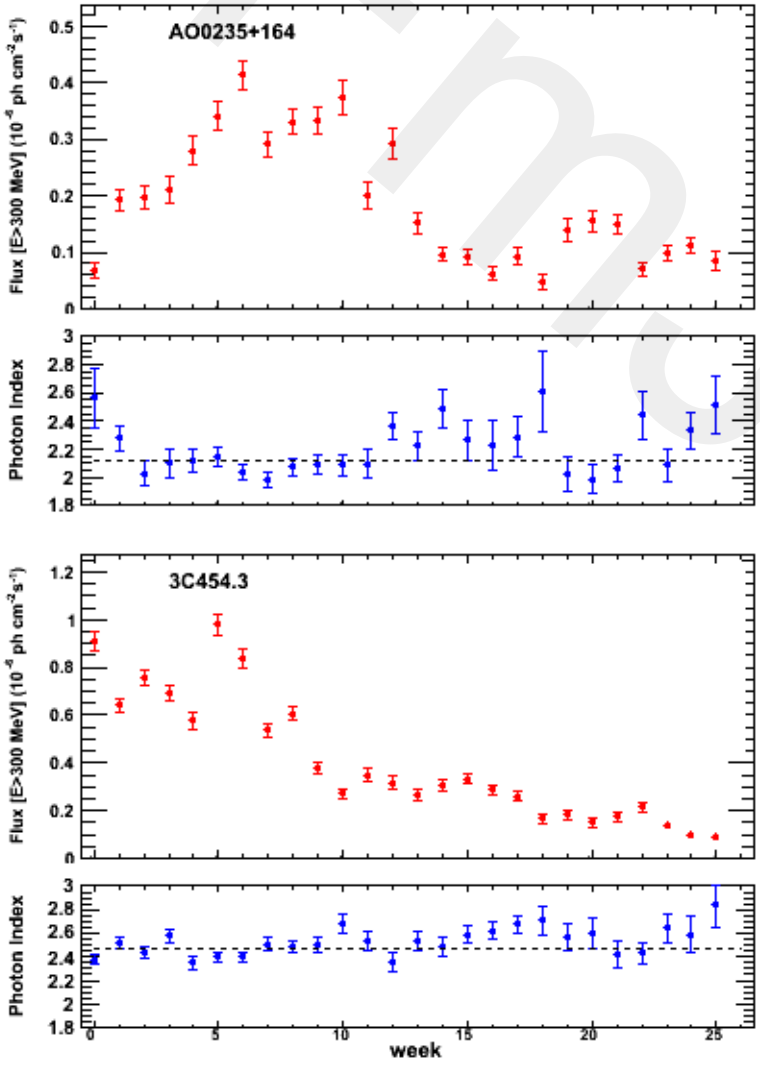
preliminary



- EGRET: sparse 15-day long viewing periods
- difficult to establish variability patterns and determine relevant parameters (duty cycle…)
- Fermi: continuous coverage of all sources in the sky

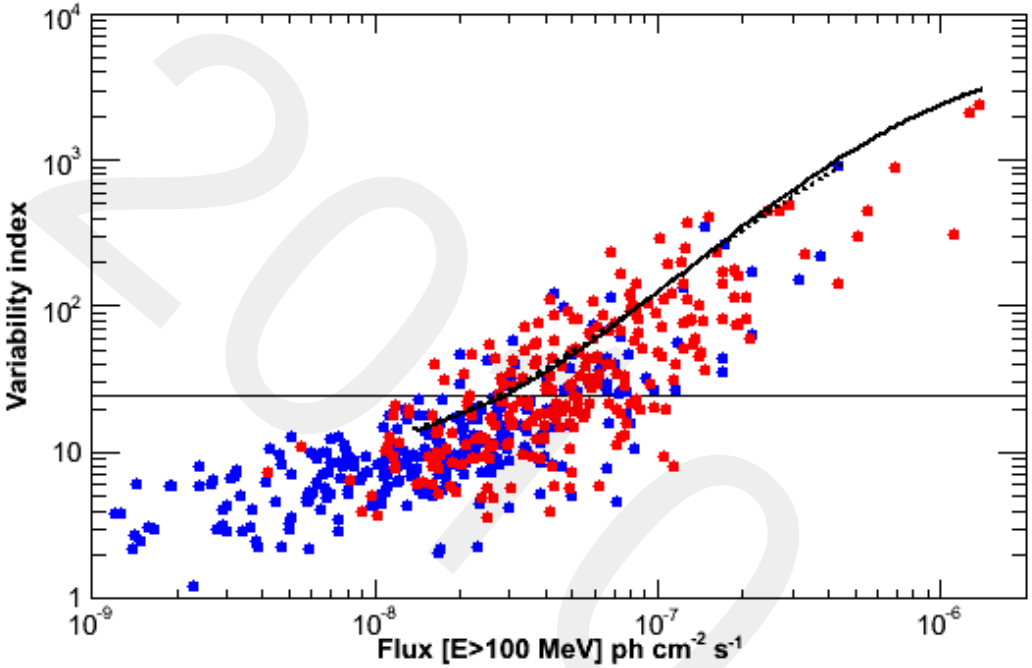
Variability index

Weekly light curves



$$V = \sum_i \frac{(F_\mathrm{i} - F_\mathrm{av})^2}{\sigma_\mathrm{i}^2 + (f_{rel} F_\mathrm{av})^2}$$

based on monthly light curves

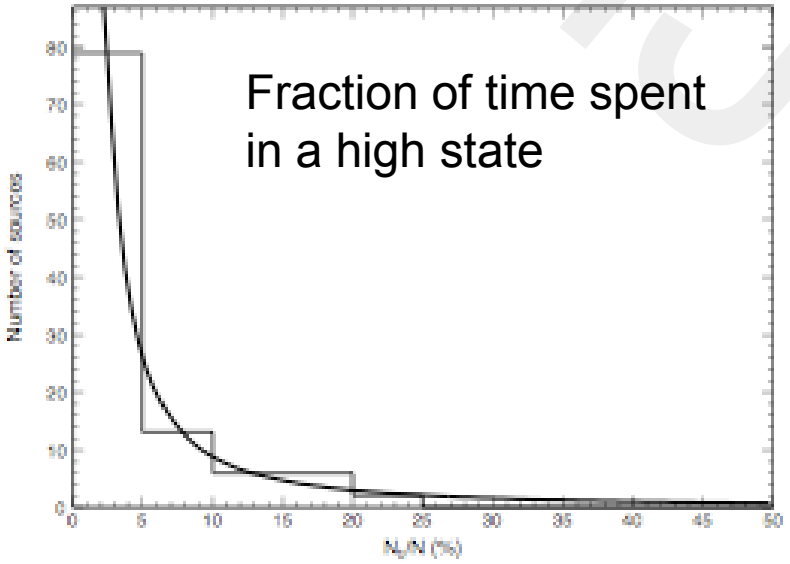


Gamma-ray light curves and variability of LBAS blazars

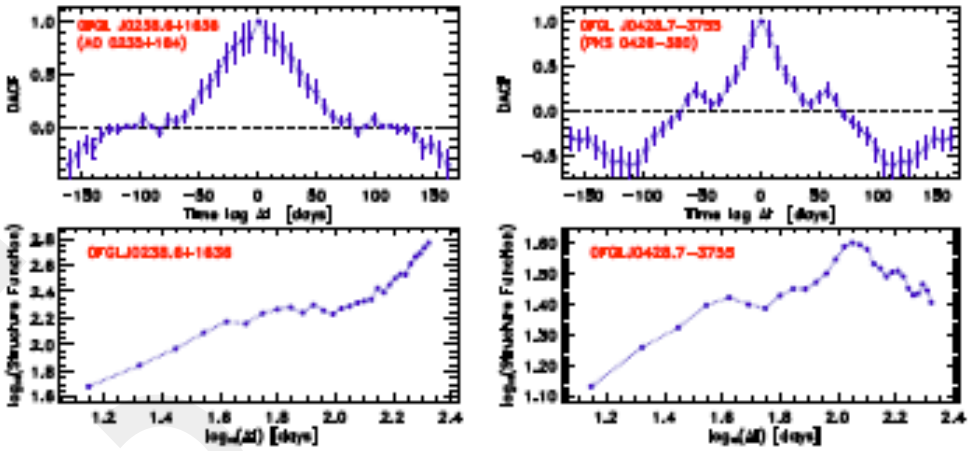
Weekly (or 3-day) light curves for 106 LBAS blazars

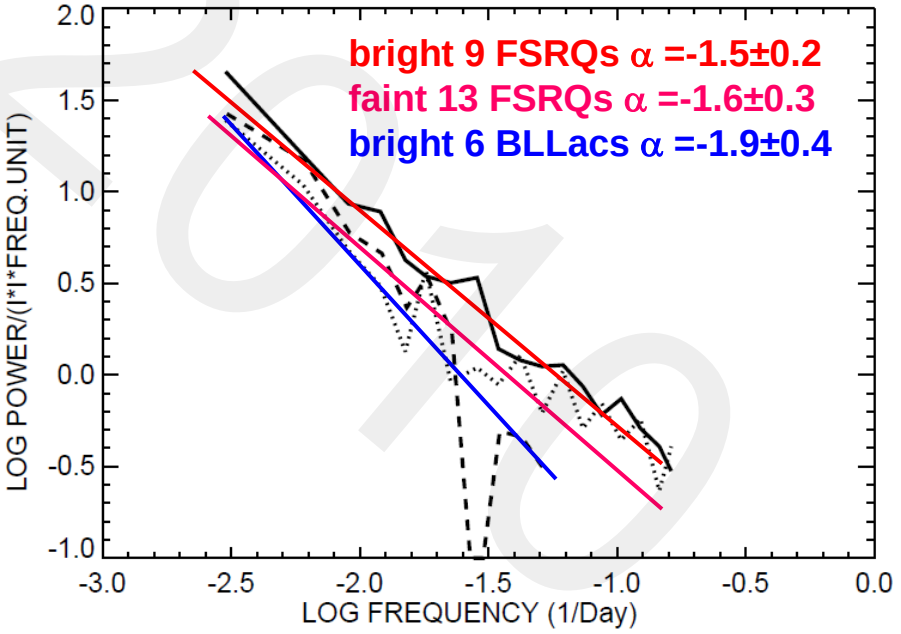
First characterization of long-term variability in the Gev band

A.A. Abdo, arXiv:1004.0348



Fraction of time spent in a high state





- PDS $1/f^{-\alpha}$ with α between 1 (« flicker », « pink-noise ») and 2 (« shot noise », «Brownian») with peak around 1.6-1.7 (similar to optical or radio)

Radio- γ-ray connection *(Fermi symposium)*

Investigation of correlations between

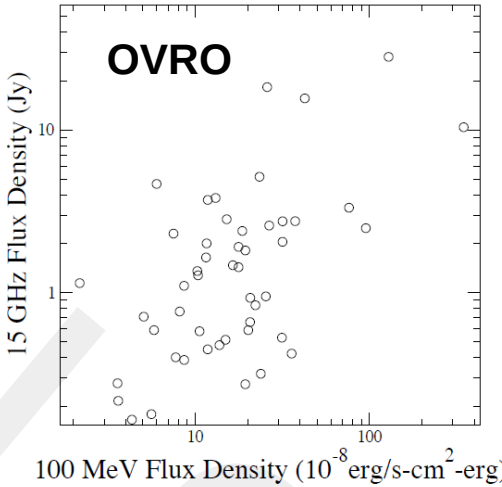
γ-ray and radio correlated variability

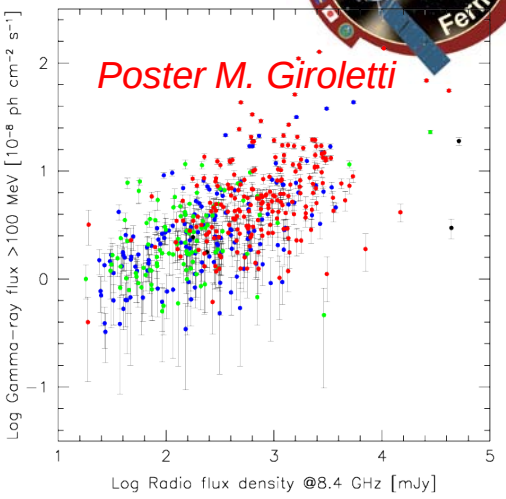
γ-ray and radio luminosities

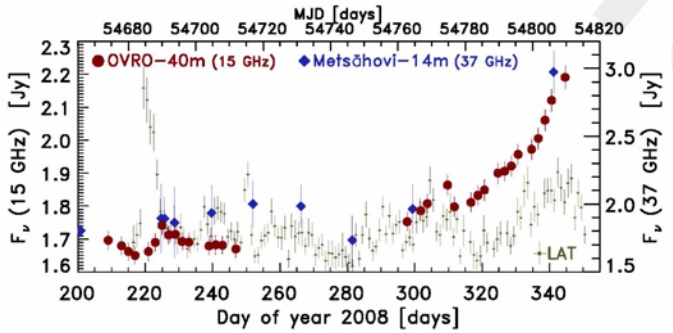
γ-ray luminosity and jet properties

γ-ray flares and ejection of new radio components

Preliminary

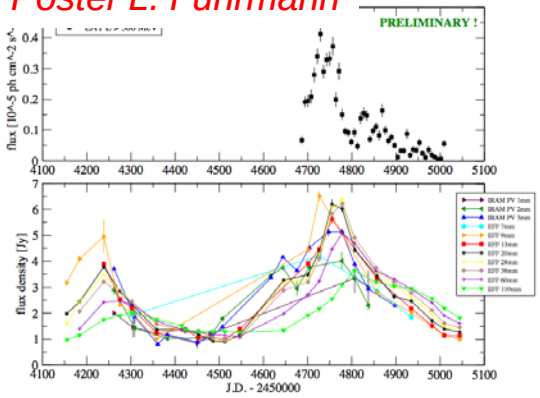


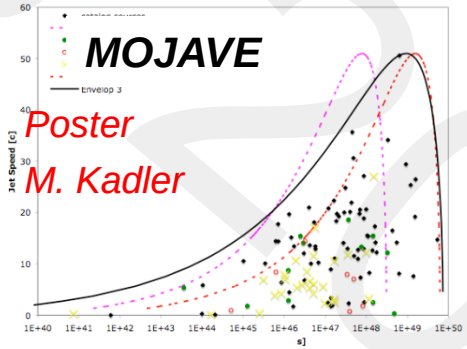




Effelsberg &

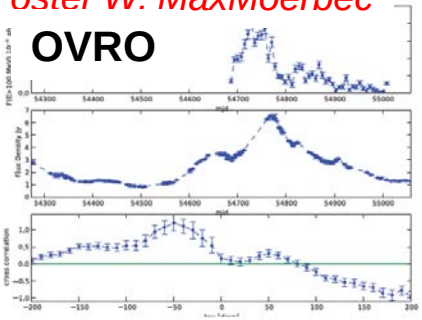
Poster L. Fuhrmann



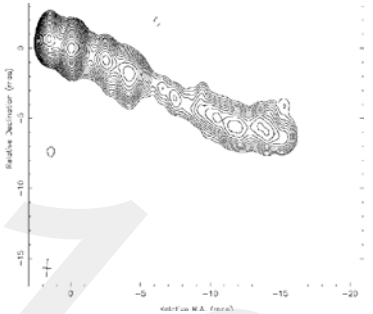


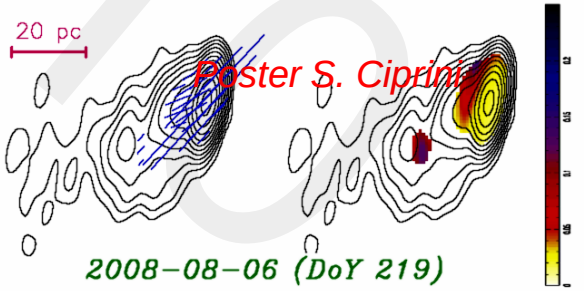
Poster M. Kadler

Poster W. MaxMoerbec



Poster Chin-Shin Chang





Poster S. Ciprini

Extragalactic Background Light (EBL)

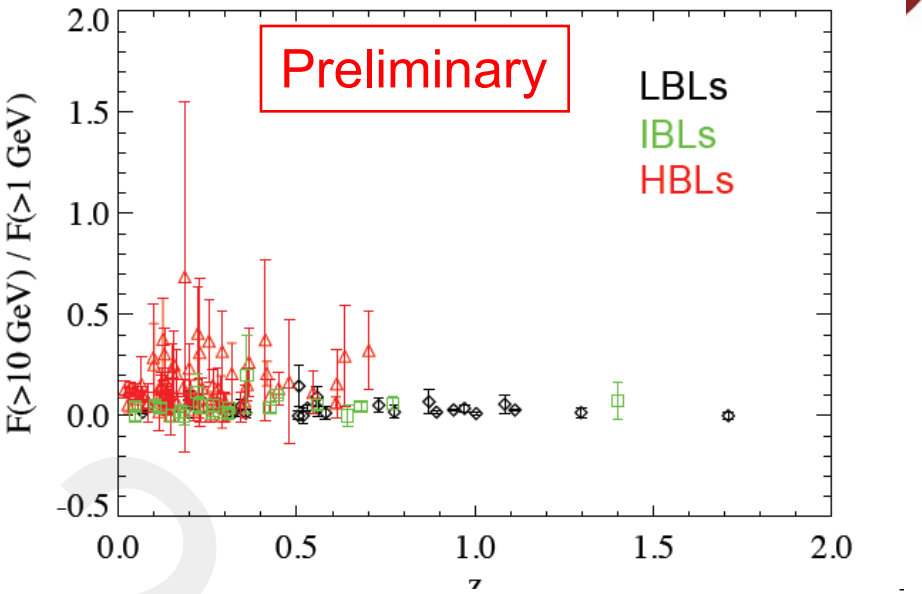
- **LAT-detected blazars at high z have soft spectra, many exhibiting breaks**

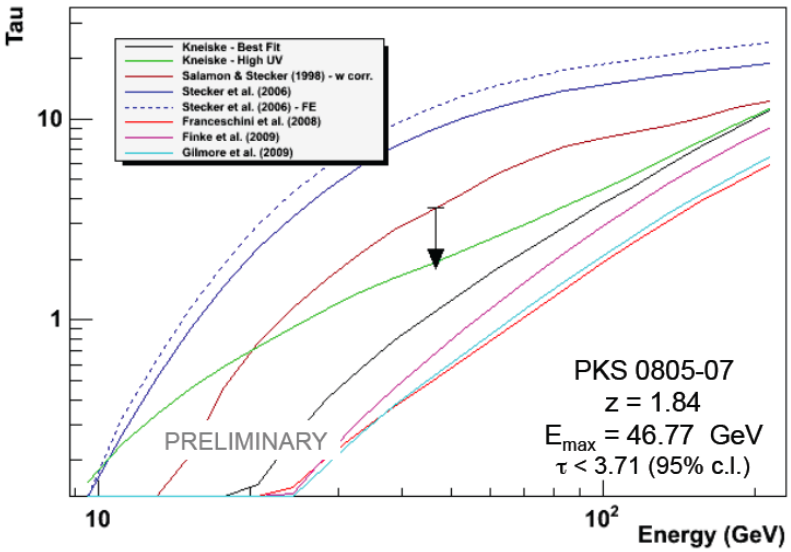
- **Little-constraining results provided by initially planned method based on**

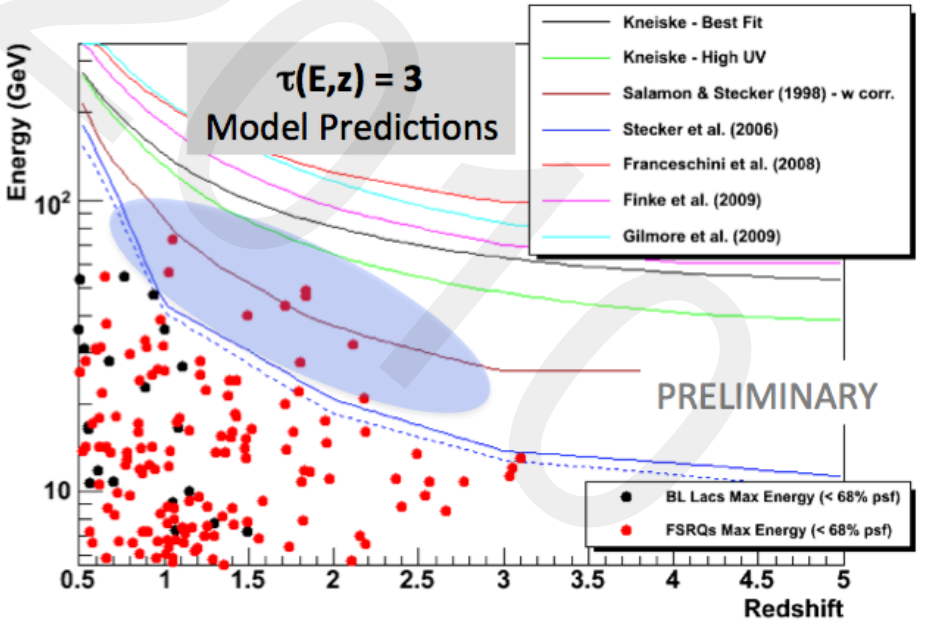
$$\frac{F(E > 10\,GeV)}{F(E > 1\,GeV)}$$

ratio

- **However, highest-energy photons from distant blazars rule out models that predict the highest opacities.**







Summary

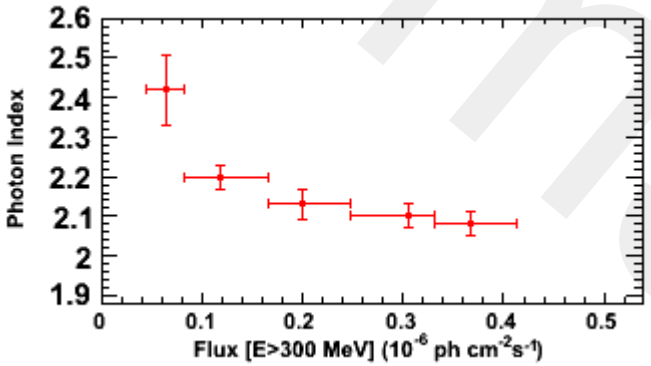
- 1LAC catalog
  - BLLacs (x~20 wrt EGRET)
  - FSRQs (x~5 wrt EGRET)
- Low number of misaligned blazars, 6 radiogalaxies
- Redshift distributions peaking at z ~ 1 for FSRQs and at low redshift for BL Lacs with known redshifts
- A high BL Lac/FSRQ ratio, close to unity
- A high HSP/LSP ratio among BL Lacs
- A fairly strong correlation between photon spectral index and blazar class for the detected sources
- Important spectral properties:
  correlation of photon index & gamma-ray luminosity with blazar class, spectral breaks, relative constancy of photon index with flux
- Variability time scales range from sub-day to several months

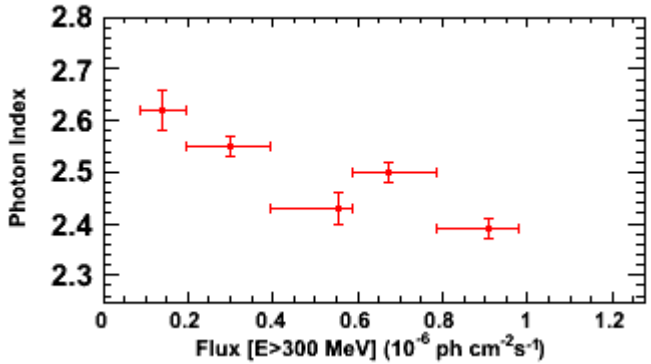
Back up slides

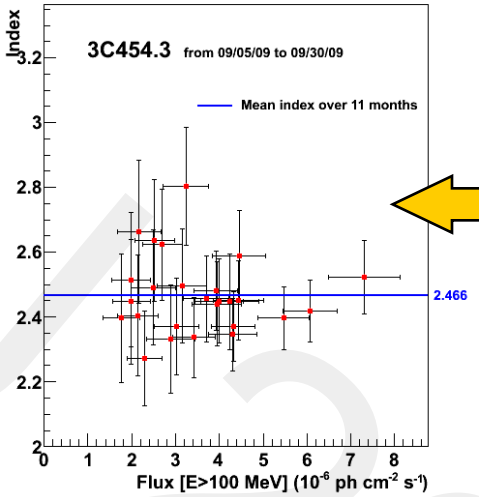
Relative constancy of photon index

Preliminary

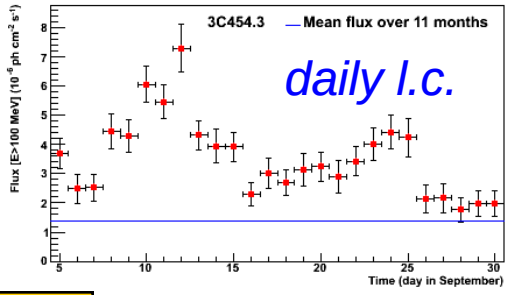
weekly l.c.

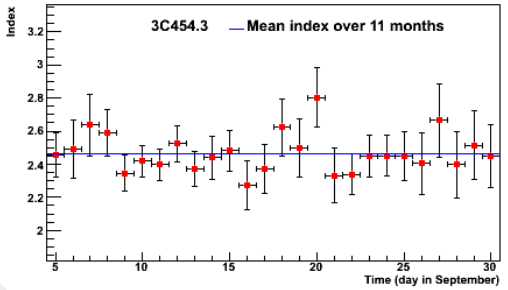


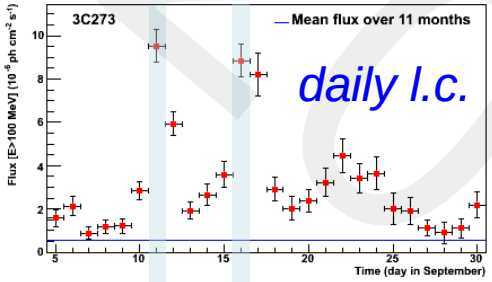




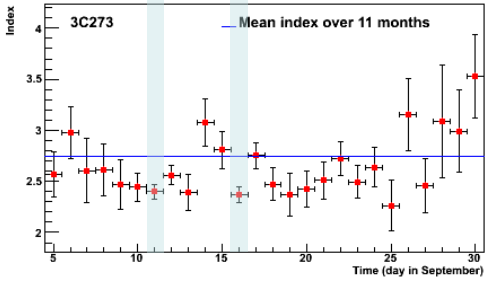
daily l.c.

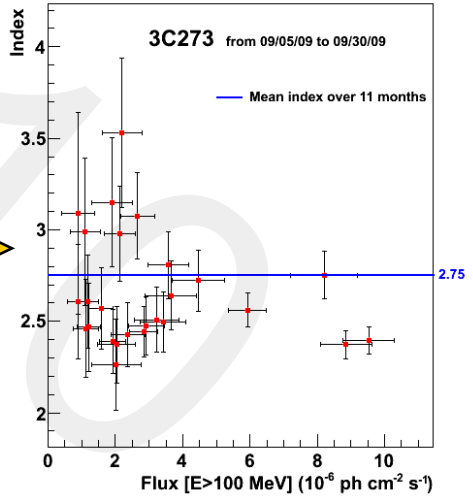






daily l.c.



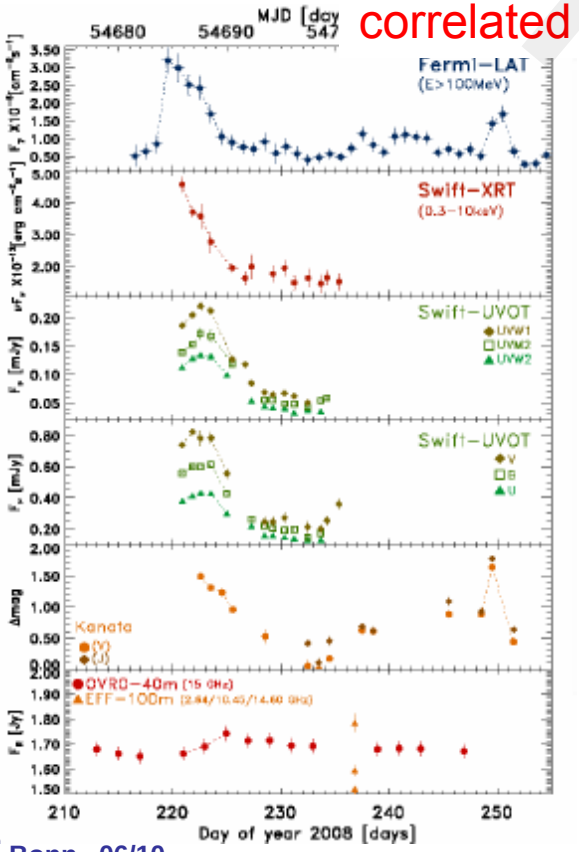


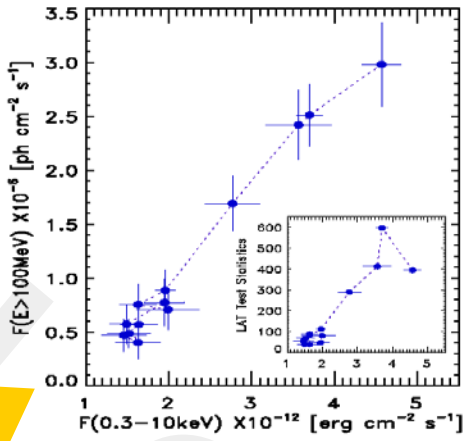
« Harder when brighter » effects observed but moderate variations ($\Delta\Gamma$ <0.3) seem to be the rule
Process stabilizing the spectral shape?

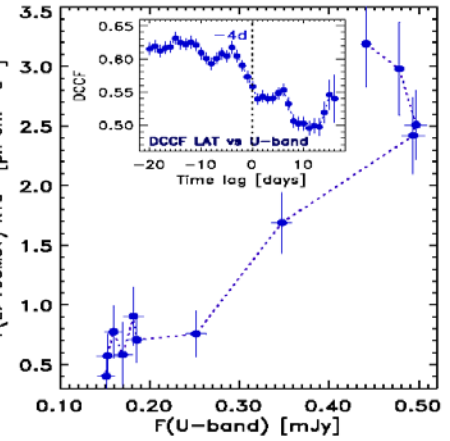
Multiwavelength data for PKS1502+106

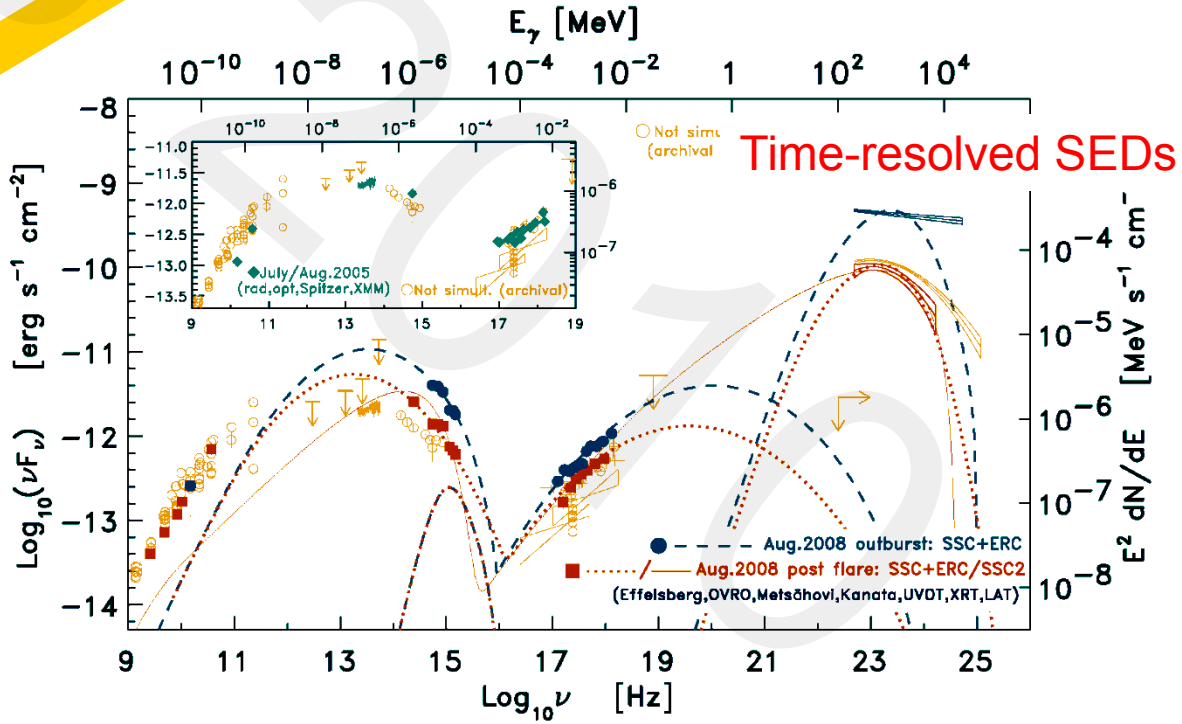
- first blazar discovered by Fermi
- luminous FSRQ at z=1.839
- strong correlations between γ-ray and other bands: optical,X-ray
- SED well reproduced by EC+SSC models

correlated variability



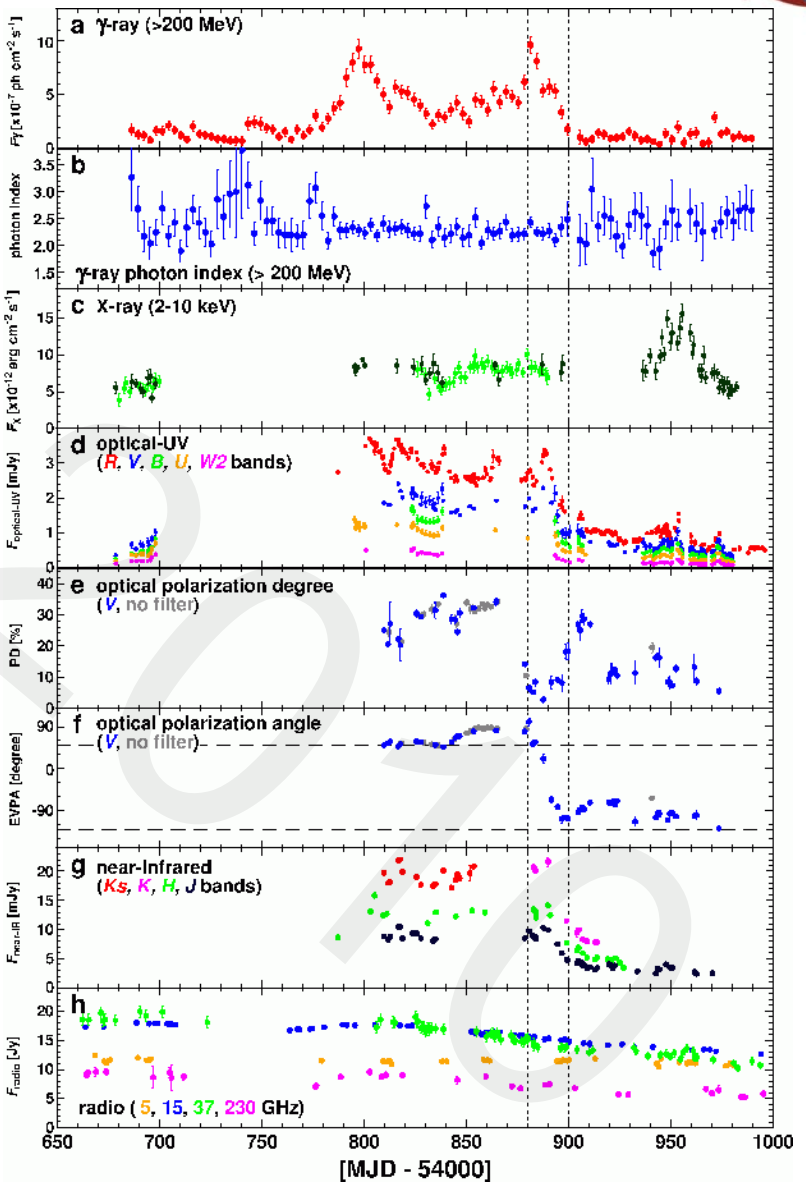






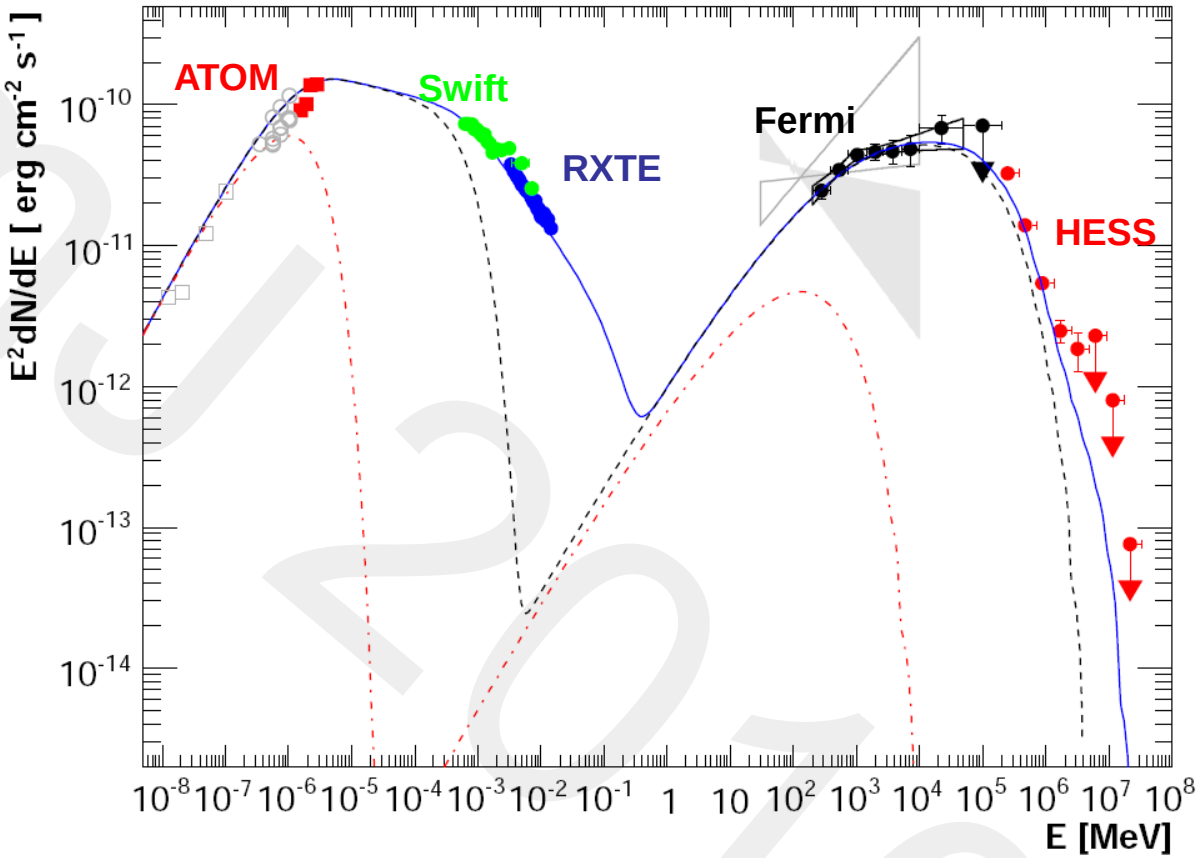
Multi-wavelength campaign on 3C279

- Bright FSRQ, z=0.536
- Intensive Multiwavelength Campaign~300 d
- Coincidence of γ-ray flare and change in optical polarization (KANATA)
- Drop from 30% to 5%
- EVPA changes by 208°
- Orphan X-ray flare detected
- Polarization event lasts 20 days
- Co-spatiality of γ-ray and optical emissions
- Non-axisymmetric structure of the emission zone
- Curved trajectory along the jet
- $r_{event}>10^5$ Schwarzschild radii



MW campaign on PKS 2155–304 (with HESS)

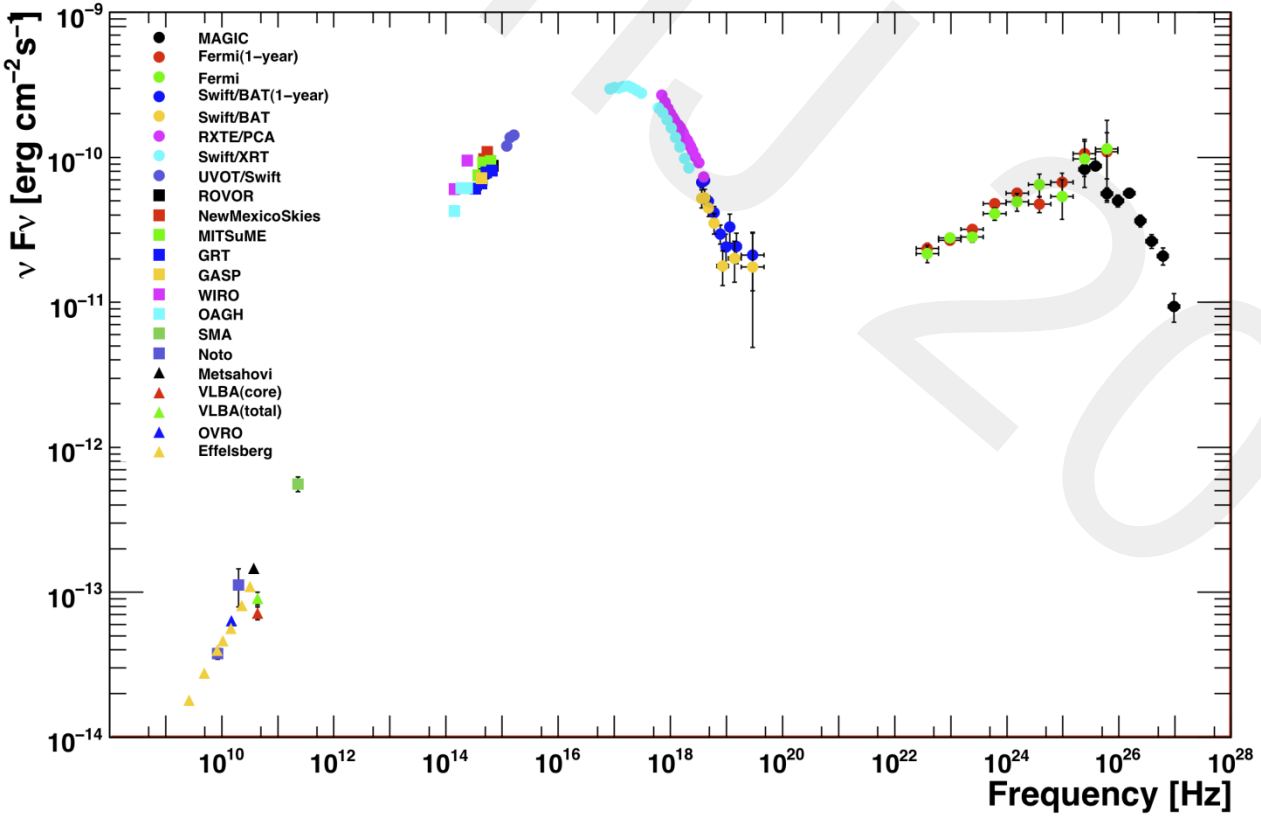
HSP-BLLac, z=0.116
nonflaring,low/quiescent state
First simultaneous SED including GeV-TeV
Unexpected correlations:
• strong correlation between optical and TeV fluxes
• X-ray flux varies independently of TeV flux
• correlation between X-ray flux and GeV photon index
Challenge simple SSC models



Aharonian, F. et al. 2009, ApJL, 696 L150
contact authors: B. Giebels & J. Chiang

MW campaign on Mrk421

- 4.5 months long (Jan 20th – June 1st , 2009)
- ~20 instruments participated covering frequencies from radio to TeV
- 2-day sampling at at optical/X-ray and TeV (when possible: breaks due to moon, weather…)



Most complete SED collected for Mrk421 until now

First time that the high energy bump is resolved without gaps from 0.1 GeV to almost 10 TeV