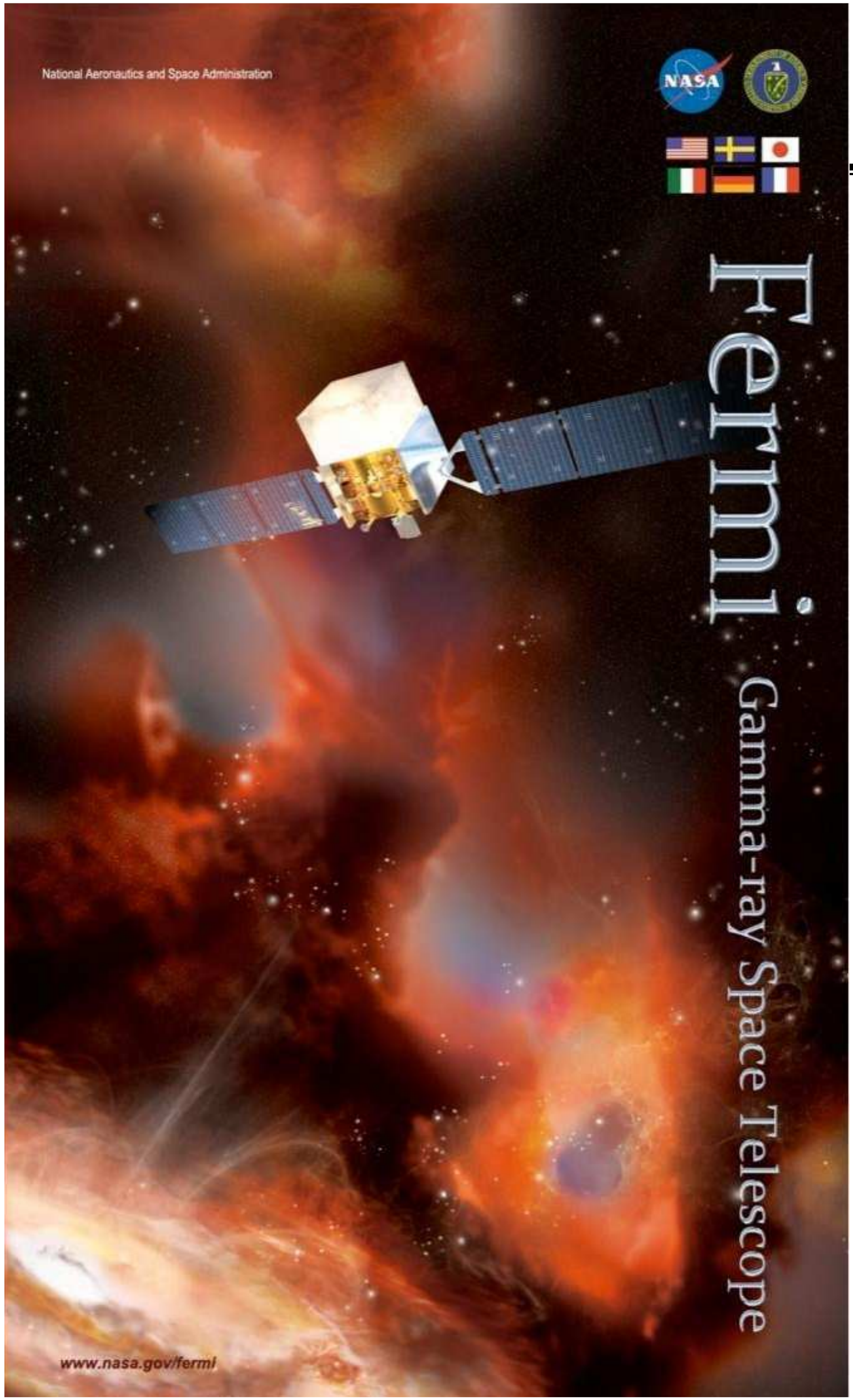

AGNs with the Fermi-LAT: General properties

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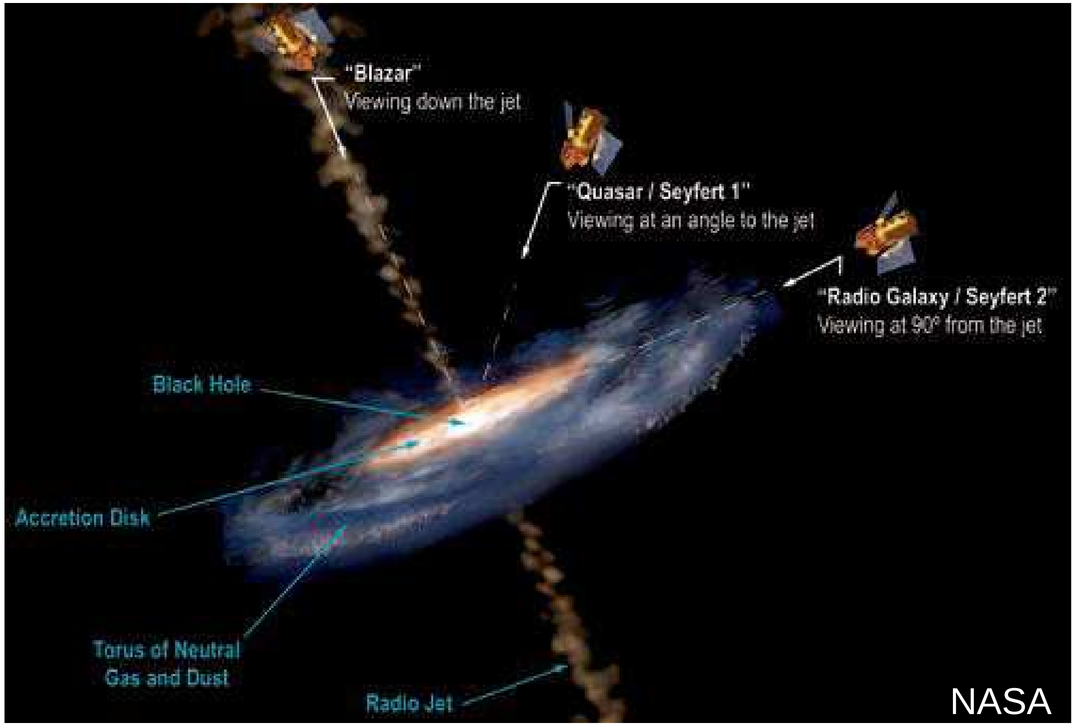
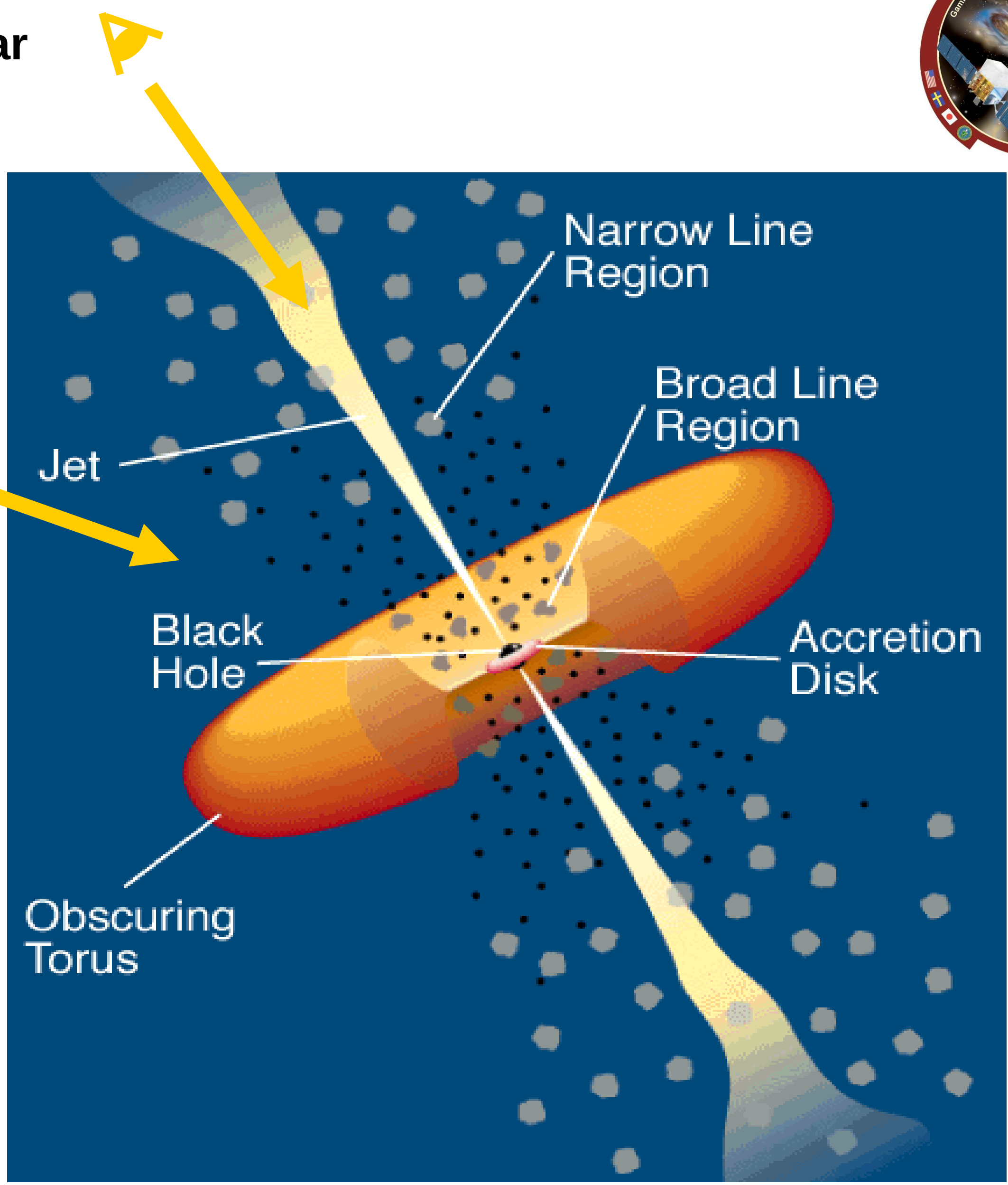
on behalf of the *Fermi*-LAT collaboration

"Blazars, other AGNs and Galaxy Clusters" Science Working Group

Introduction to radio-loud AGNs

- **Powered by accretion onto a central, supermassive black hole $10^{8\text{-}9}\ M_{\odot}$**
- **Accretion disks produce optical/UV/X-ray emission via various thermal processes**
- **Jets: highly collimated outflows with $\Gamma \sim 10$**
- **Unified Model: observer line-of-sight determines source properties, e.g., radio galaxy vs blazar**
- **Other factors: accretion rate, BH mass and spin, host galaxy**





1 pc= 3 10^{16} m

r_S=10^{-5} (M/10^8 $M_\odot$) pc

Disk size:10^{-3}pc

Base of VLBI jet: 1-10 pc

BLR: 0.01-0.1pc

Tore: 100 pc

Galaxy diameter: 100 kpc

Radio lobes: 1 Mpc

Urry & Padovani

Credit: NASA/Goddard Space Flight Center Conceptual Image Lab

Relativistic Jet

Particles accelerated within the jets possibly in shocks between different clumps of plasma moving at different speeds

Large brightness temperature superluminal motion, rapid variability in γ-rays

Relativistic aberrations!

Doppler factor:

$$\delta = \frac{1}{\Gamma(1-\beta\cos\theta)}$$

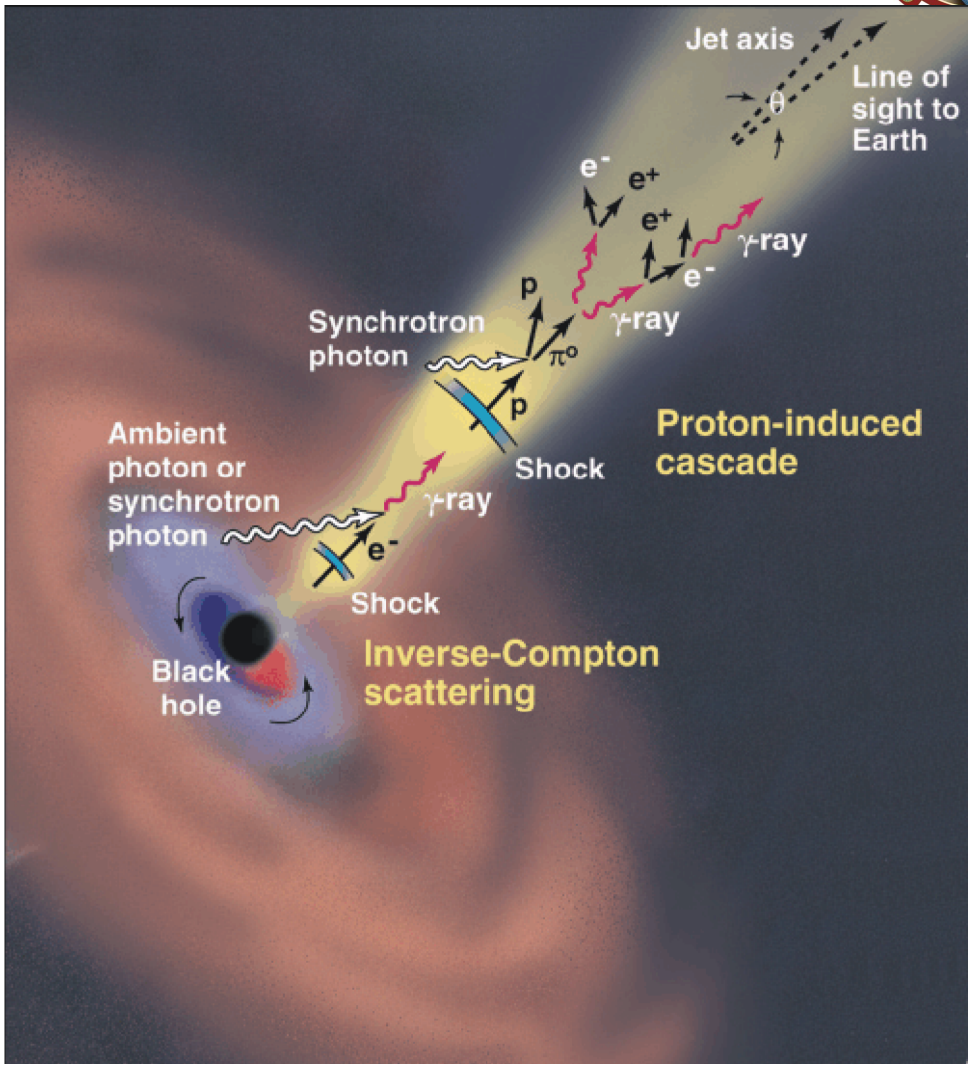
For θ=0, δ=2Γ. δ≅10–50

$$\Delta t_{obs} = \delta^{-1}\Delta t'$$

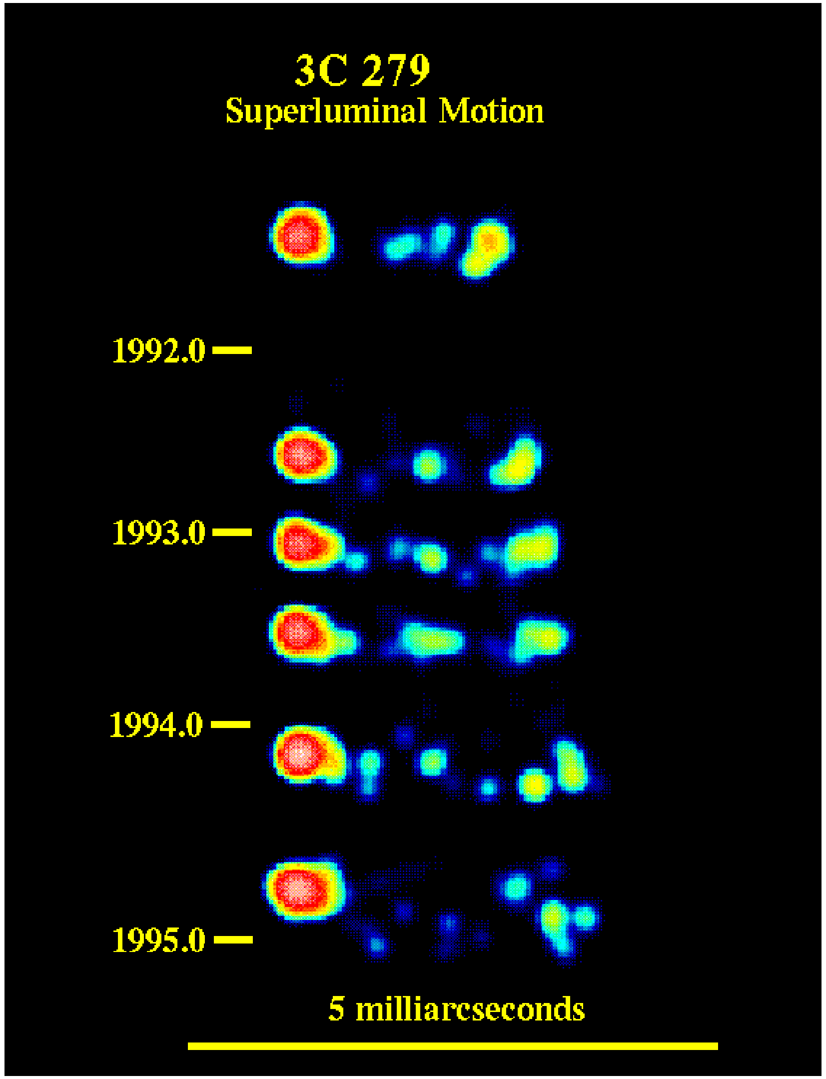
$$\nu = \delta\nu'$$

$$I(\nu) = \delta^3 I'(\nu')$$

$$I = \delta^4 I'$$



Superluminal motion



Observation VLBI: v_{app}=4 c!

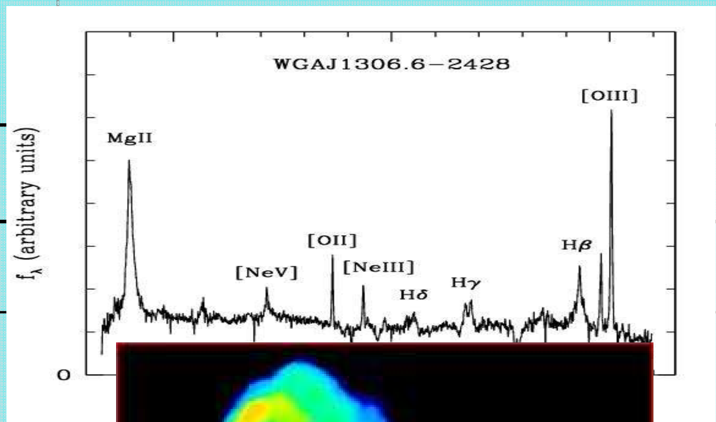
$$v_{app} = \frac{v \sin \alpha}{1 - \frac{v}{c} \cos \alpha}$$

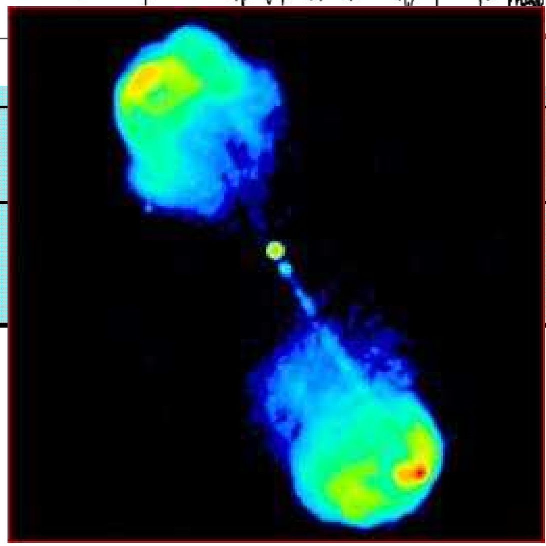
$$\beta_{app} = \frac{v_{app}}{c} < \Gamma$$

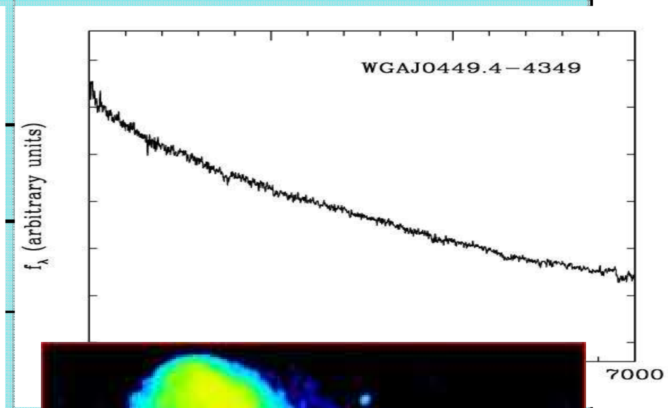
Superluminal motion observed if v>0.707 c
v_{app} observed up to 46 c!

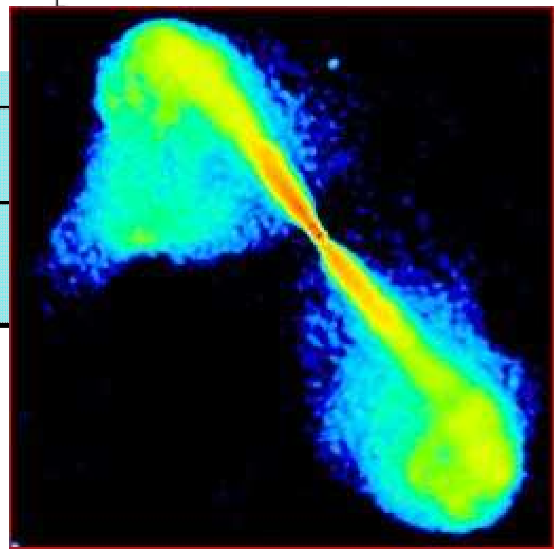
Blazar classes

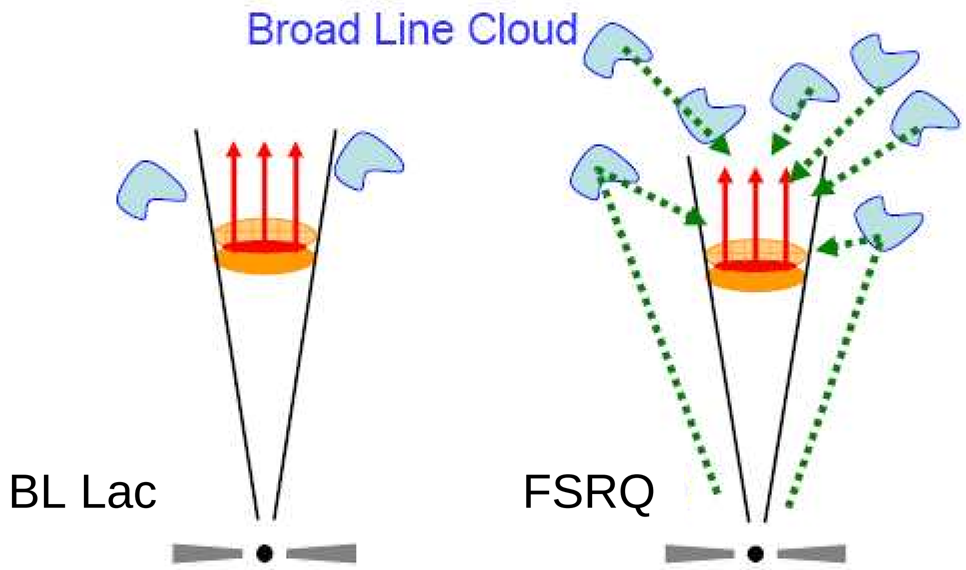
class	FSRQs	BLLacs
Defining property	strong emission lines	nearly lineless
Environment		
Power		
Parent population		
Synchrotron hump in SED		
EGRET-detected		
Redshift of EGRET sources		











Disk +BLR faint
Synchrotron Self Compton

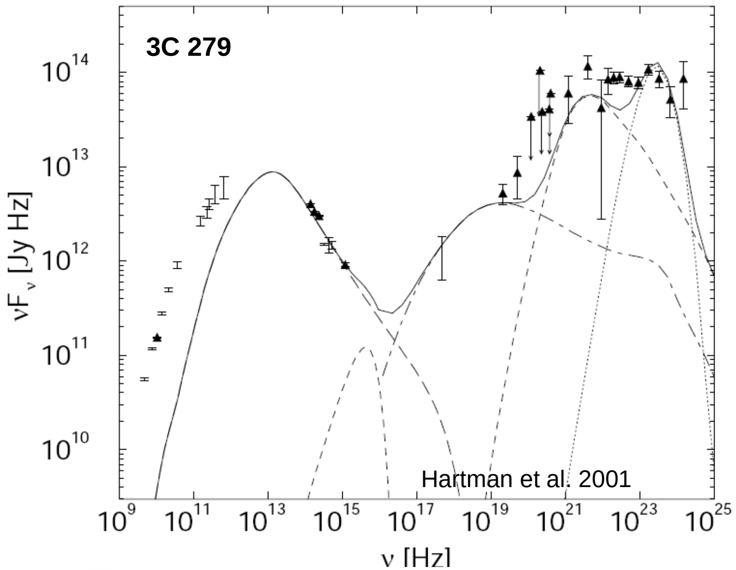
Bright disk
Light scattered off the BLR into the jet
Synchrotron Self Compton + External Compton

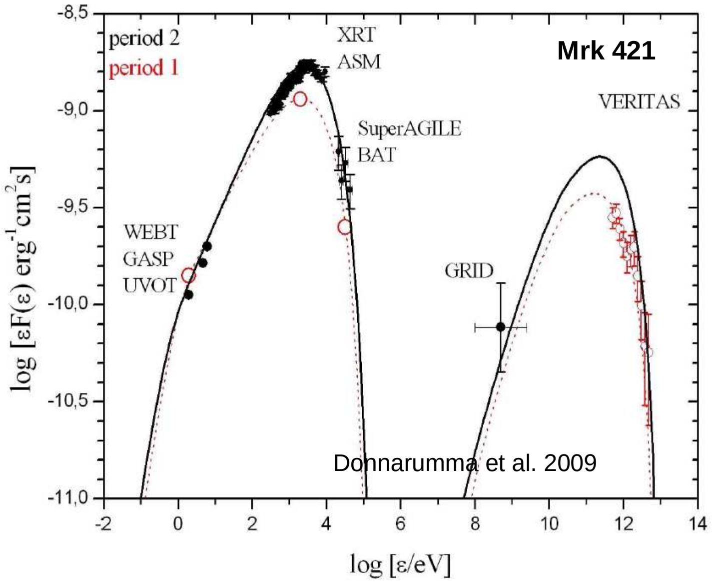
$$L \propto (U_B + U_{SYNC} + \Gamma^2 U_{EXT})$$

Γ Bulk Lorentz factor

Blazar Spectral Energy Distributions

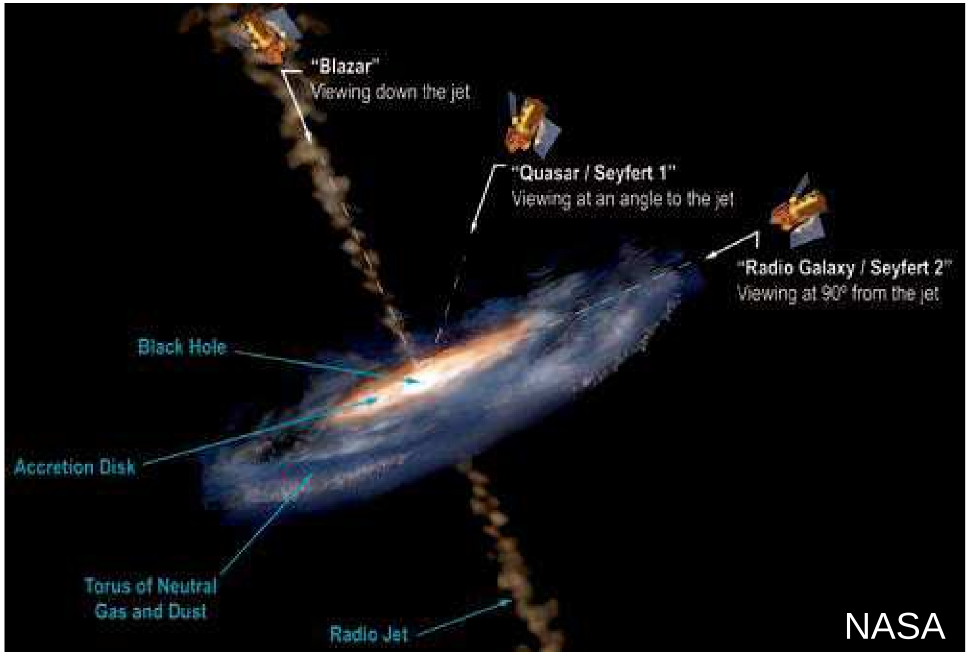
- **Smooth, broad, non-thermal continuum (radio to γ-rays)**
- **Compact, flat-spectrum (α_r< 0.5) radio sources (f_{core} >> $f_{extended}$)**
- **Rapid variability (high $\Delta L/\Delta t$), high and variable polarization (P_{opt} > 3%)**
- **“two-hump” spectral energy distributions (SEDs)**
  - **Synchrotron at low energies**
    - **LSP: low-synchrotron peaked: IR-optical**
    - **ISP intermediate-synchrotron peaked :U V**
    - **High-synchrotron peaked: X-rays**
  - **Inverse Compton and/or “hadronic” at higher energies**





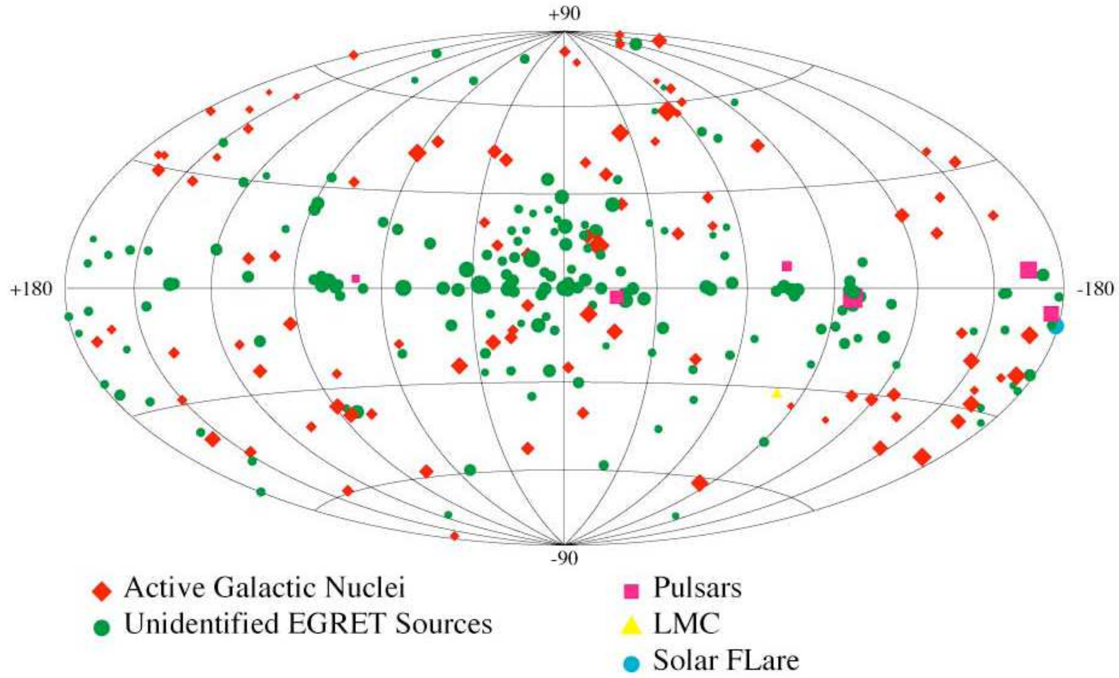
Key questions on blazars

- Emission mechanisms (for HE component)
  - Leptonic (IC of synchrotron or external photons) vs hadronic ($\pi^0 \rightarrow \gamma\gamma$, proton synchrotron)
- Emission location
  - Single zone for all wavebands (completely constraining for simplest leptonic models)
  - Opacity effects and energy-dependent photospheres
- Particle acceleration mechanisms
  - Shocks, magnetic reconnection, turbulence acceleration
- Jet composition
  - Poynting flux, leptonic, ions
- FSRQ/BLLac dichotomy
- Jet confinement
  - External pressure, magnetic stresses
- Accretion disk—black hole—jet connection
- Effect of blazar emission on host galaxies and galaxy clusters
- Blazars as probes of the extragalactic background light (EBL)



Populations

The EGRET legacy (1)

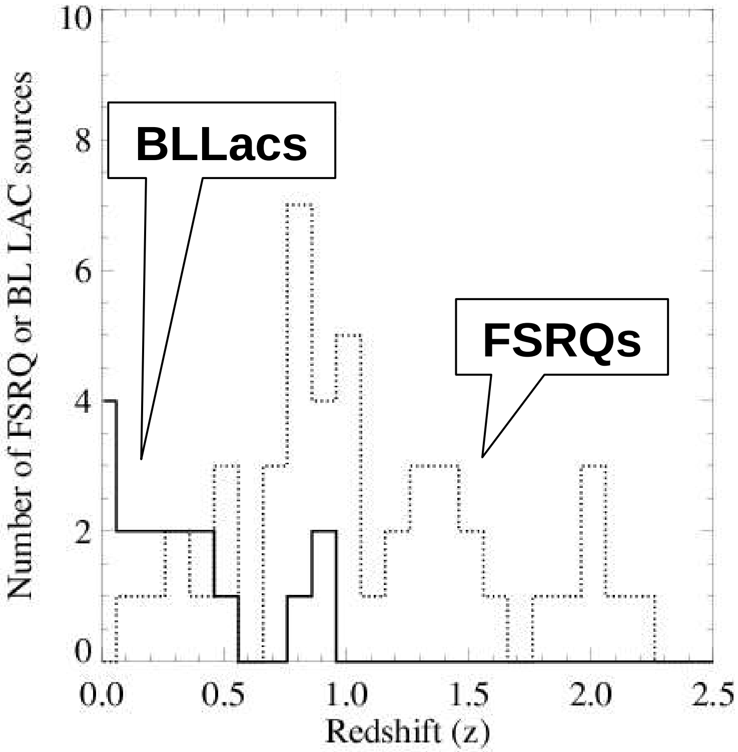


~ 100 AGNs

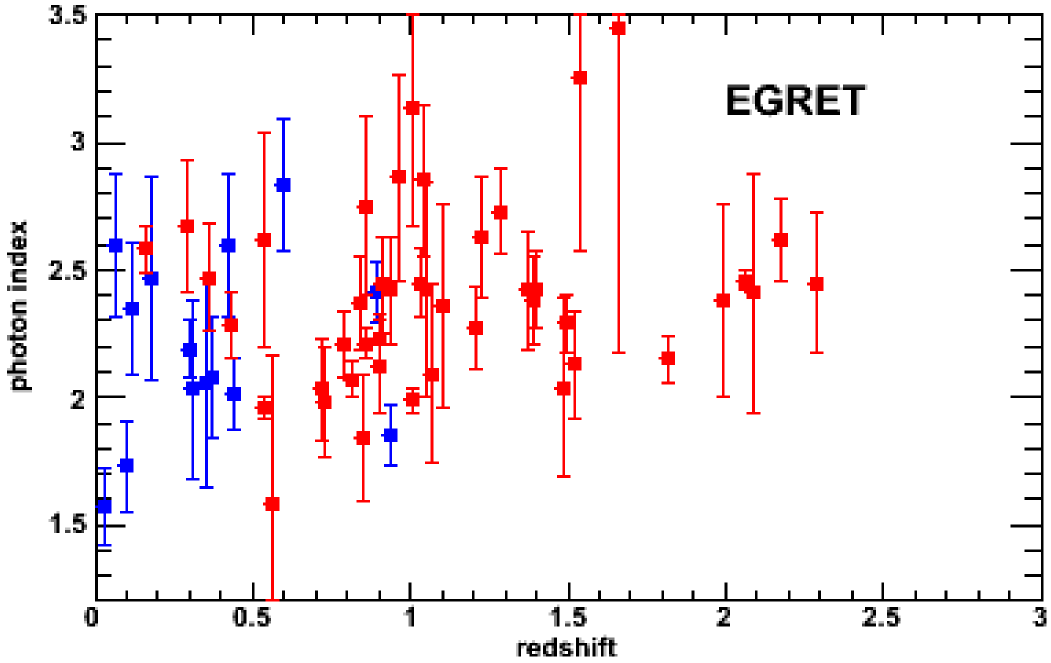
- **all radio-loud**
- **~ 97% blazars**
- **3 radio galaxies: Cen A, NGC 6251, 3C 111**
- **Mostly FSRQs: FSRQ: 75% BL Lac: 25%**
- **Mostly (> 90%) low-energy peaked blazars (synchrotron peak in opt/UV)**
- **13 blazars in first AGILE catalog**

The EGRET legacy (2)

redshift distribution

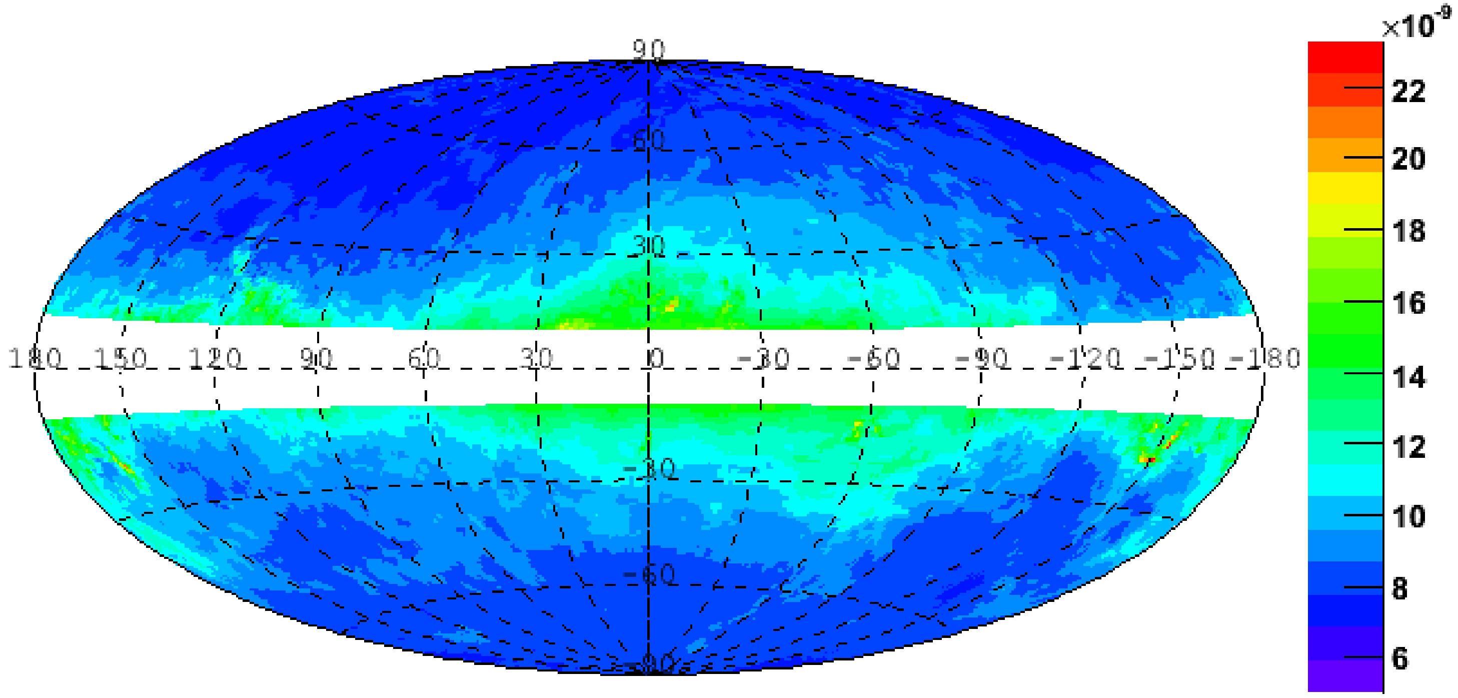


photon index vs redshift



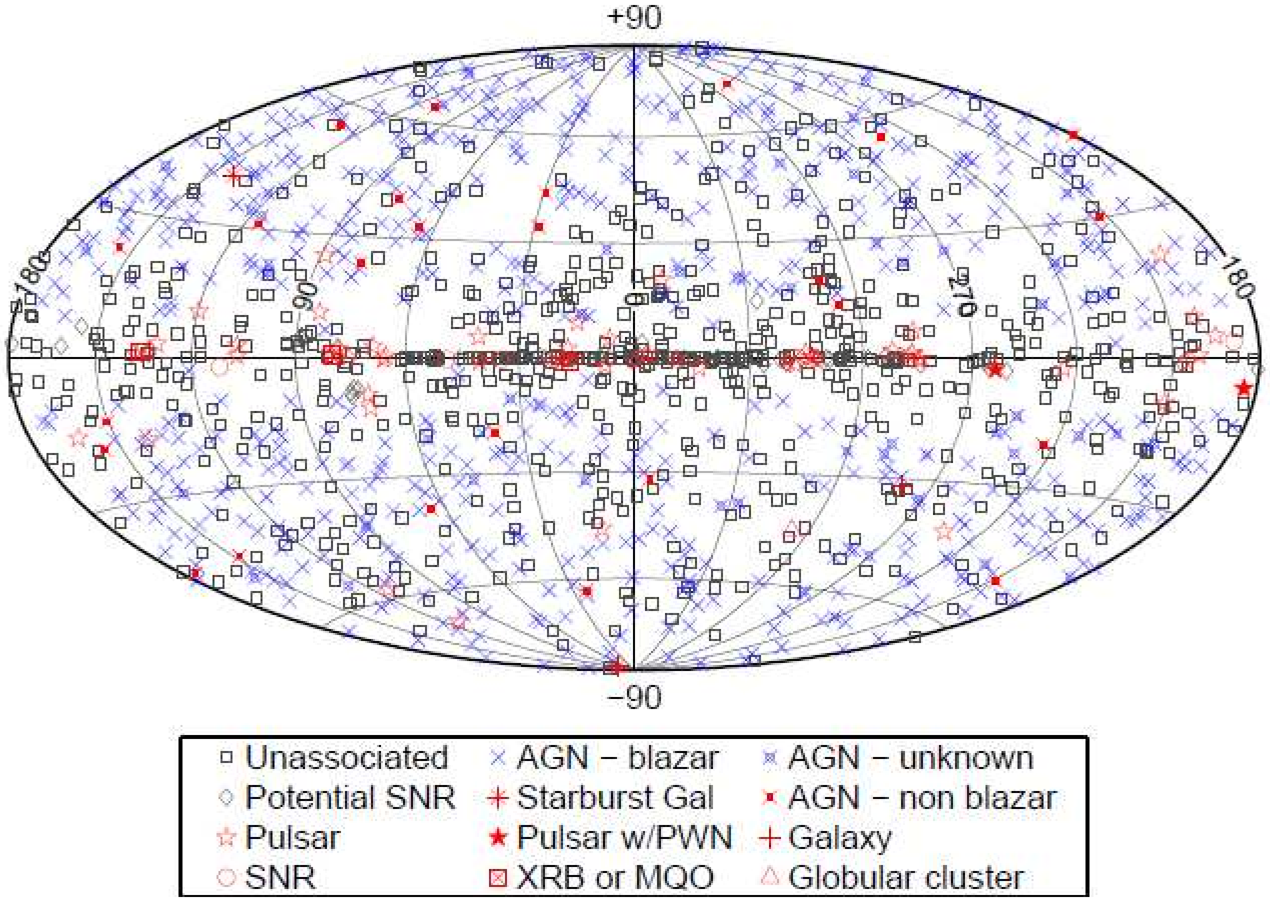
11-month sky survey

TS=100, photon index=2.2



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

1FGL catalog



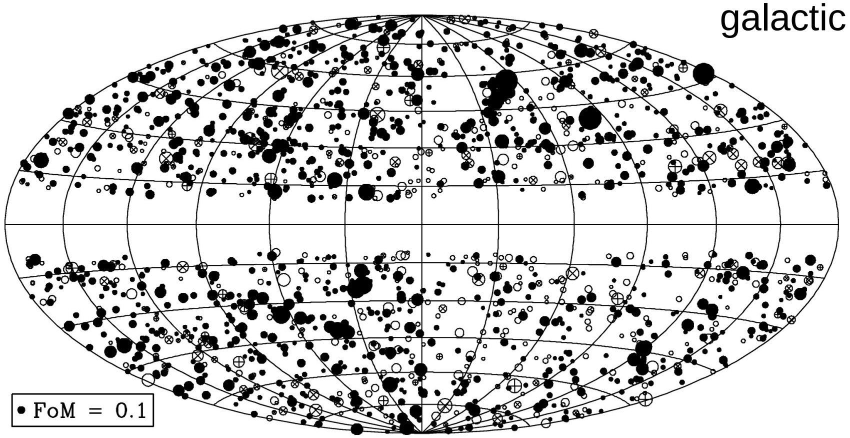
Associations

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

CGRaBS (Healey et al. 08)

1627 radio sources from CRATES association based on Figure-of-Merit (spatial, radio and X spectrum) established from EGRET

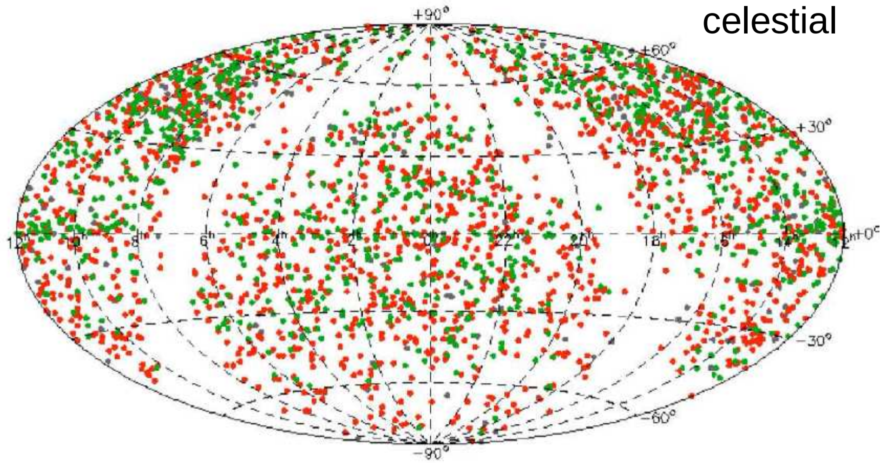
galactic



BZCat (Massaro et al. 08)

Compilation of 2500 known blazars association based on spatial coincidence (Mattox et al., 01)

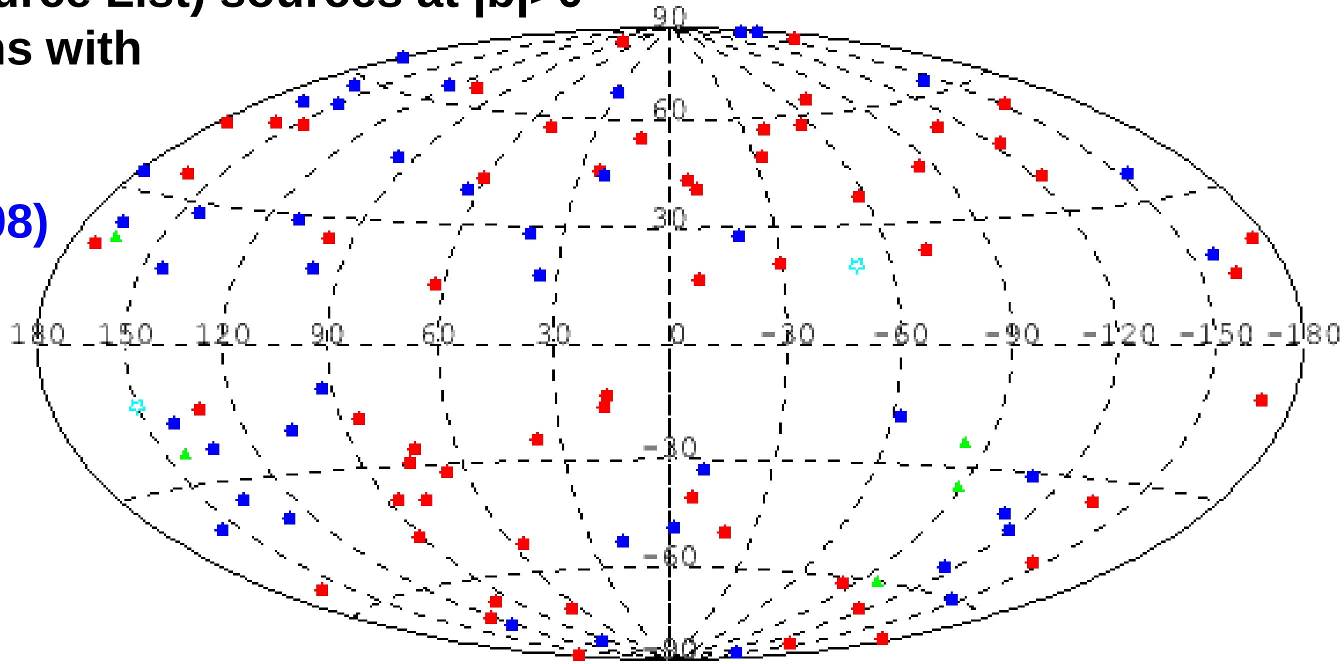
celestial



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%

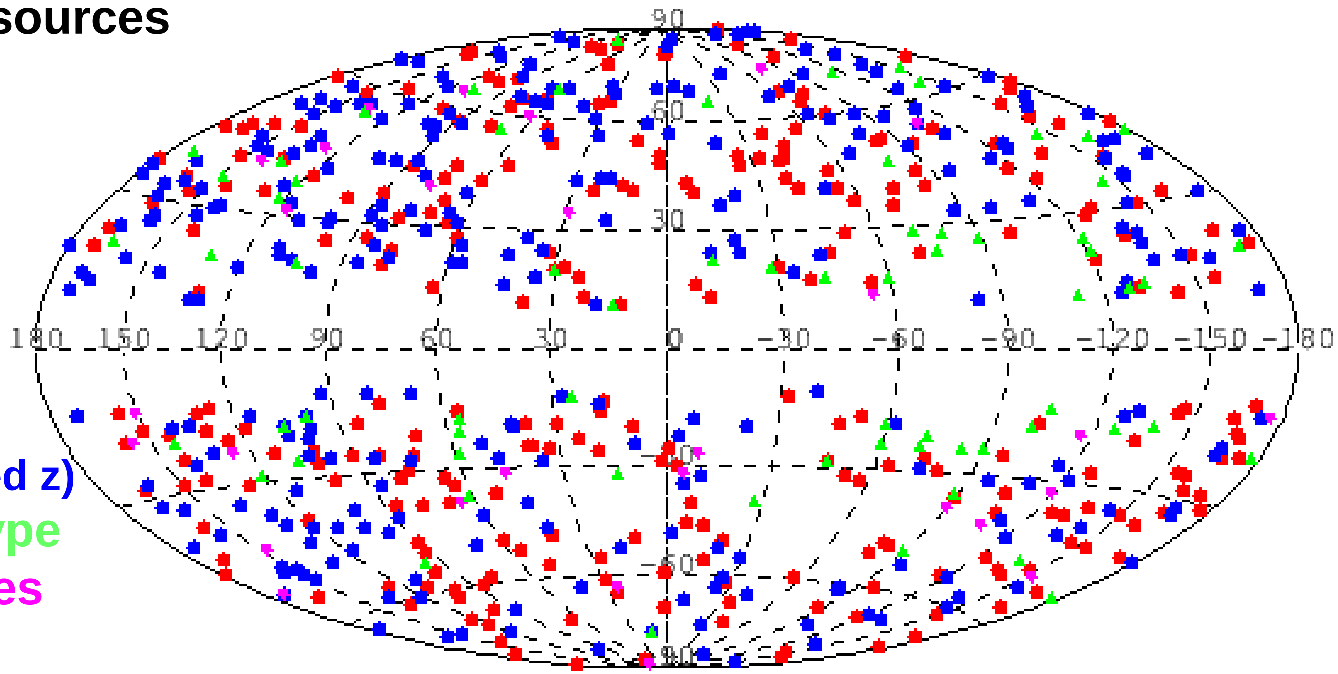
The First LAT AGN catalog (1LAC)

- **11 month data set**

Preliminary

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

- **Census:**
  - **281 FSRQs**
  - **291 BLLacs (~141 with measured z)**
  - **50 of unknown type**
  - **~10 Radio galaxies**

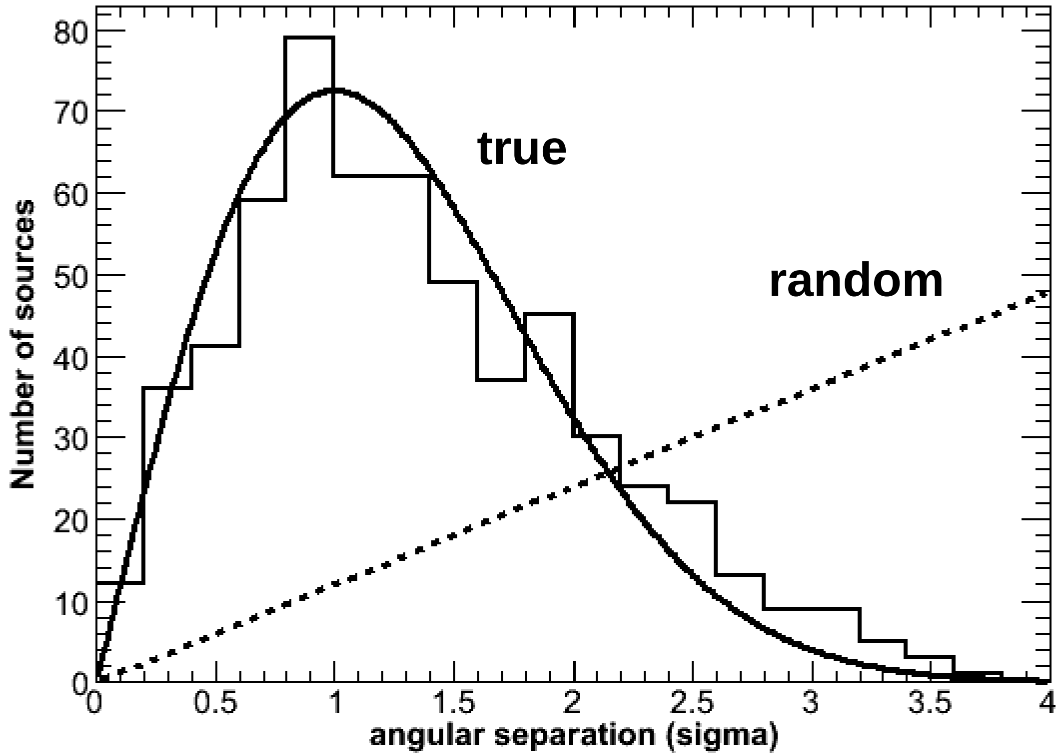


Differences between Northern Hemisphere and Southern one (FSRQs: 4%, BLLACs: 18 %)

The First Catalog of Active Galactic Nuclei Detected by the Fermi LAT
Abdo, A. A. et al. 2010, arXiv: 1002.0150

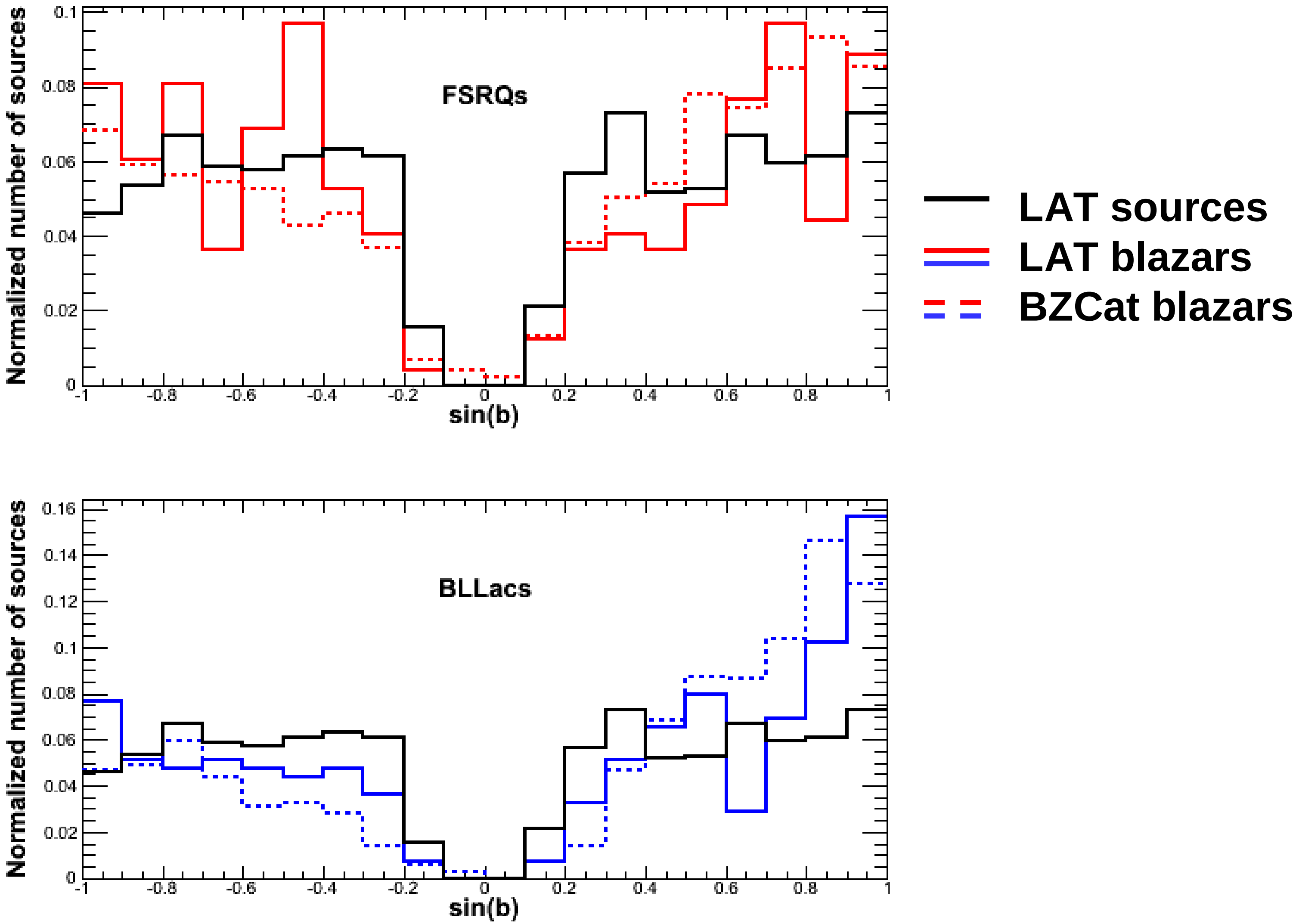
Angular separation

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

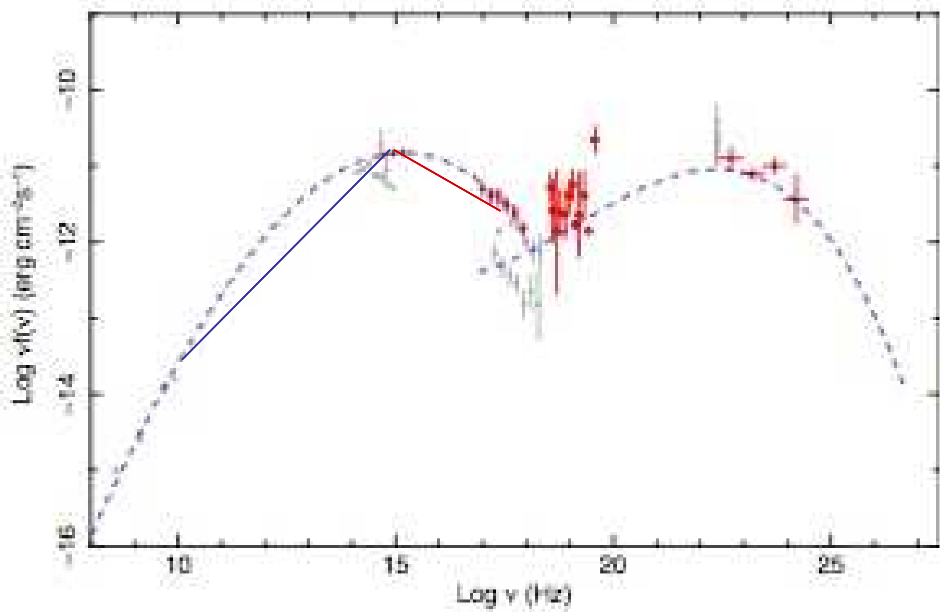


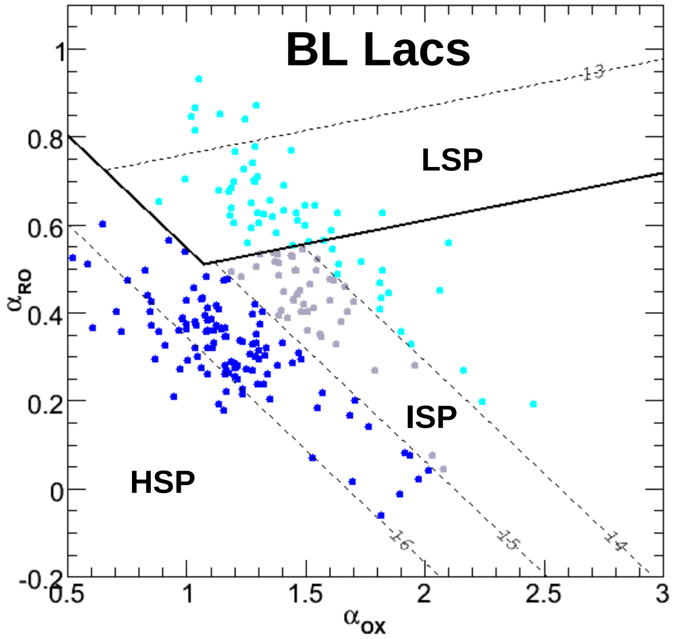
Distance between LAT source and AGN counterpart normalized to the 68% containment radius

Galactic latitude distributions



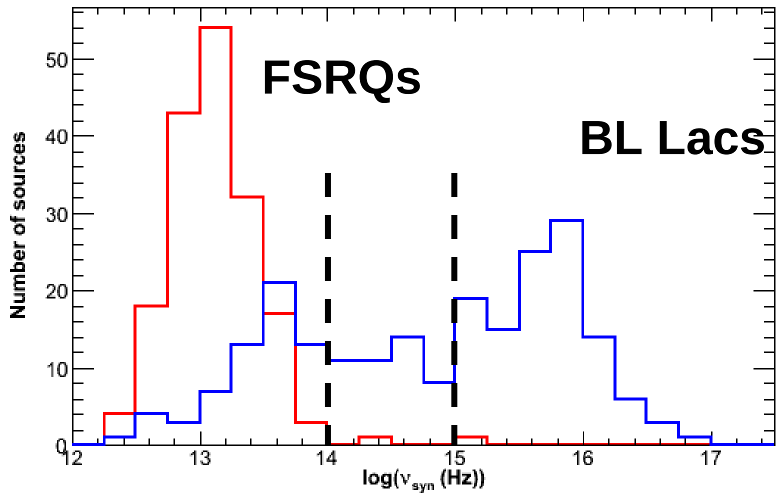
SED-based classification





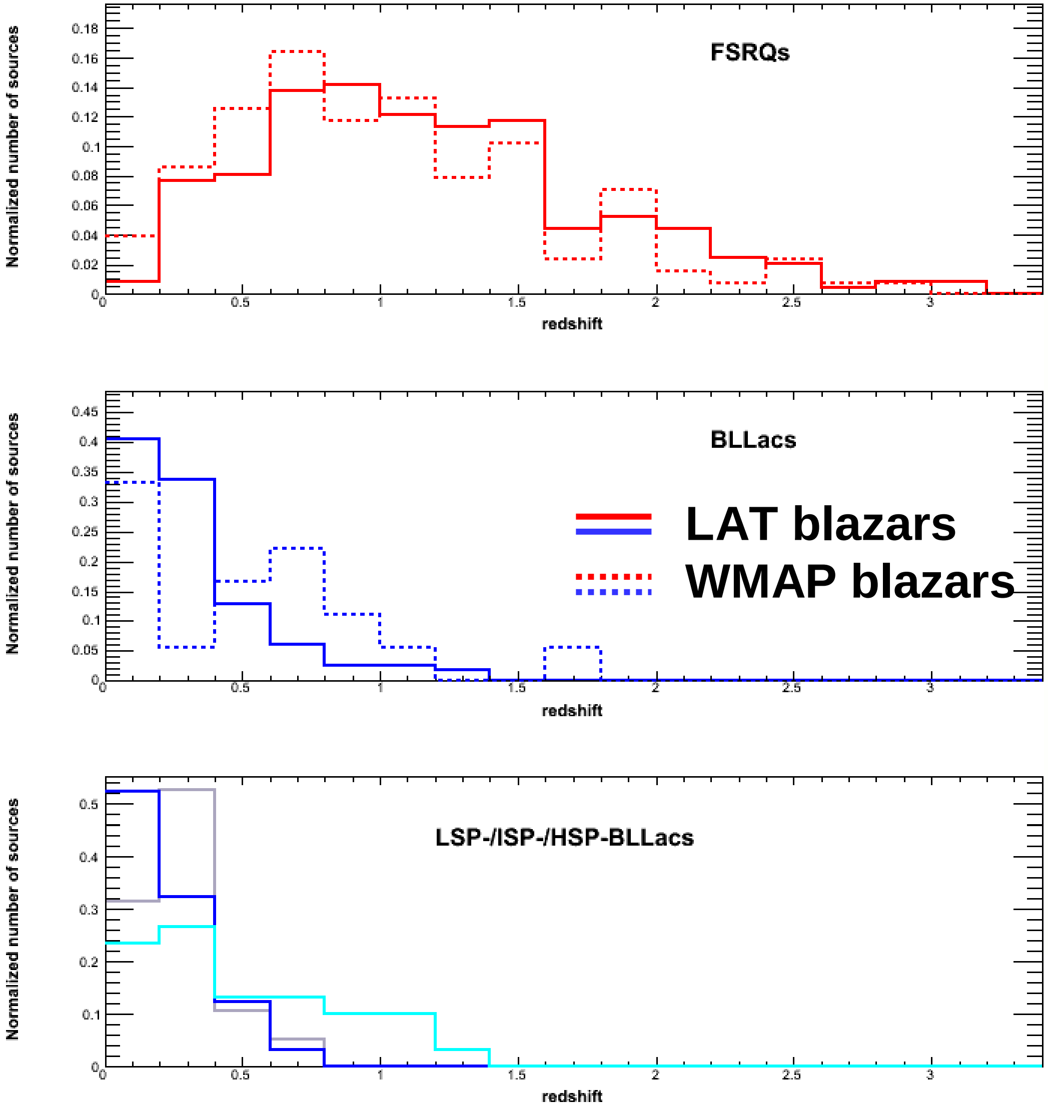
- relation with ν_{syn} estimated from α_{ox}, α_{ro}
- subclasses assigned from ν_{syn}
  LSP, ISP, HSP: low-, intermediate-, high-synchrotron peaked blazars, resp.
  - LSP: $\log(\nu_{syn}) < 14$
  - ISP: $14 < \log(\nu_{syn}) < 15$
  - HSP: $\log(\nu_{syn}) > 15$

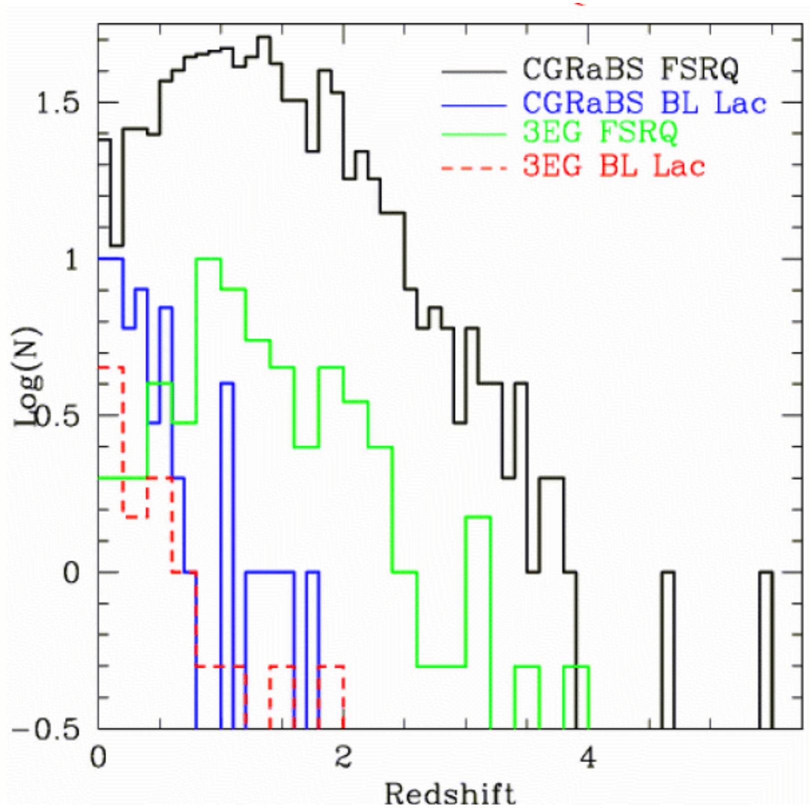
  with ν_{syn} in Hz



Redshift distributions

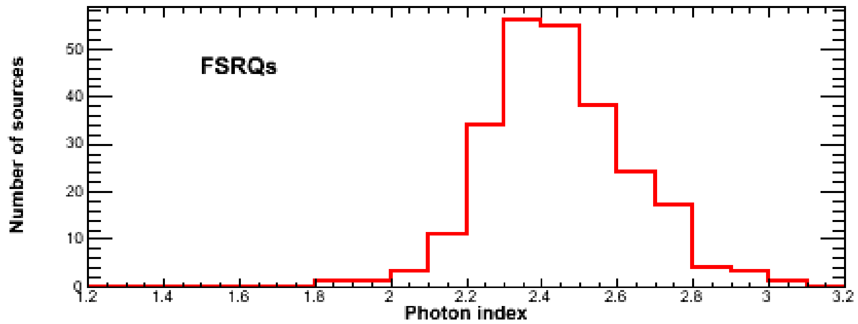
Preliminary

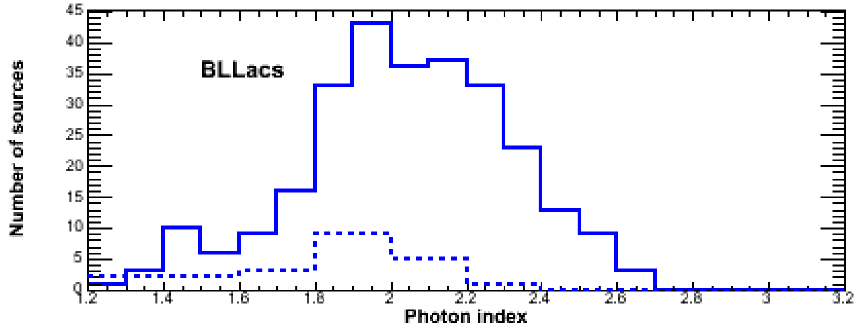


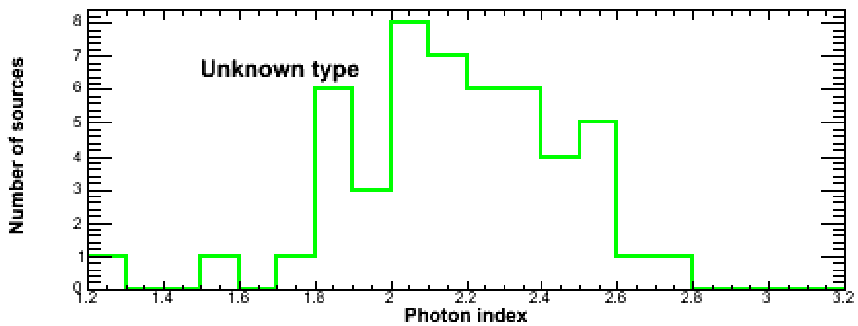


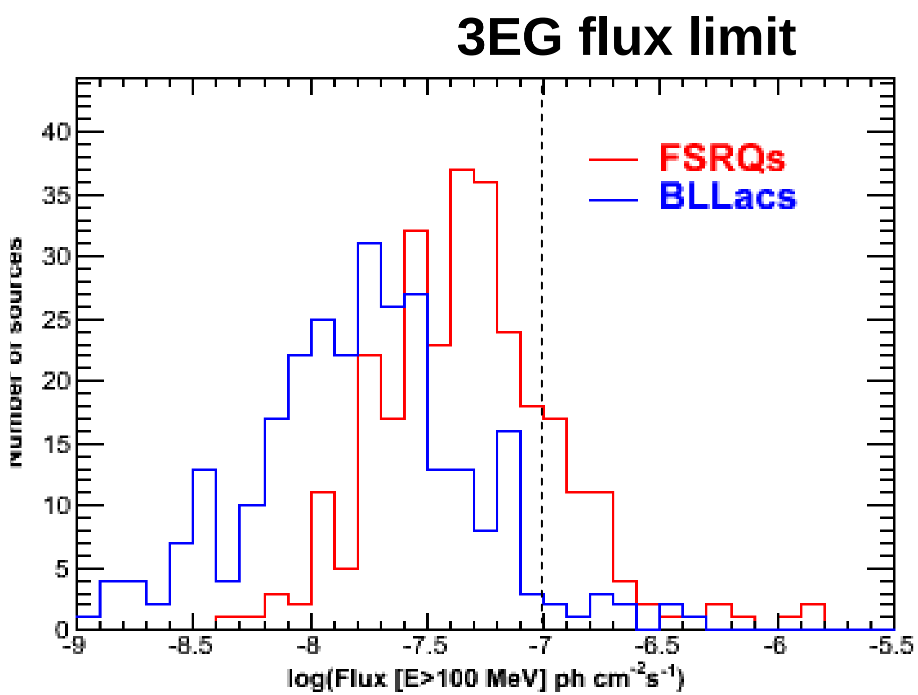
Photon index – Flux distributions

Preliminary

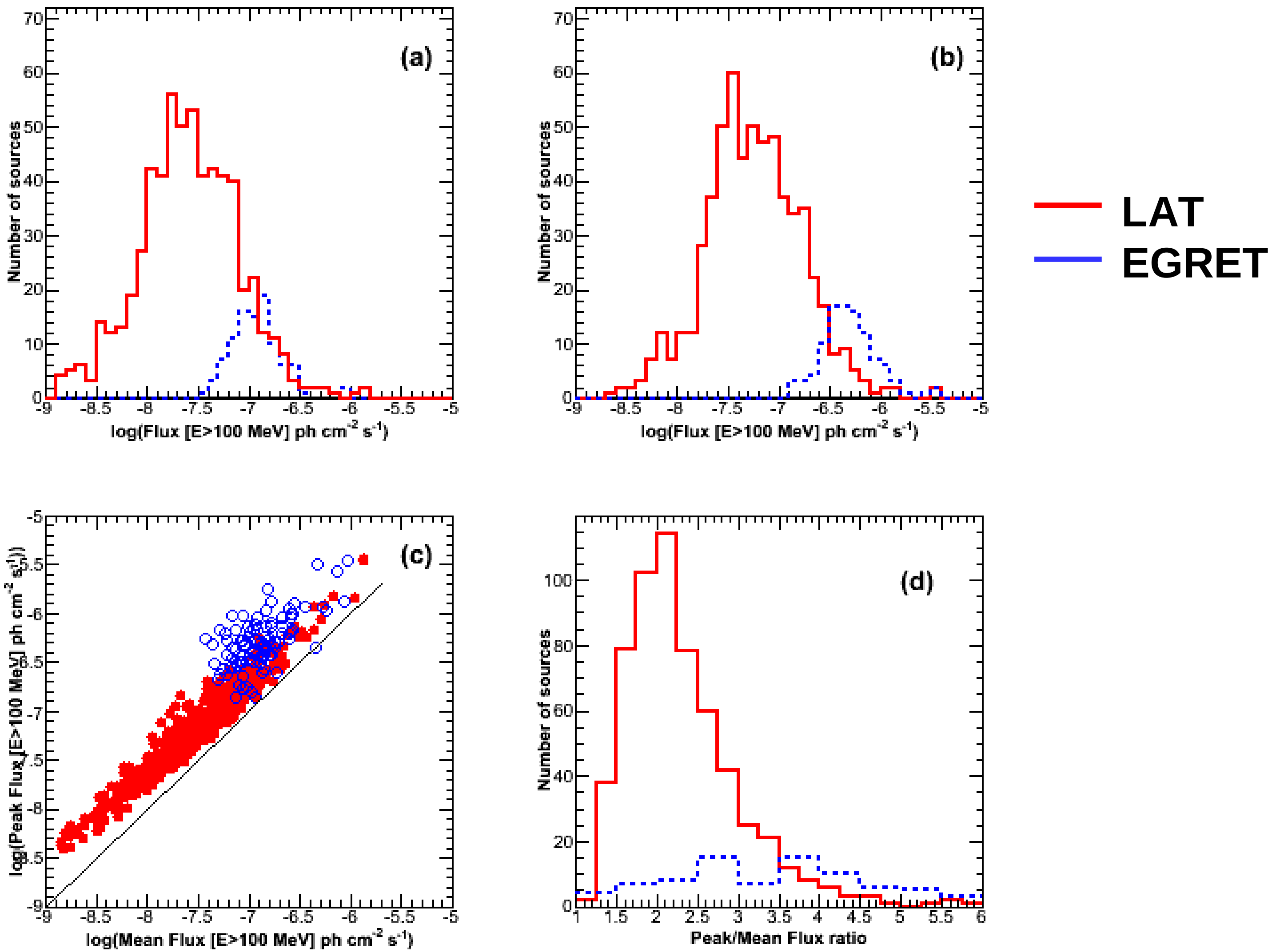




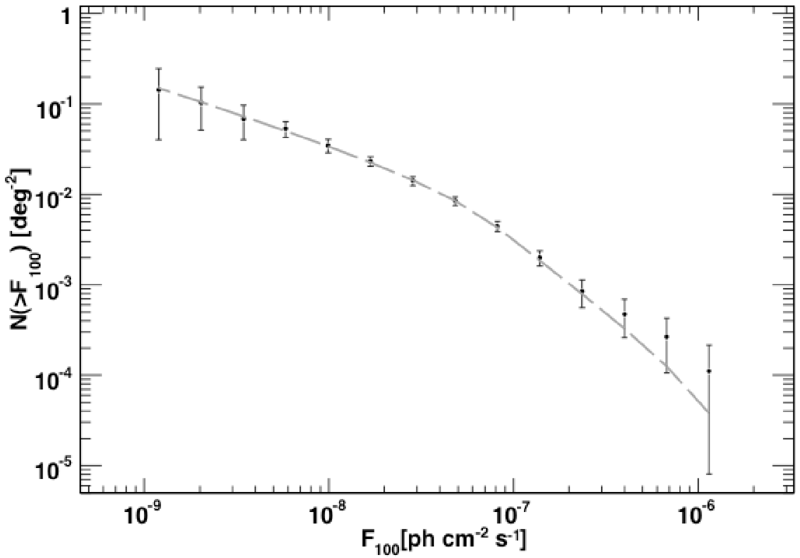




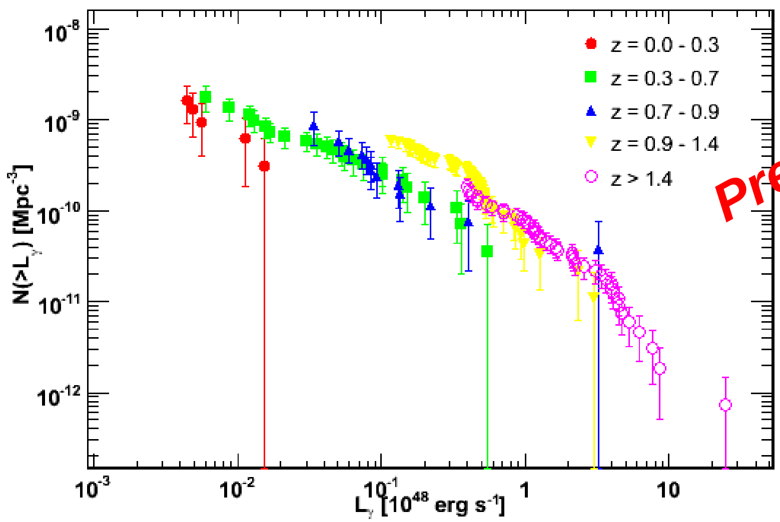
Mean/Peak Flux distributions

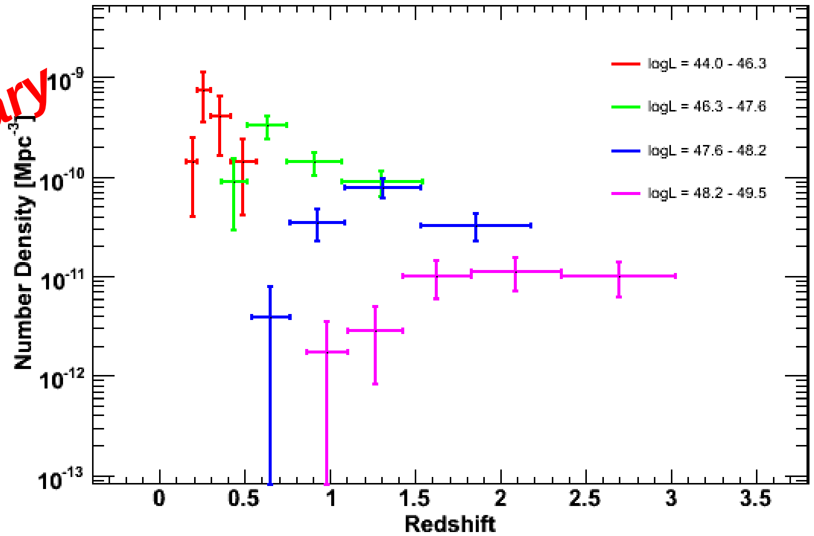


Population studies



- Log N- Log S presents a flattening around F[E>100 MeV]=6.7 x10^{-8} ph $cm^{-2}s^{-1}$
- FSRQ densities peak at a redshift which increases with increasing luminosity
- contribution of blazars to Extragalactic Diffuse Background under evaluation





GeV-TeV connection

28 TeV Blazars/AGNs in the 1 LAC

Their hard spectra makes the LAT detection easier !

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

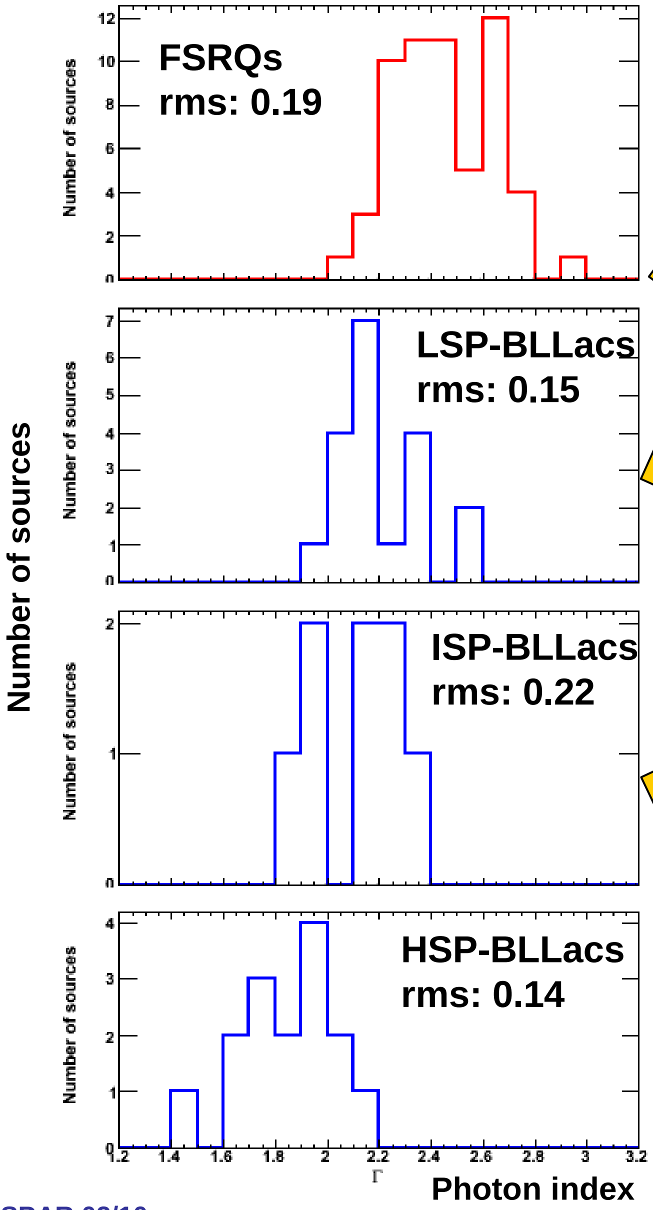
LAT Source	TeV Association	RA[a]	DEC[a]
1FGL J0222.6+4302	3C 66A	35.8000	43.0117
1FGL J0319.7+1847	RBS 0413	49.9658	18.7594
1FGL J0416.8+0107	1ES 0414+009	64.2184	1.0901
1FGL J0449.5−4350	PKS 0447−437	72.3529	−43.8358
1FGL J0507.9+6738	1ES 0502+675	76.9842	67.6233
1FGL J0521.7+2114[b]	VER J0521+211[b]	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/).

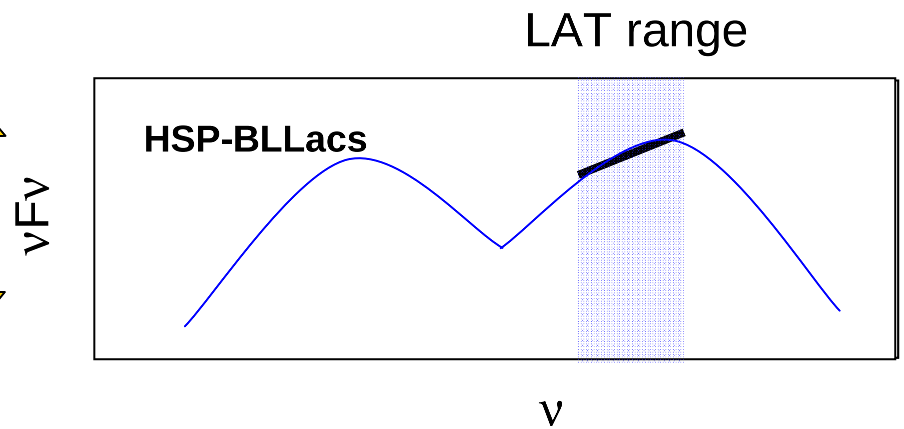
[b]This source is at low Galactic latitude ($|b| < 10°$) and is thus not formally in the 1LAC but appears in Table 2.

Spectral properties in the γ-ray band

Photon index distributions in LBAS

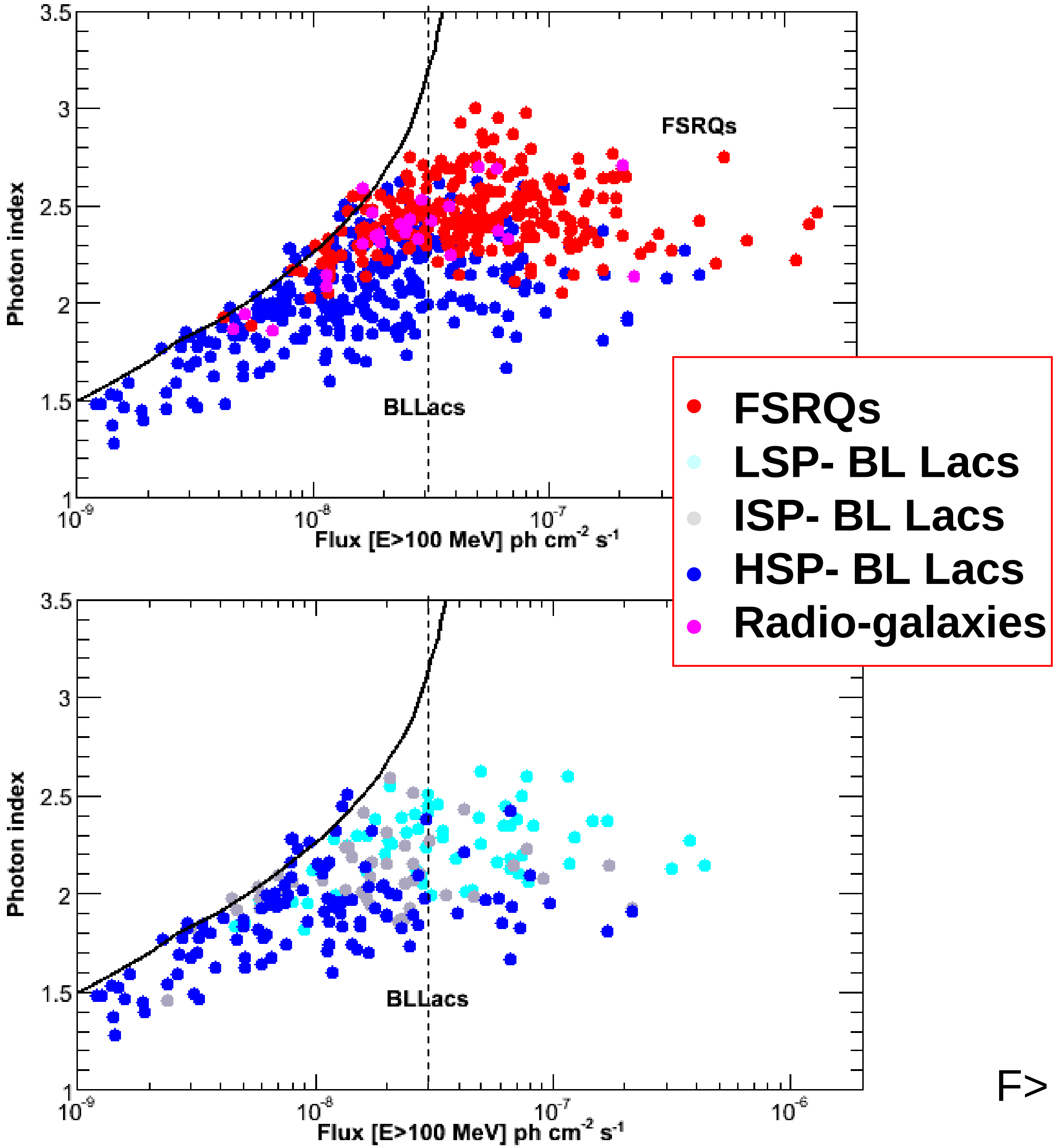


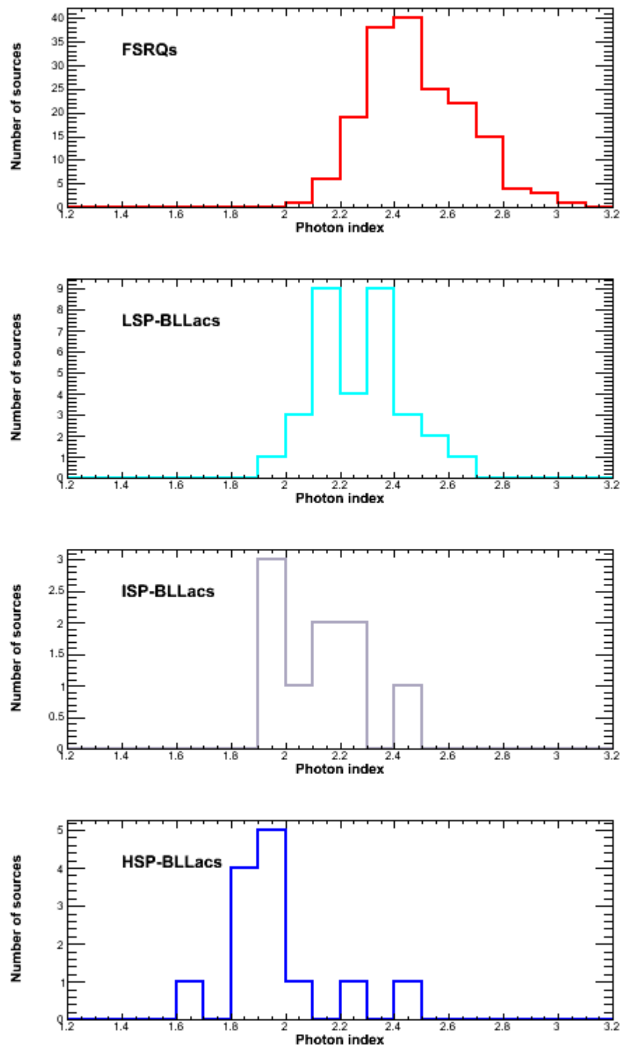
Photon index determined with the first 6-month data set



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

Photon index distributions





F> 3x10^{-8} ph cm^{-2}s^{-1}

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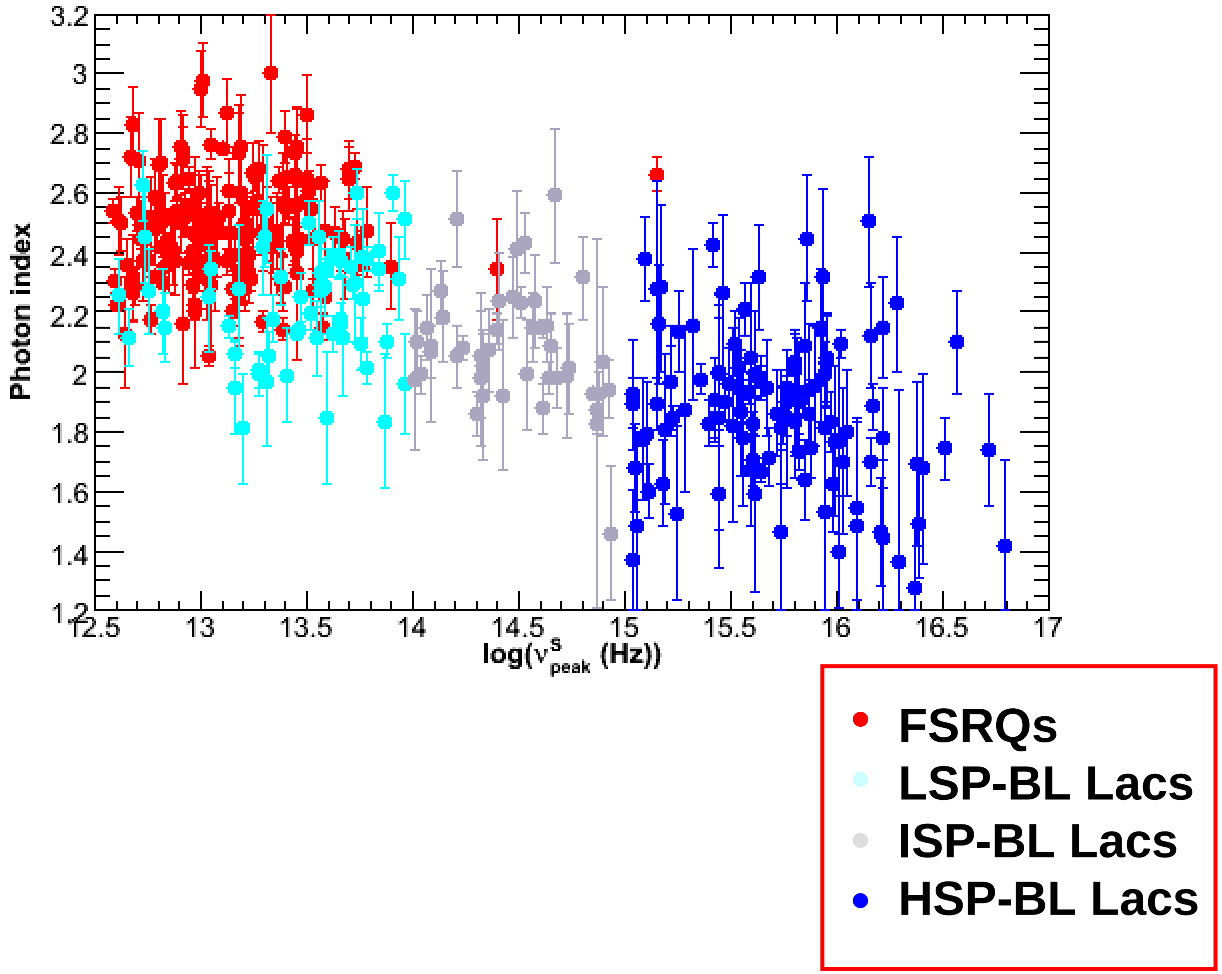
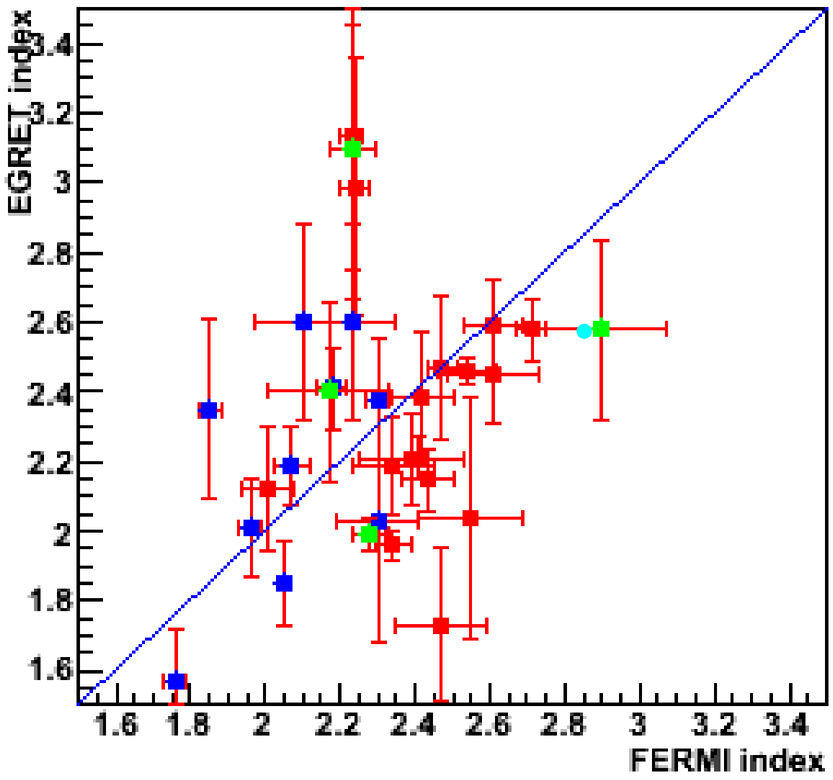

Photon index
log(ν^S_peak (Hz))
FSRQs
LSP-BL Lacs
ISP-BL Lacs
HSP-BL Lacs

EGRET vs FERMI photon index

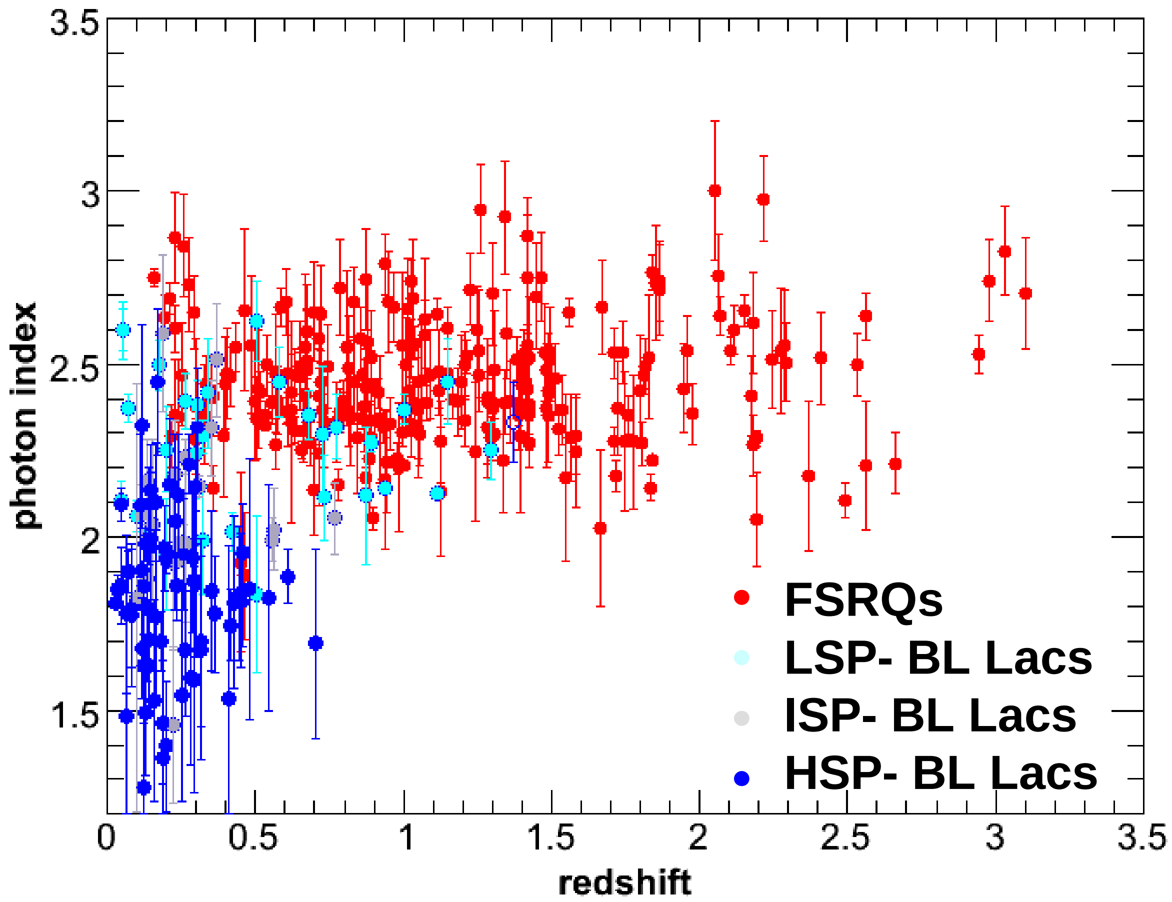


FSRQ
BLLac
Uncertain
Radio galaxies

photon index vs redshift

No evolution of photon index vs z for FSRQs

Strong evolution for BLLacs but just due to different subclasses (LSP, ISP, HSP) having different redshift distributions



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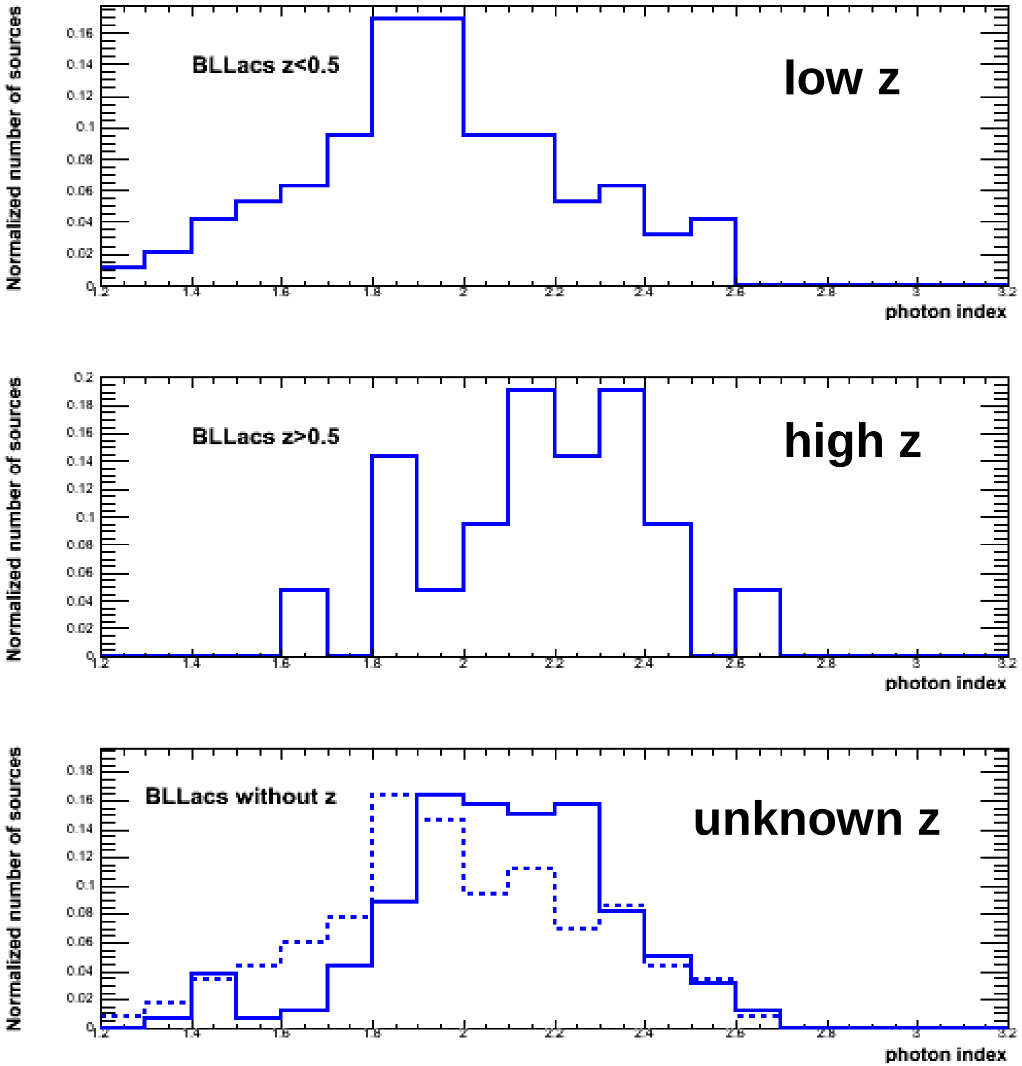
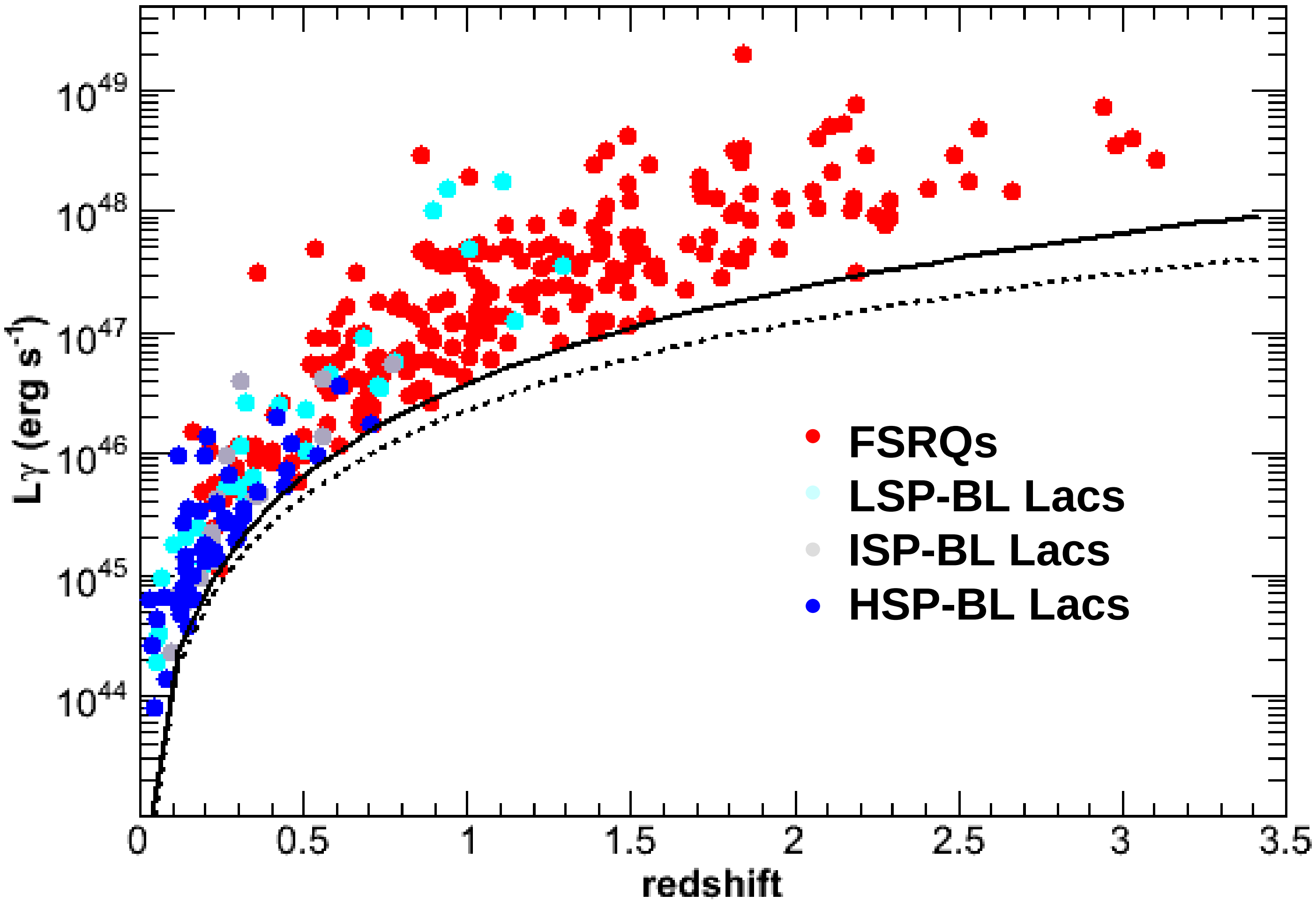
photon index for BLLacs



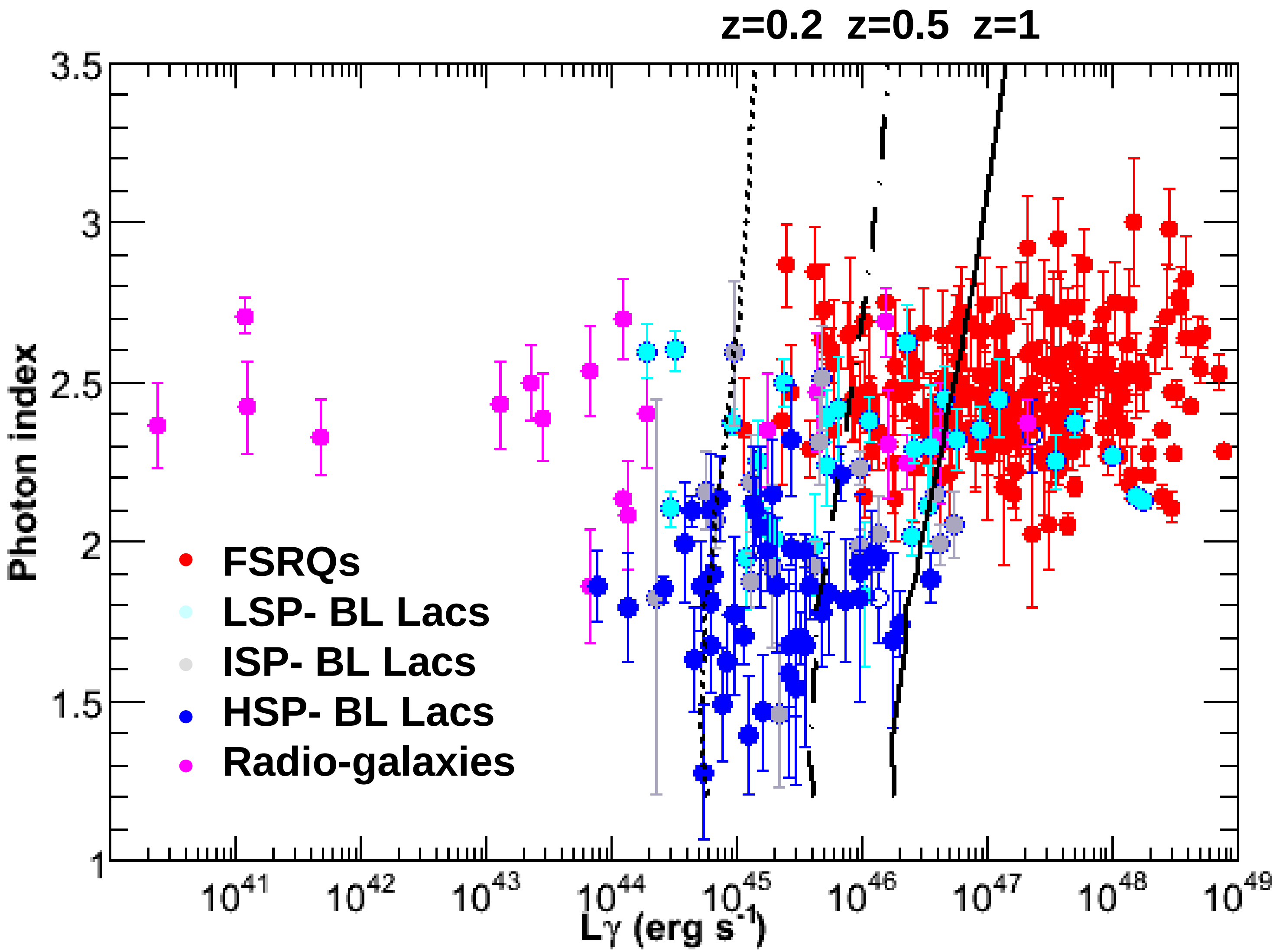
Luminosity vs redshift

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

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



Photon index vs luminosity



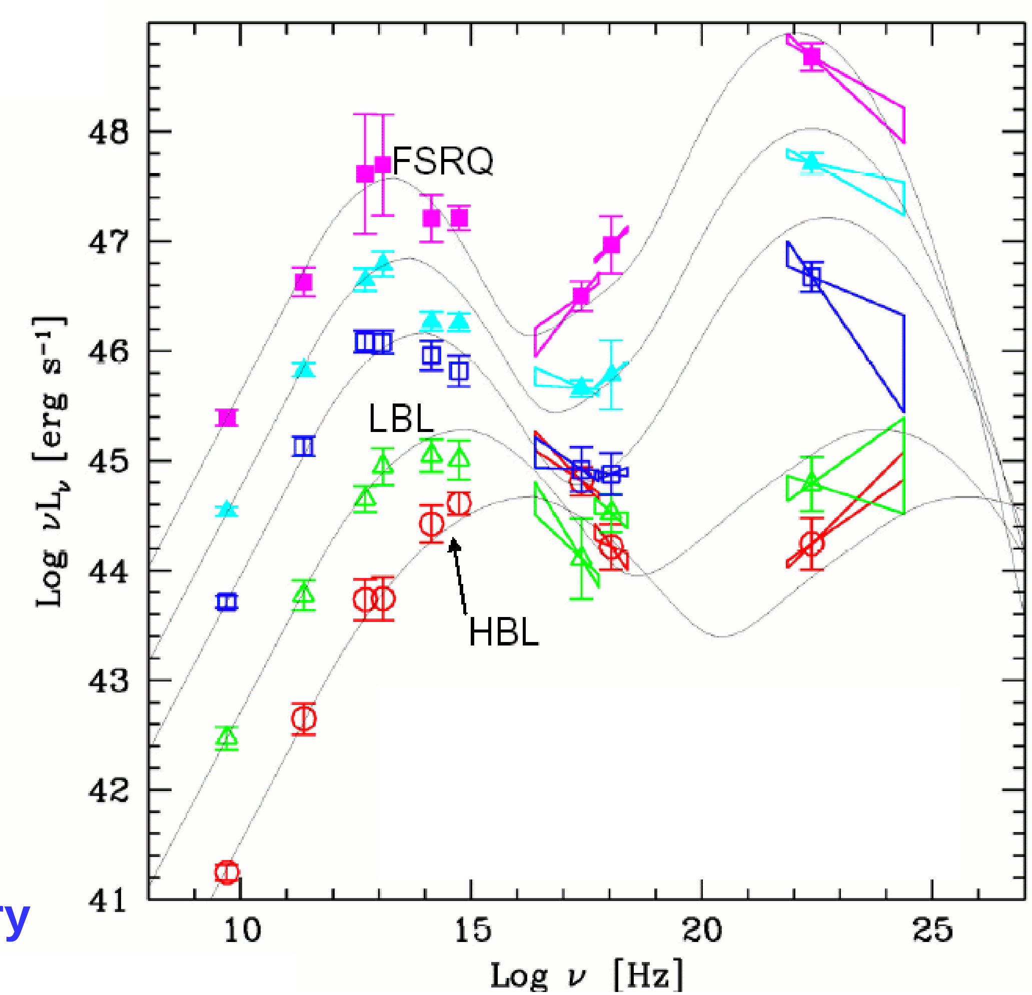
Blazar Sequence: « Grand Unification » (?)

Donato+ (2002) Fossati+(1998)

Average SEDs of blazars binned according to radi luminosity

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

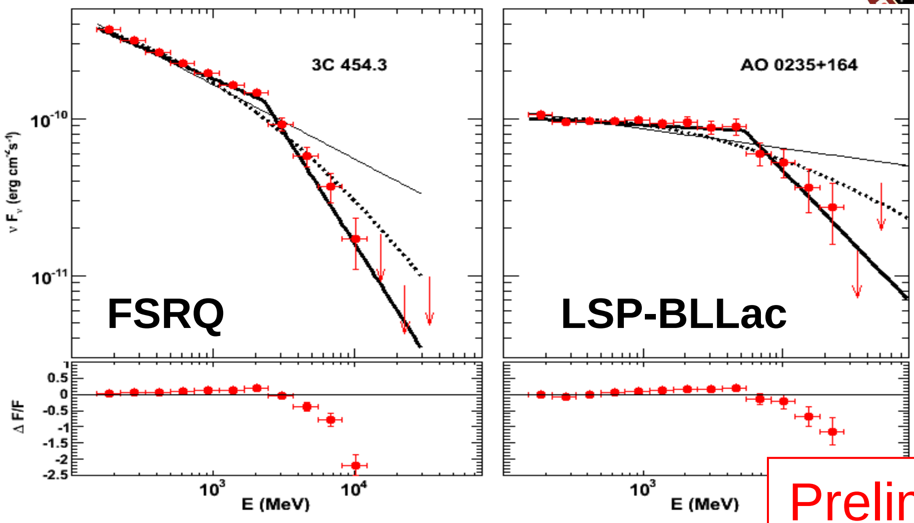
- $\nu_{peak} \propto L^{-1}$
- ν_{HE}/ν_{LE} =cst
- $L_{HE} \propto L_{radio}$



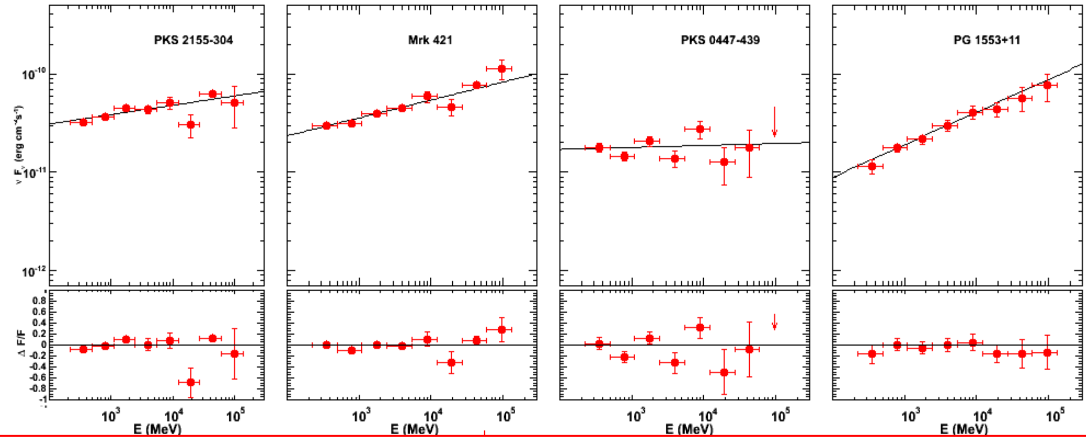
Hypothesis:
Results of reduced accretion rate leading to an evolutionary link between classes:
FSRQ →LSP BLLacs →HSP BLLacs
(Ghisellini et al., Boettcher and Dermer, Cavaliere and D'Elia)

Non-power law spectra

- General feature in FSRQs and many LSP-BLLacs
- Absent in HSP-BLLacs
- Broken power law model seems to be favored
- $\Delta\Gamma$~1.0 > 0.5 $\rightarrow$ not from radiative cooling
- Possible explanations:
  - feature in the underlying particle distribution
  - Klein-Nishina effect
  - γ–γ absorption effect
- Implications for EBL studies and blazar contribution to extragalactic diffuse emission



Preliminary

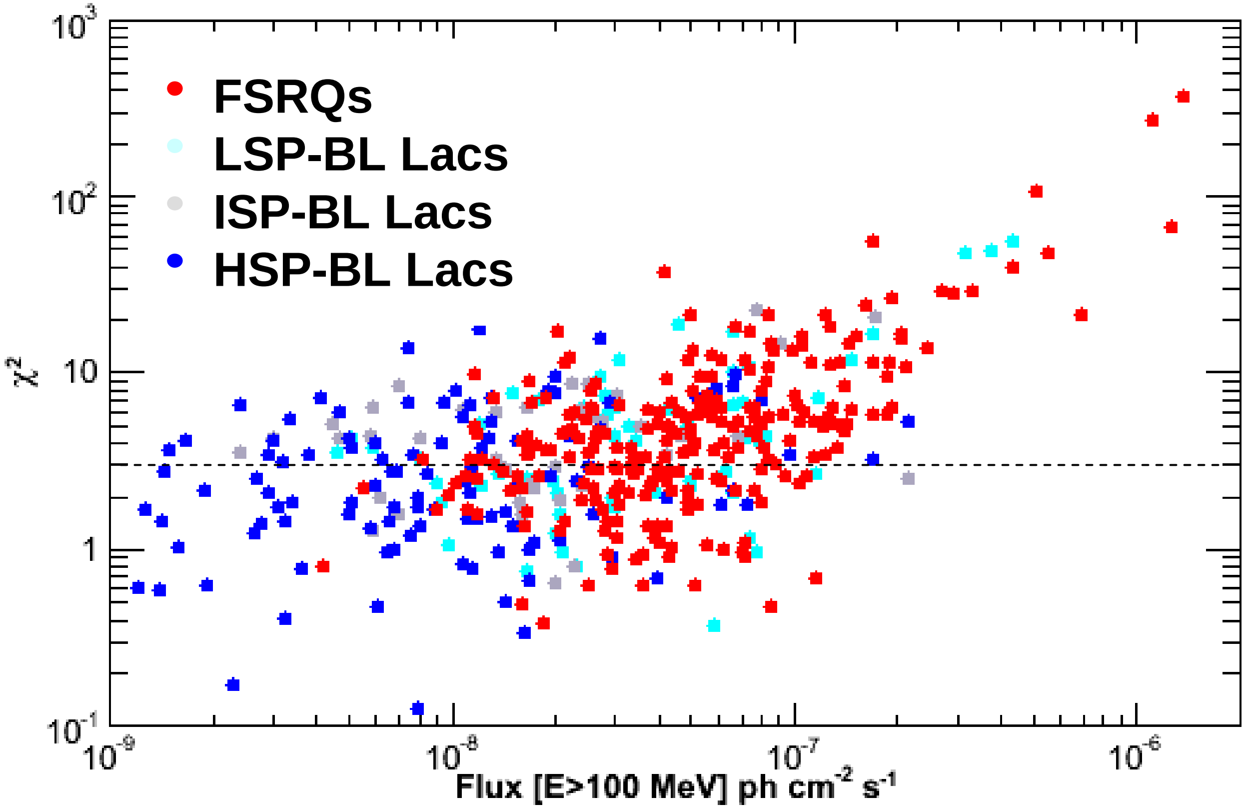


Challenge for modelers to account for the break and the relative constancy of spectral index with time

curved spectra

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

$$C = \sum_i \frac{(F_i - F_i^{\rm PL})^2}{\sigma_i^2 + (f_i^{\rm rel} F_i)^2}$$



Benoit Lott

Relative constancy of photon index

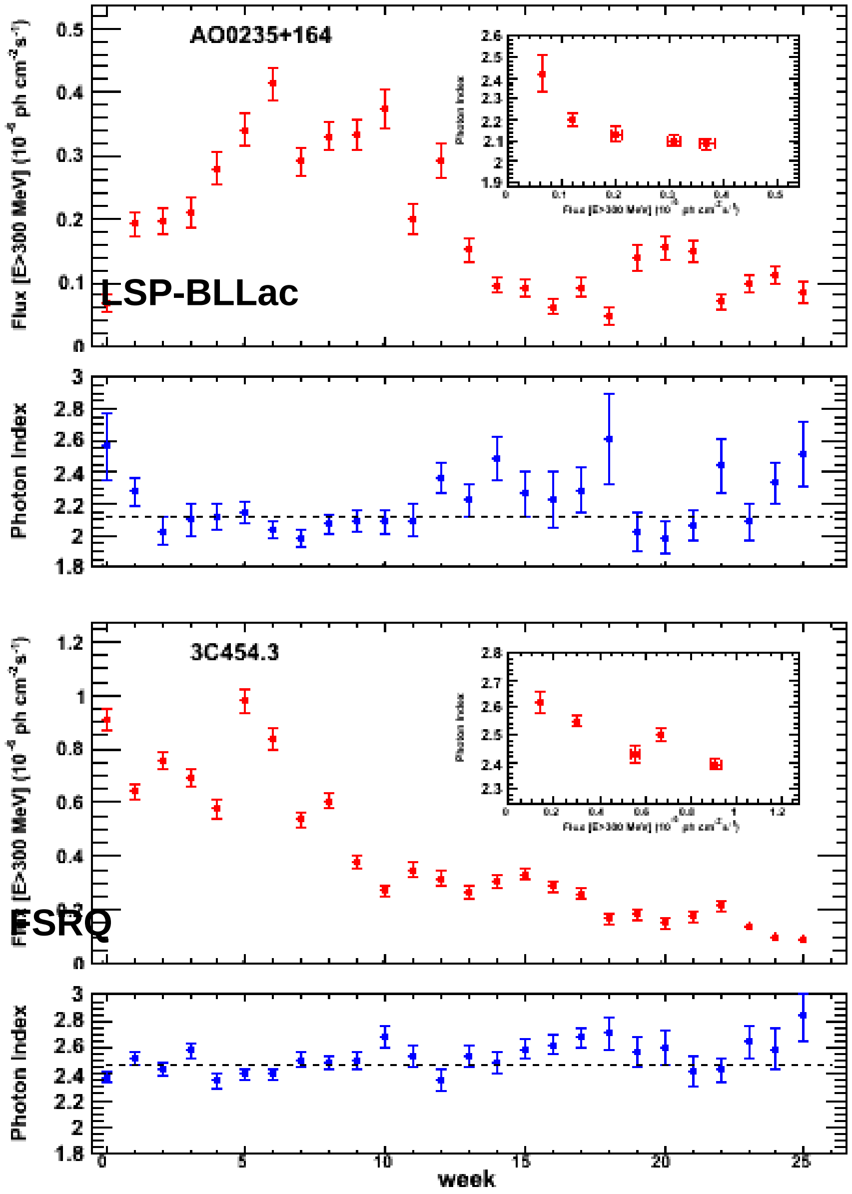
Weekly light curves

Slight « harder when brighter » effect observed

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

Process stabilizing the spectral shape at work?

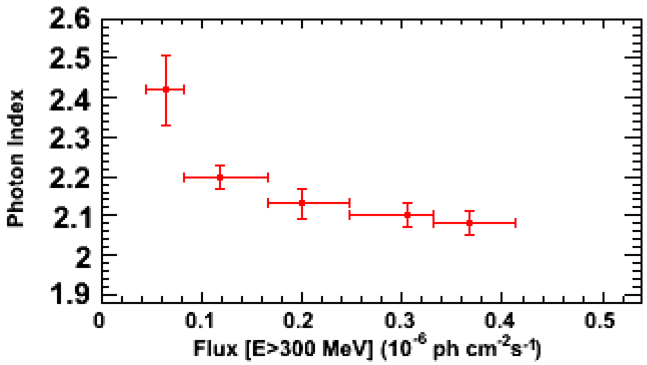
Continous injection of particles?

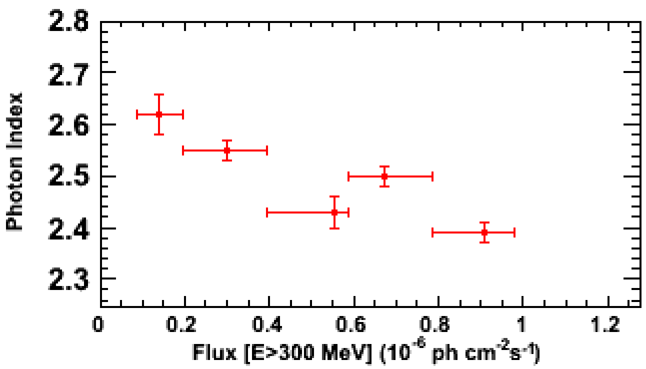


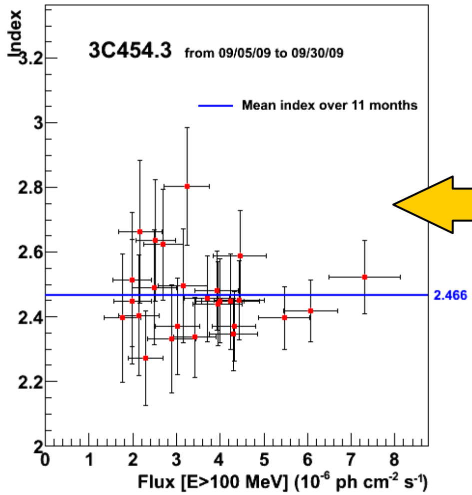
Relative constancy of photon index

Preliminary

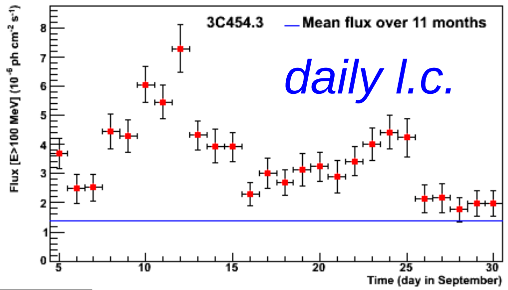
weekly l.c.

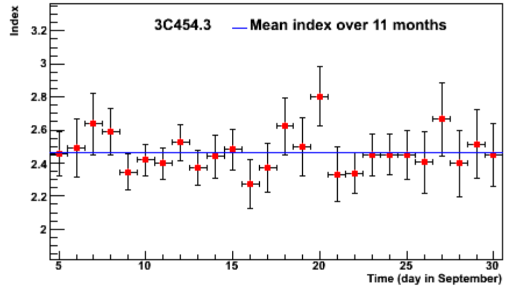




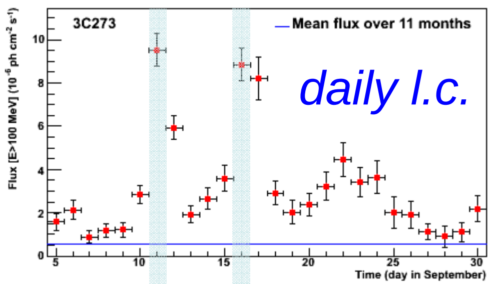


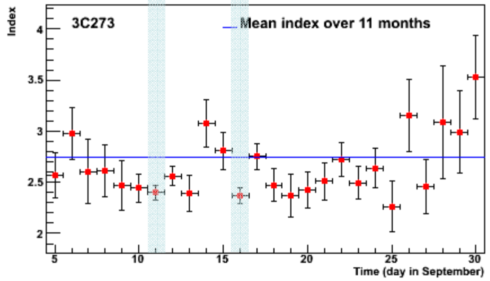
daily l.c.

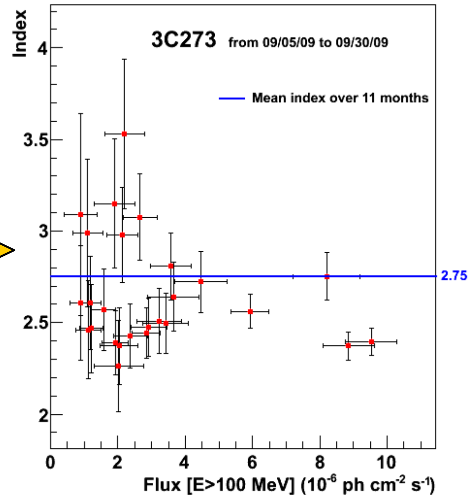




daily l.c.



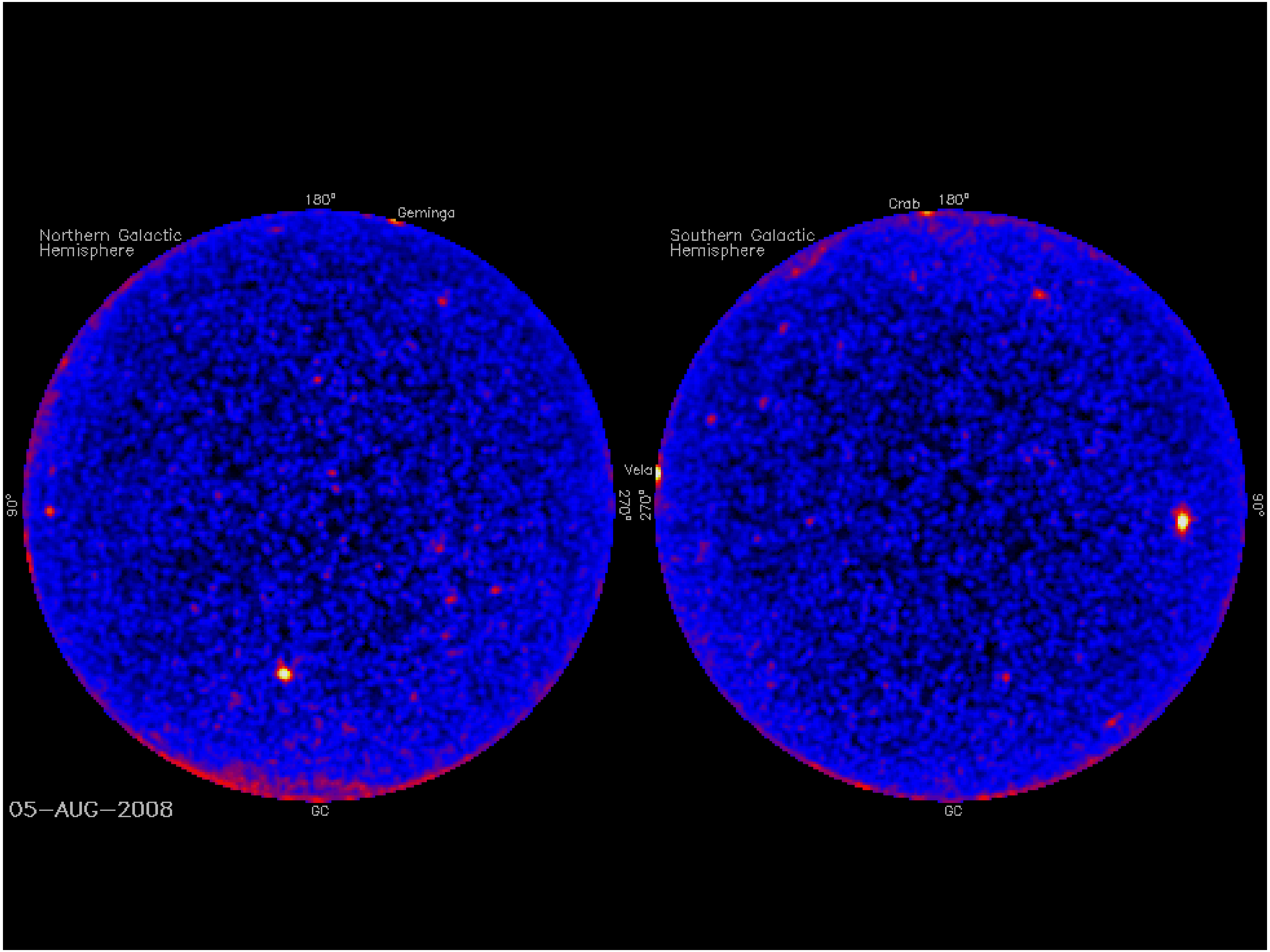




« Harder when brighter » effects observed but moderate variations ($\Delta\Gamma$ <0.3) seem to be the rule
Process stabilizing the spectral shape?

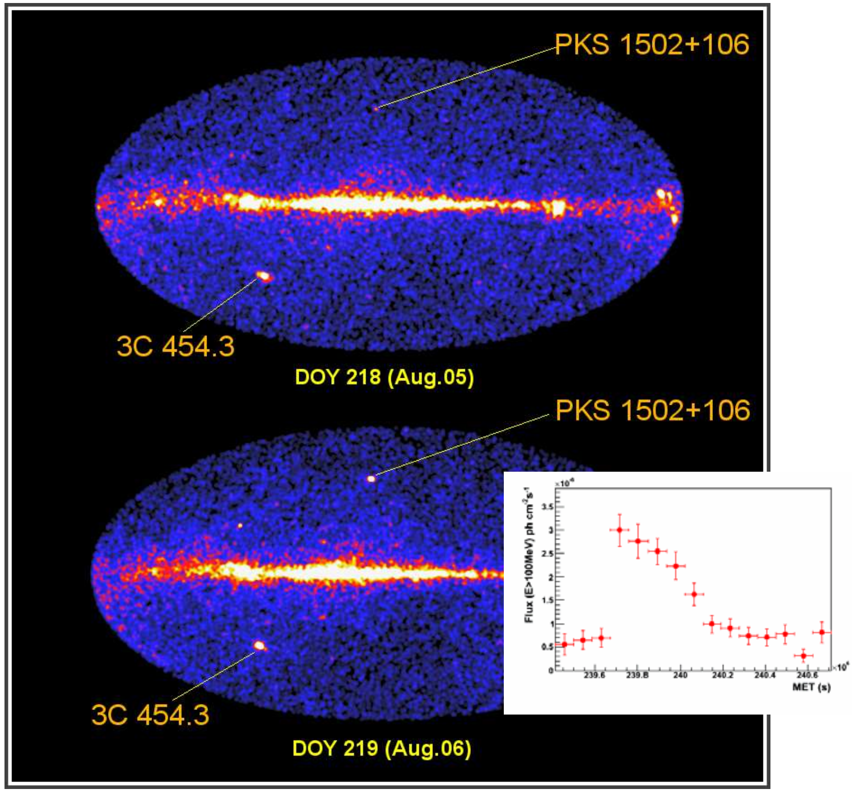
Benoit Lott

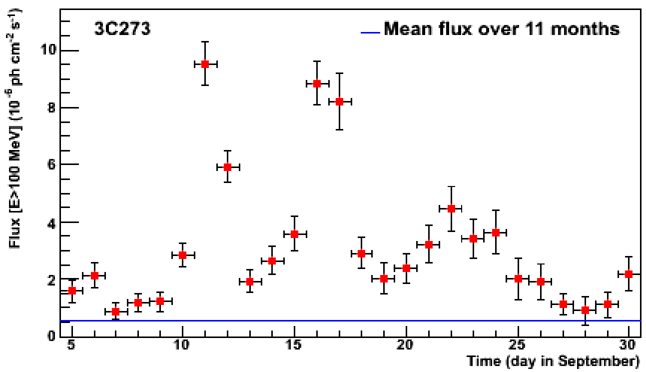
Temporal properties in the γ-ray band



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

The variable sky





~50 Astronomers telegrams

(alert threshold:

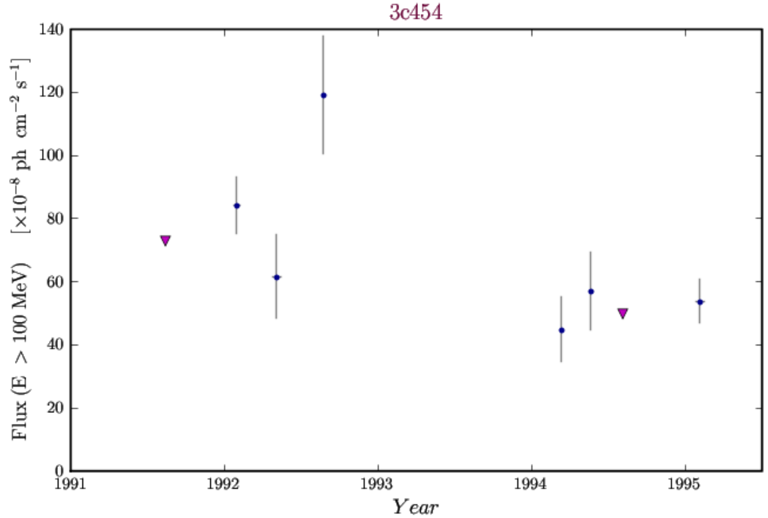
F[E>100 MeV]~10^{-6} ph cm^{-2} s^{-1})

- **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**

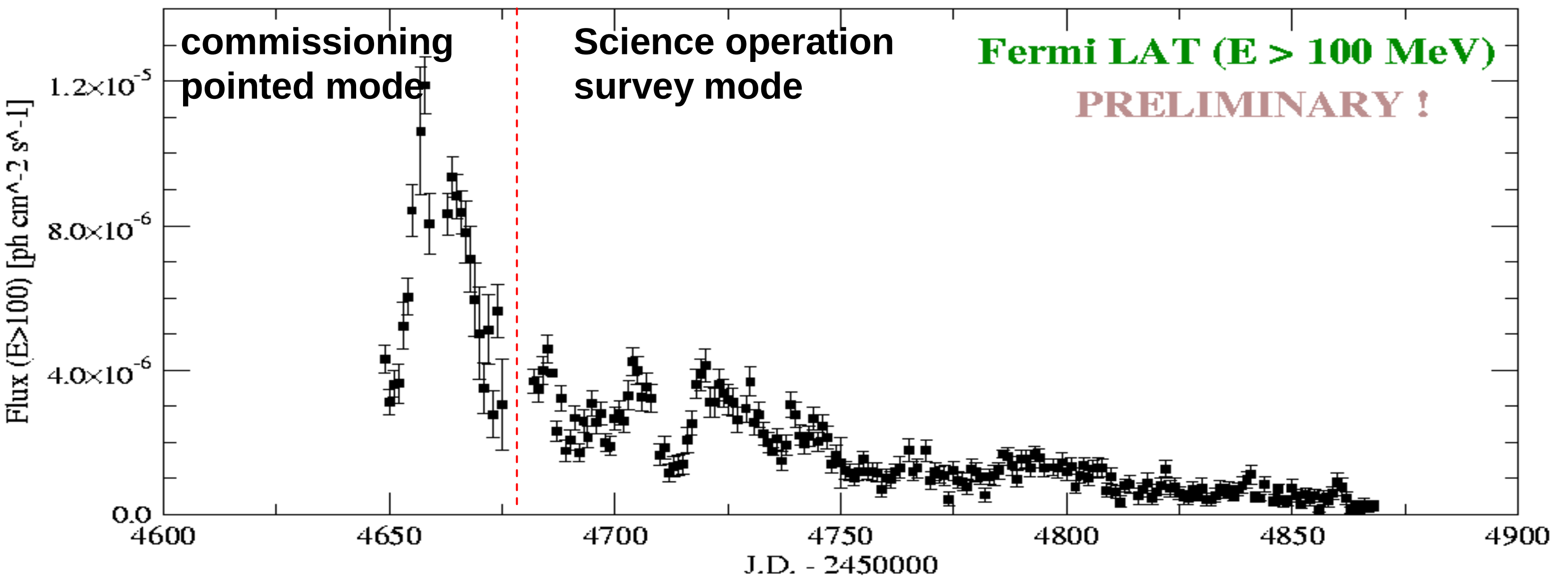
Flare Advocates issue alerts and feed the Fermi blog

Source monitoring

Ex: 3C454.3

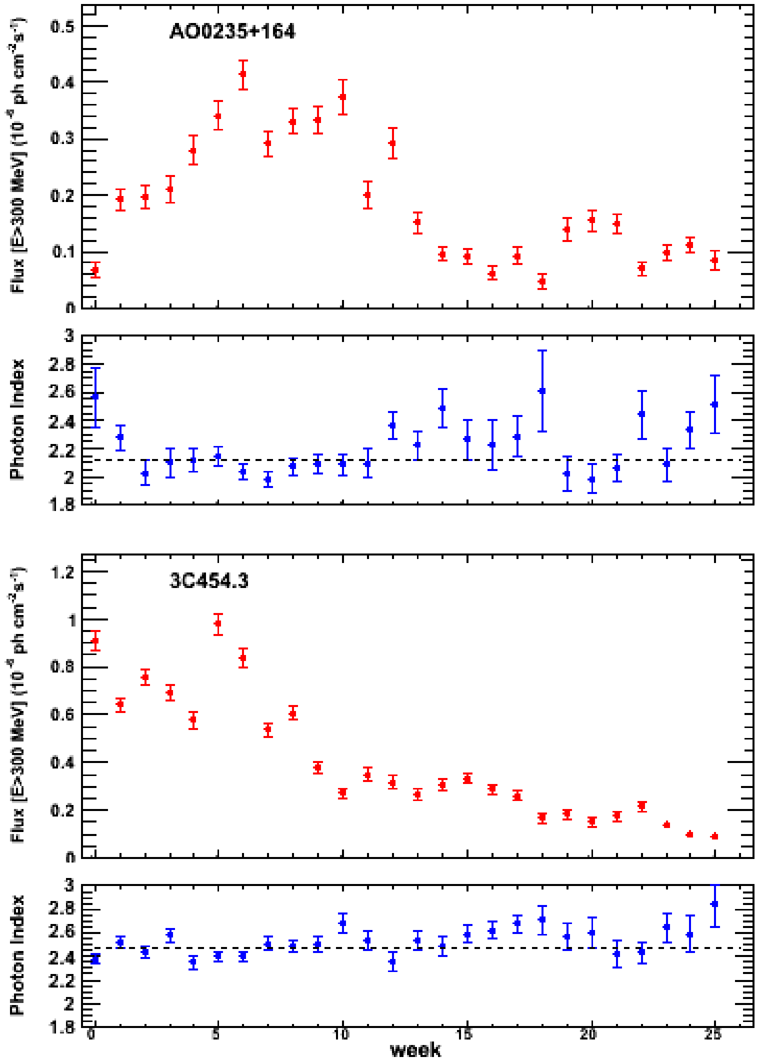


- EGRET: sparse 15-day long viewing periods
- difficult to establish variability patterns and determine relevant parameters (duty cycle…)

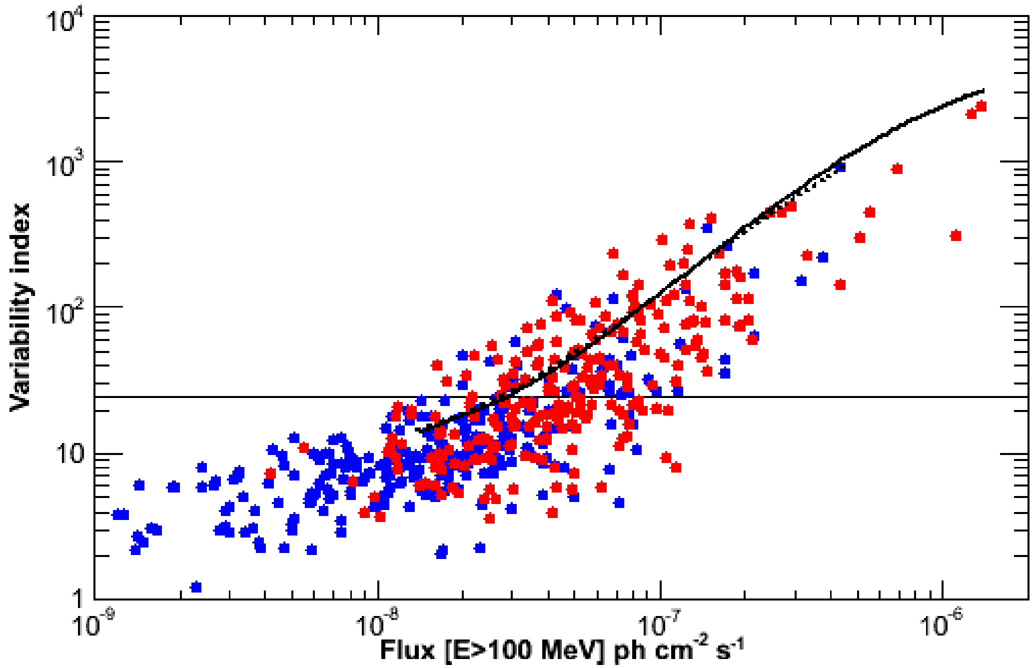


Variability index

Light curves



$$V = \sum_i \frac{(F_i - F_{av})^2}{\sigma_i^2 + (f_{rel} F_{av})^2}$$



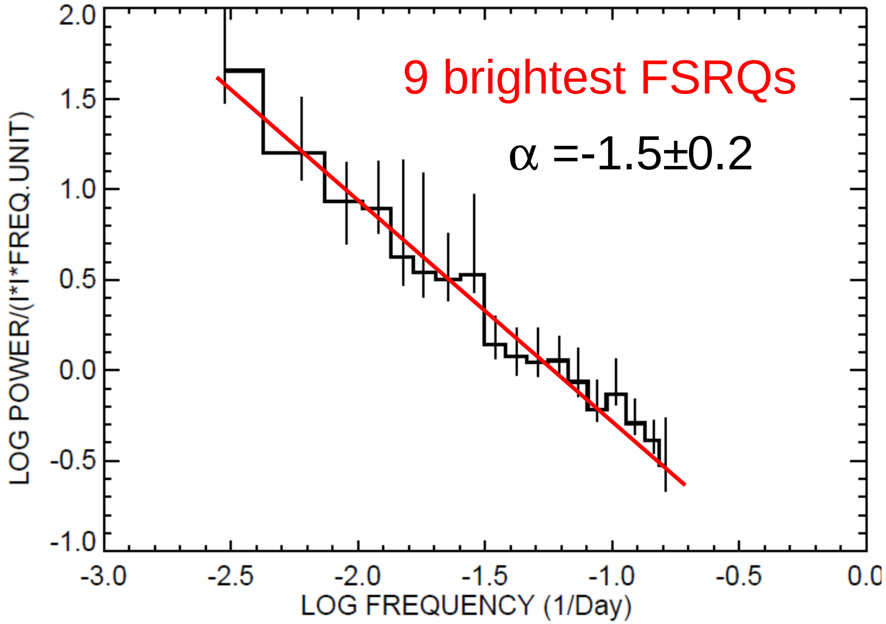
Power Density Spectrum

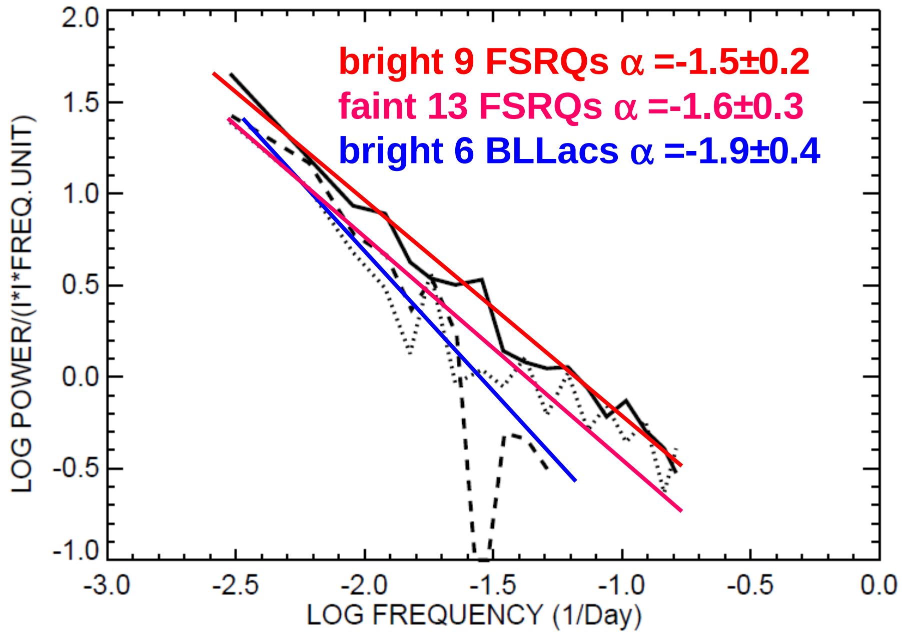
• 1/f$^{-\alpha}$ with α between 1 (« flicker », « pink-noise ») and 2 (« shot noise », «Brownian») with peak around 1.6-1.7 (similar to optical or radio)

•Caveat: weekly and 3-day bin light curves; mid- long-term temporal behavior investigated so far

Poster P1-27,S. Ciprini et al.

Preliminary





No significant difference in PDS shape between BLLacs and FSRQs but a tendency for the former to be slightly steeper. BLLacs have also a lower fractional variability.

Flux distributions

Preliminary

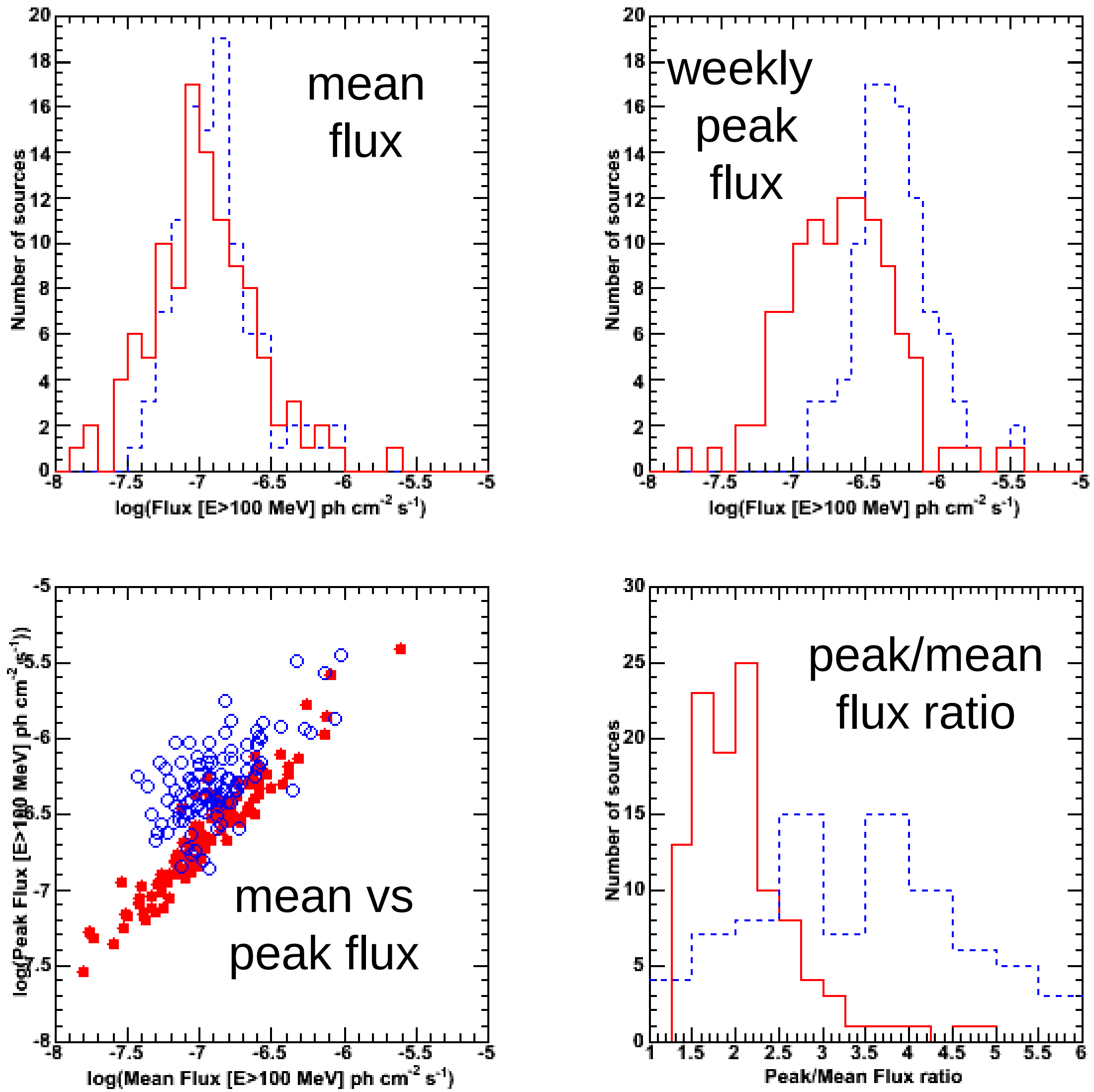
Fermi
EGRET

EGRET mean flux « 1234 VP»

EGRET peak flux: maximum in 2-w VPs

Fermi mean flux: 3-m averaged

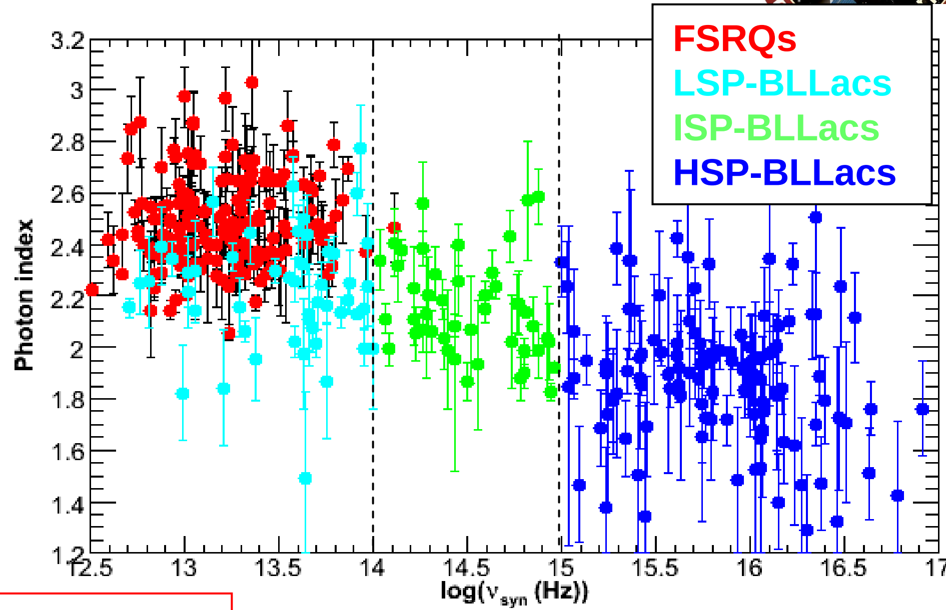
Fermi peak flux: maximum in 1-w periods



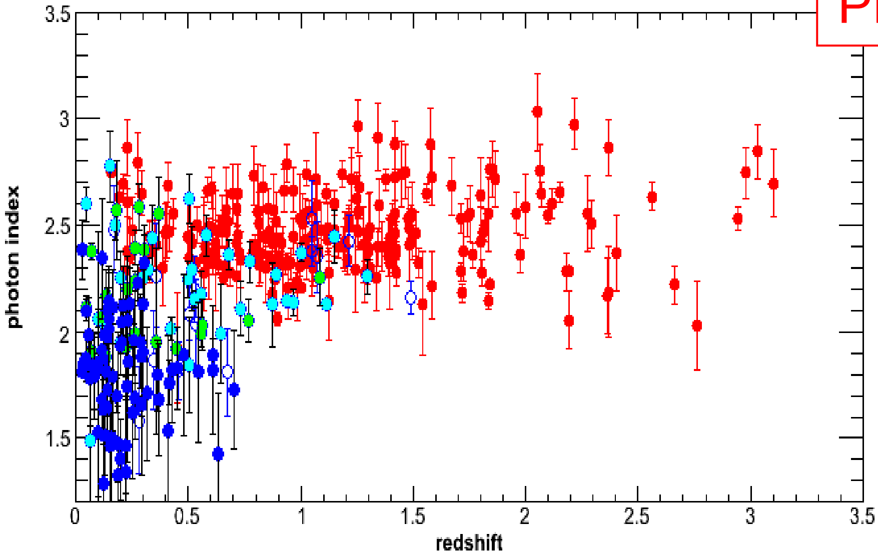
Photon index vs ν_{syn}, Lγ, redshift

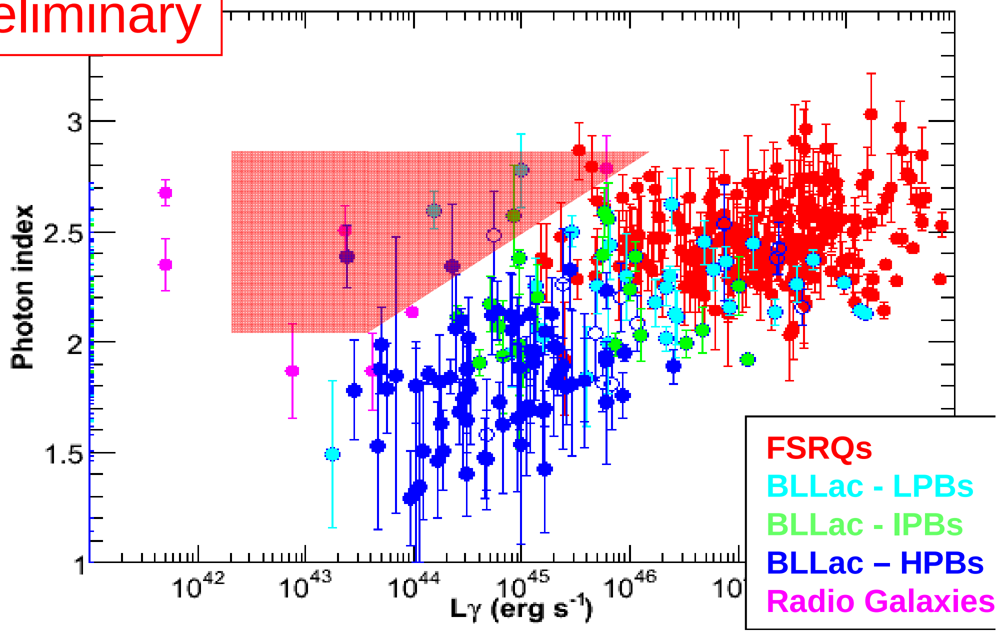
- **All (but one) FSRQs in 1LAC are LPBs**
- **Most BLLacs are HSPs**

these correlations enable the « blazar sequence » concept to be revisited but beware of limitations!



Preliminary





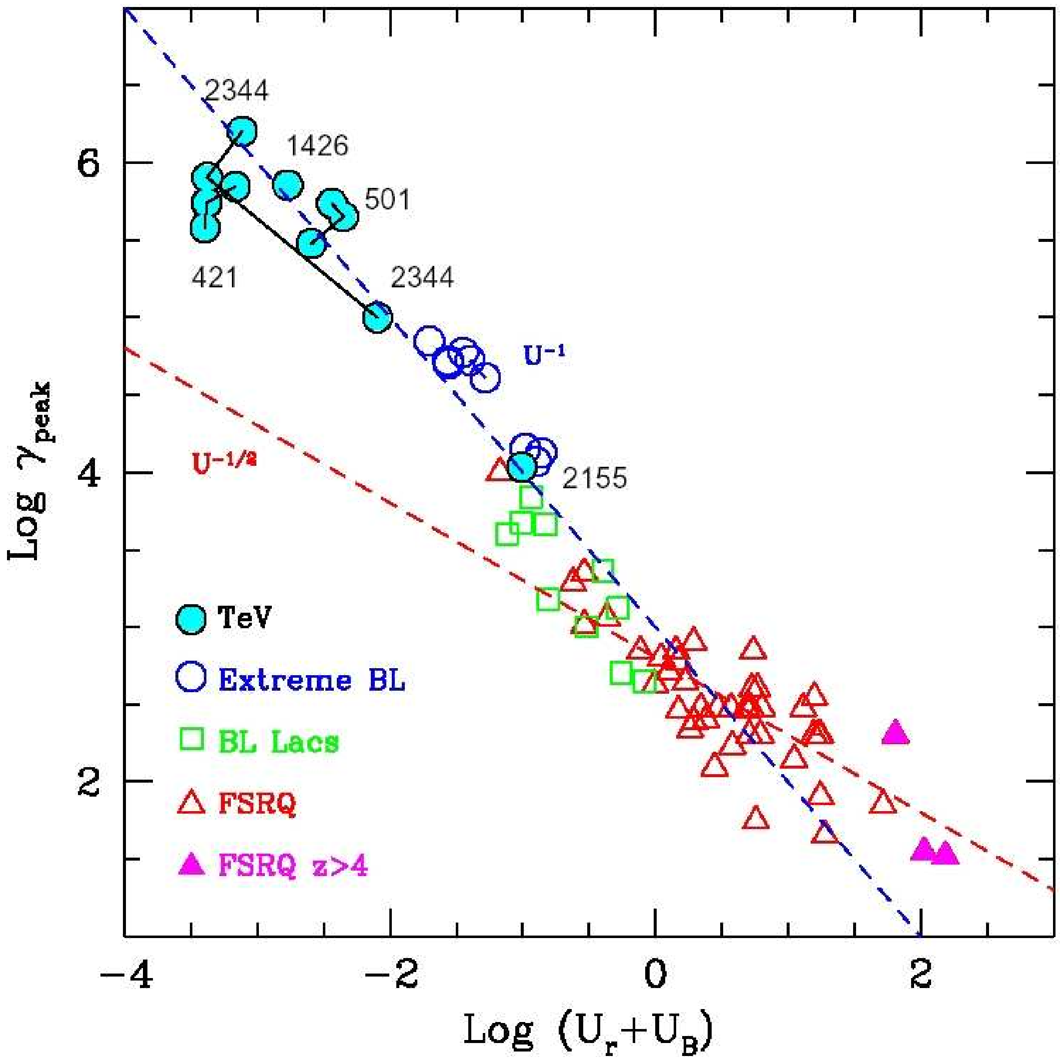
Driving parameter: radiation energy density (?)

$\nu_{peak} \propto B\delta\gamma^2_{peak}$

γ_{peak} for the electrons determined by the balance between acceleration and cooling processes (synchroton+IC)

Greater U_r : more cooling
→ lower γ_{peak}
→ greater L_{HE}

HFSRQs, if they exist, would not fit in this trend



Ghisellini et al. 2002

Evolutionary sequence

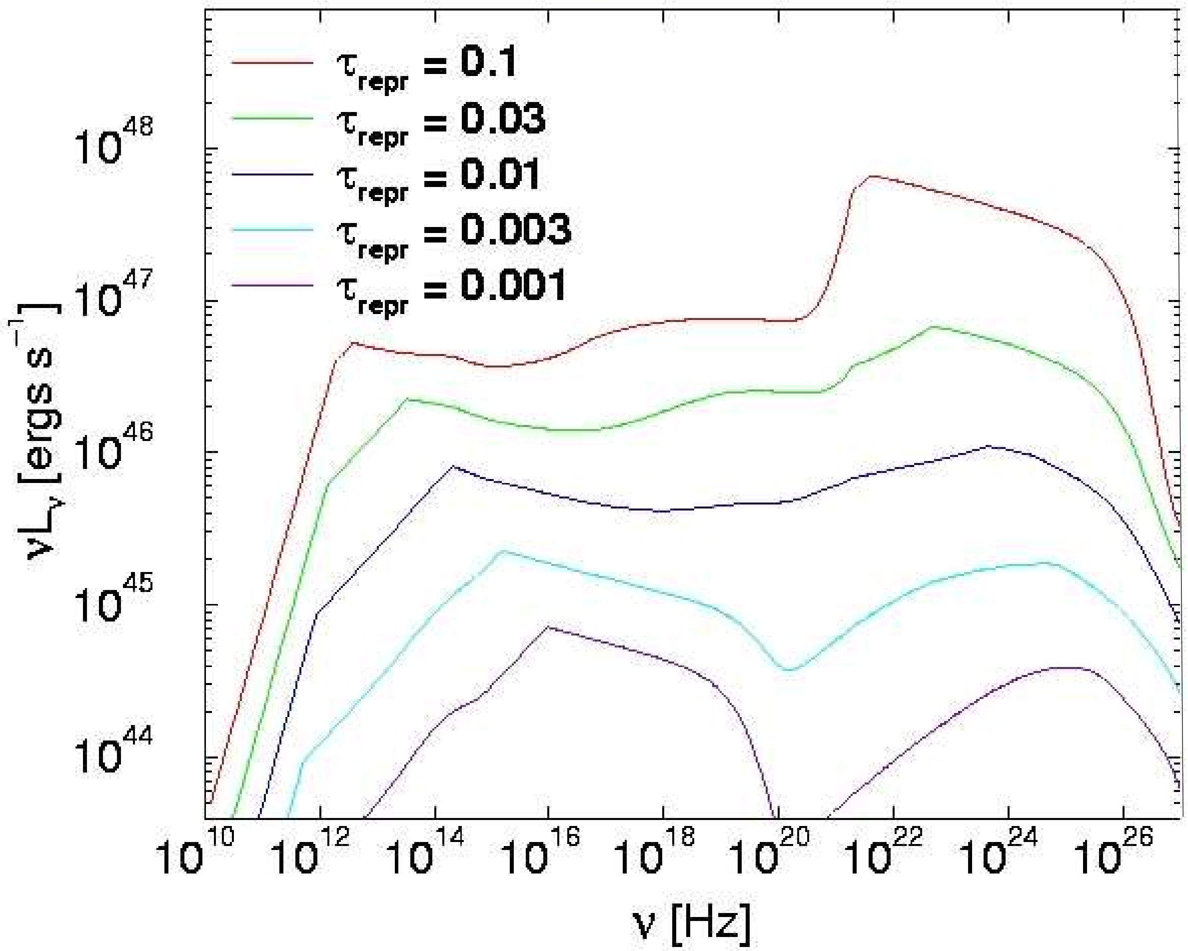
Other authors as well:
D'Elia & Cavaliere, Maraschi et al.

Böttcher & Dermer 2002

Evolutionary link
FSRQ→ LSP→ HSP
Via reduction of the
accretion rate
$\dot{M}/M_{Edd}$
("1D- problem")

Consequence:
BH mass in BLLacs
should be greater than
in FSRQs.

Current data don't
confirm this trend.

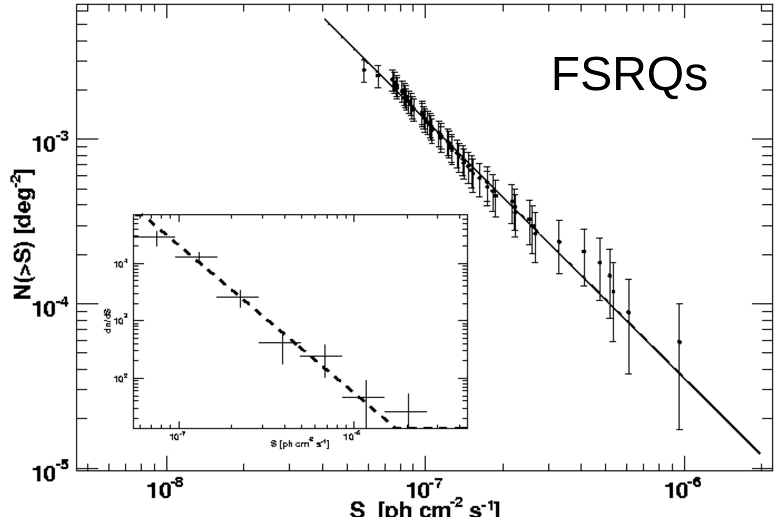


τ_{repr}= reprocessing optical depth (α L_{disk} in the model)

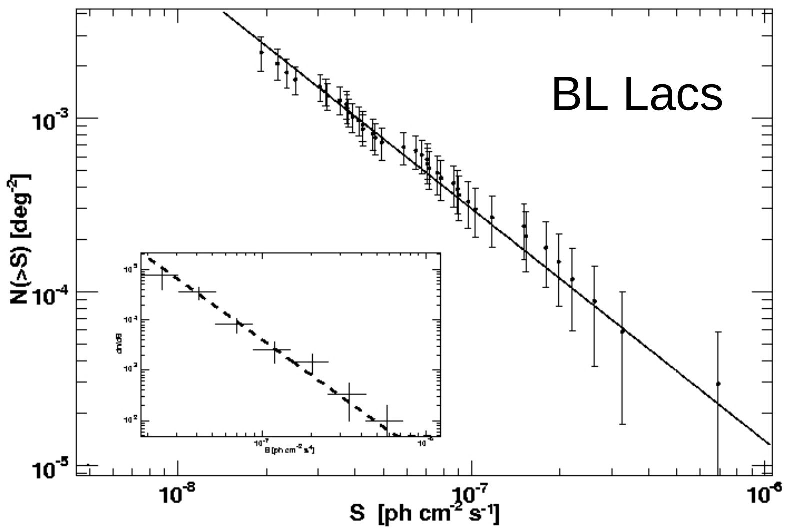
Log N - Log S

Preliminary

- « sky coverage » enables the log N-LogS to be computed
- Euclidian space: slope=2.5



Blazar class	slope
All	2.50±0.12
FSRQs	2.55 ±0.12
BLLacs	2.32 ±0.15



Marco Ajello