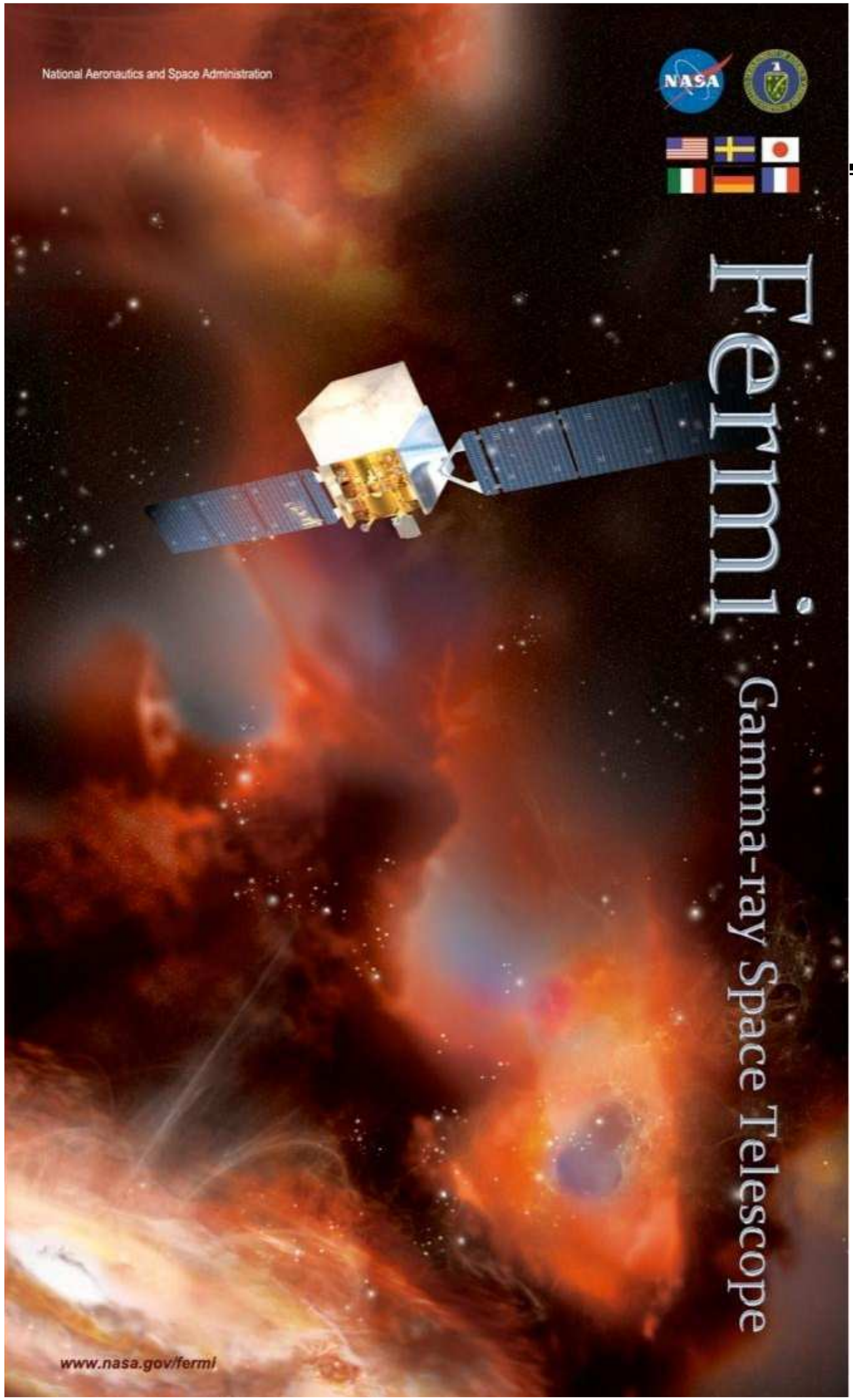

AGNs with the Fermi-LAT: What we have seen

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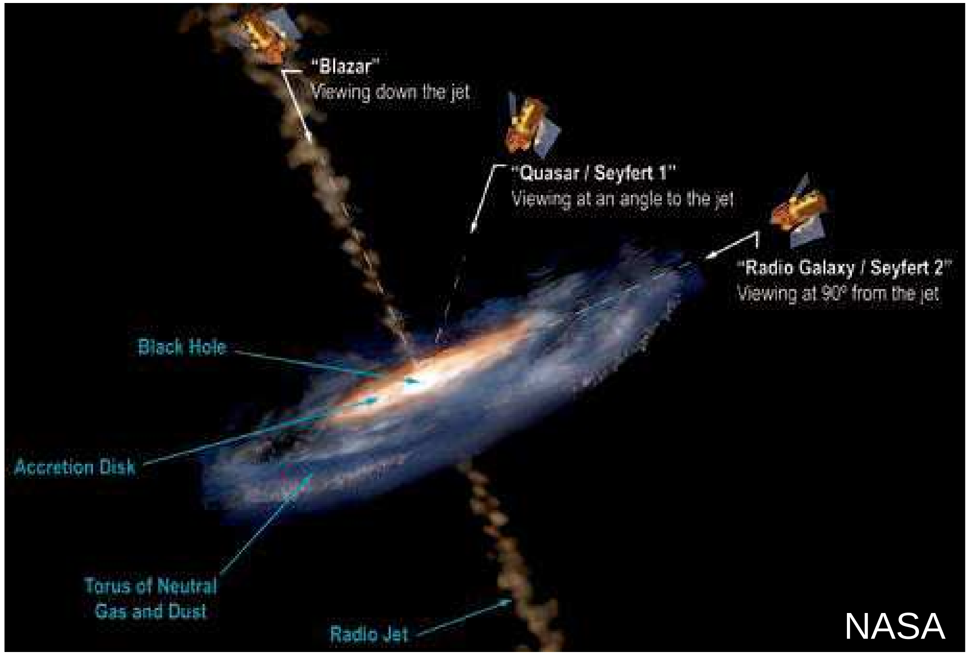
on behalf of the *Fermi*-LAT collaboration

“Blazars, other AGNs and Galaxy Clusters” Science Working Group

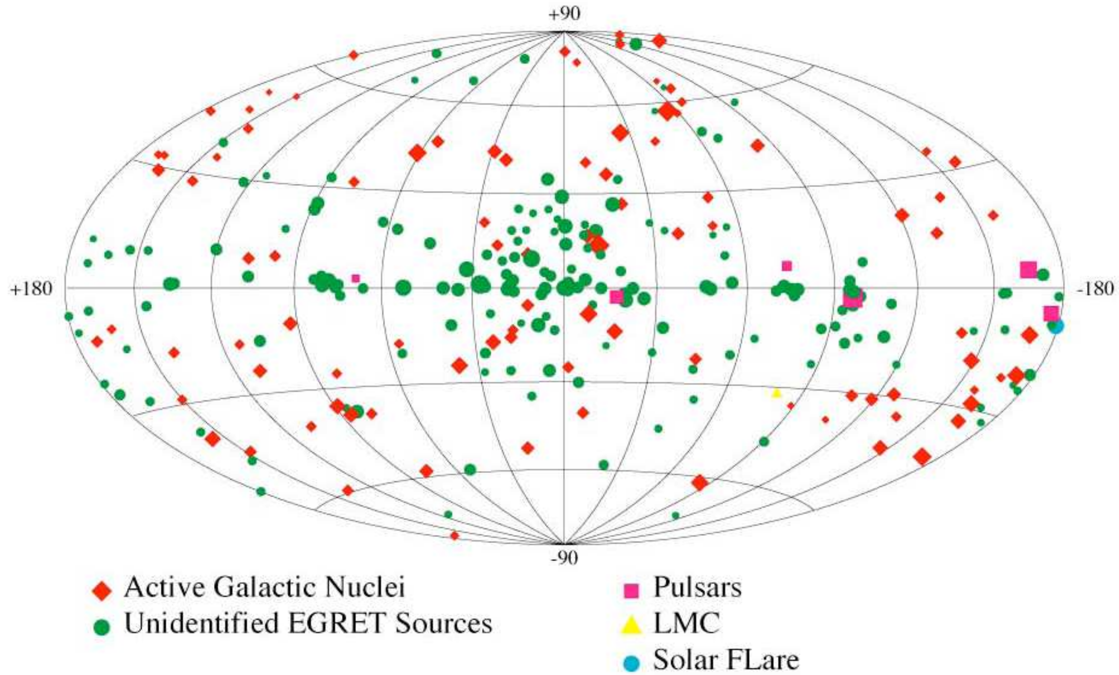
Key questions on blazars

- 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



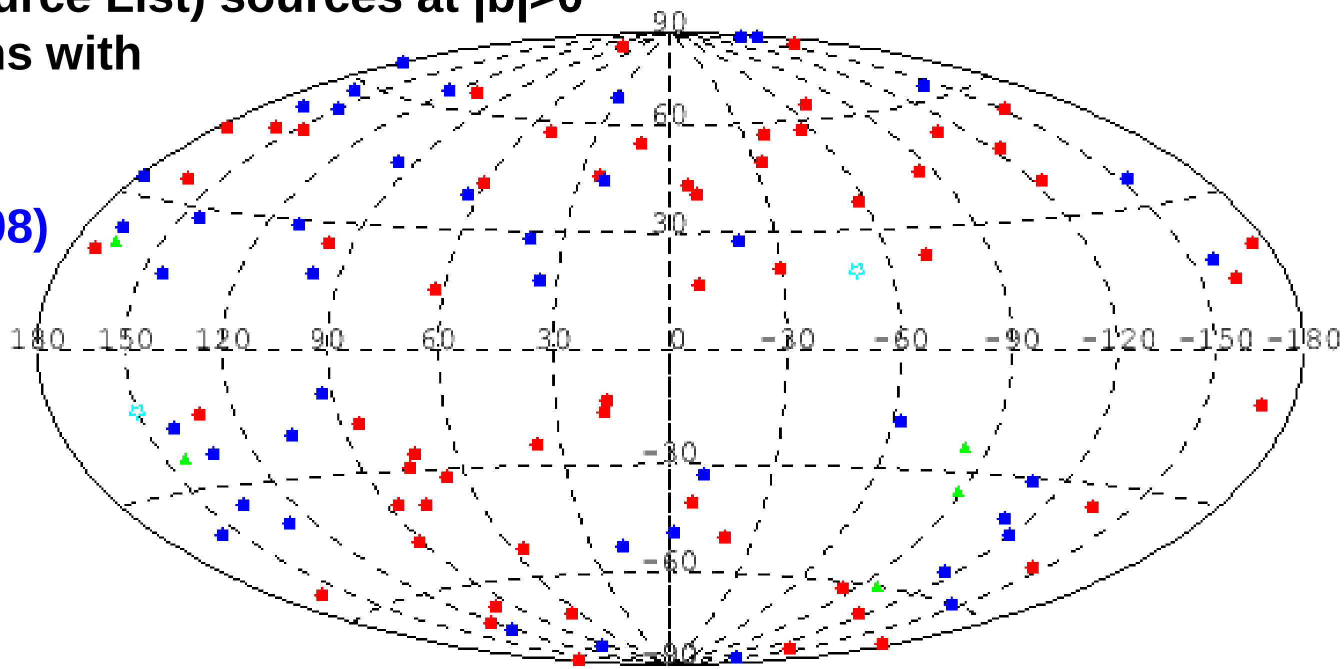
~ 100 AGNs

- **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 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**

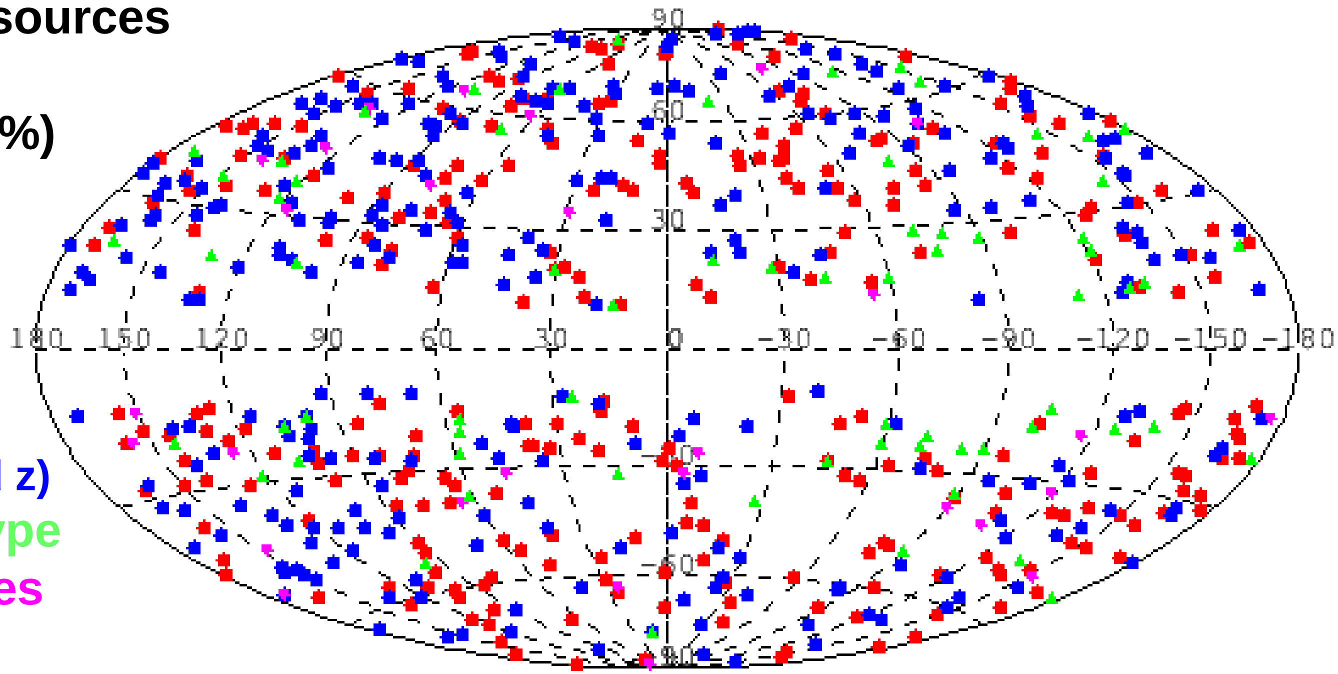
Abdo A. A. et al. 2009 ApJ 700, 597

EGRET sources: only 30%

The First LAT AGN catalog (1LAC)

Preliminary

- **11 month data set**
- **1079 TS>25, |b|>10° sources**
- **668 AGNs (P_{assoc}>80%) +186 candidates**
- **Census:**
  - **286 FSRQs**
  - **284 BLLacs (141 with measured z)**
  - **69 of unknown type**
  - **~10 Radio galaxies**

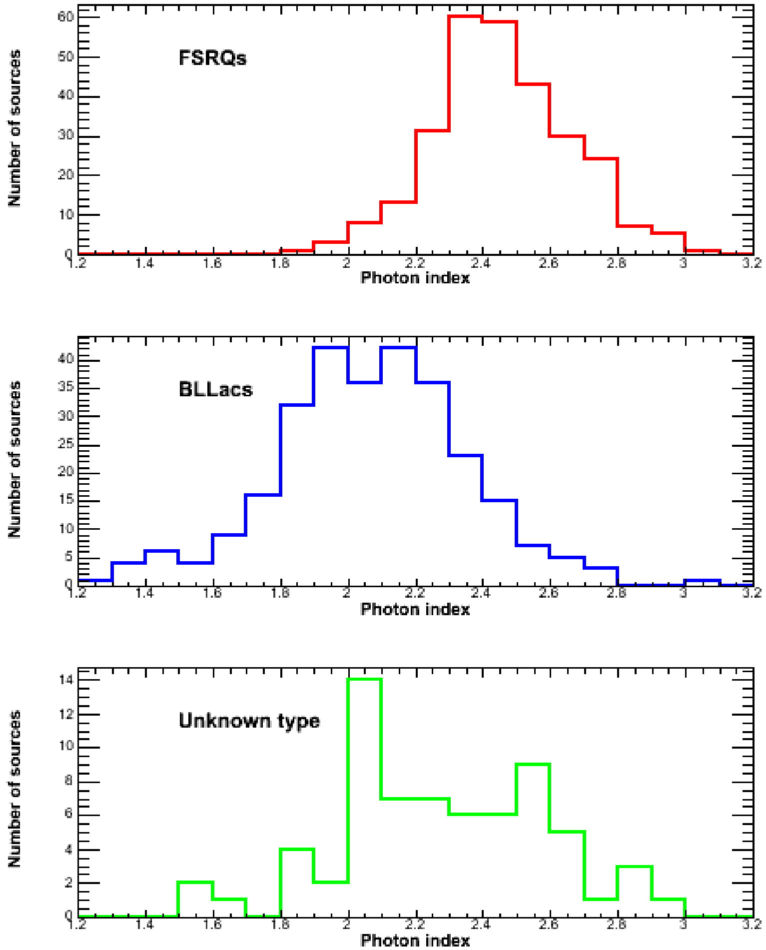


Differences between Northern Hemisphere and Southern one (FSRQs: 7%, BLLACs: 25 %)

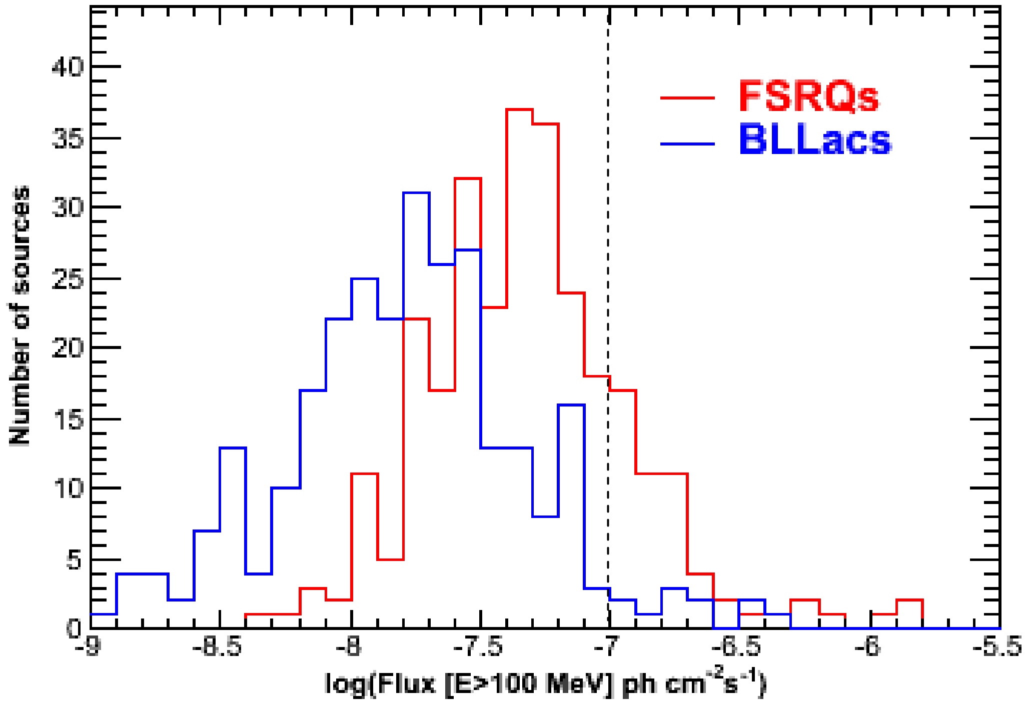
Posters: P5-188,S. Healey et al. P1-37,M. Shaw et al.

Photon index – Flux distributions

Preliminary

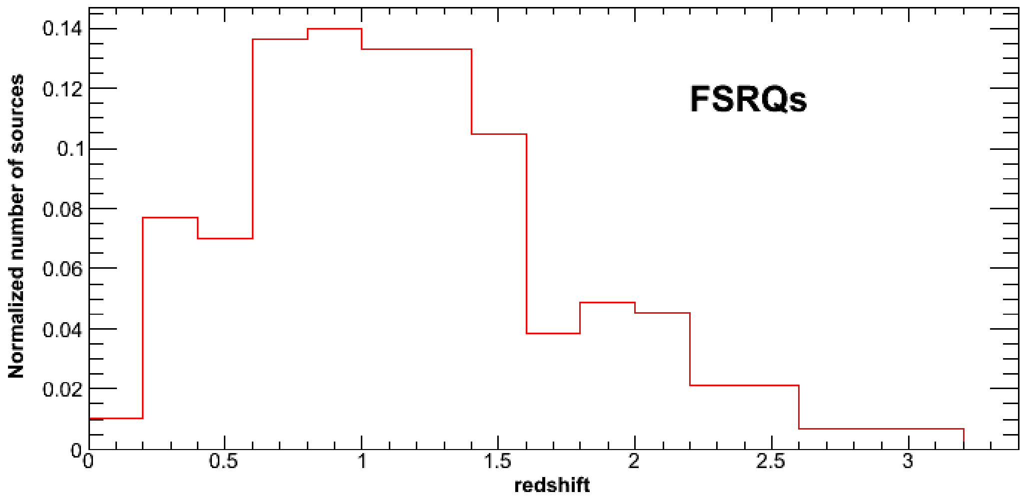


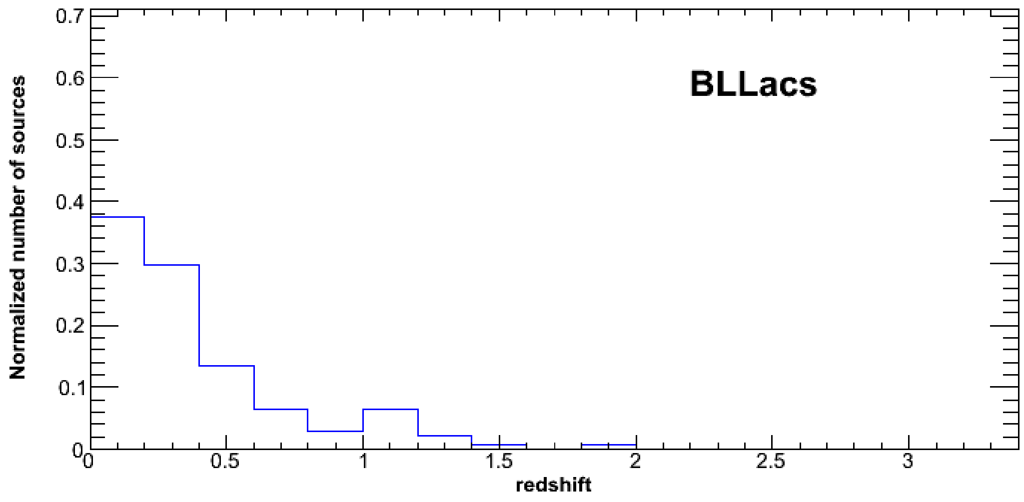
3EG flux limit



Poster P5-188, S. Healey et al.

Redshift distributions

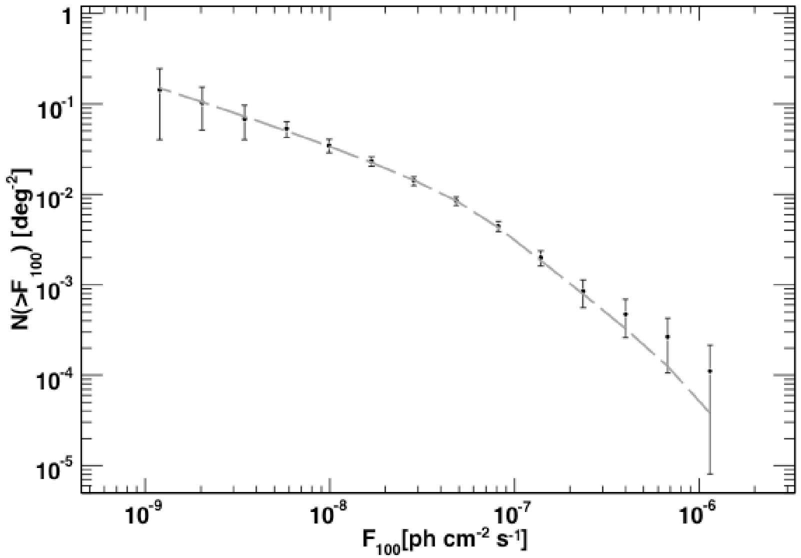




Preliminary

Poster P5-188, S. Healey et al.

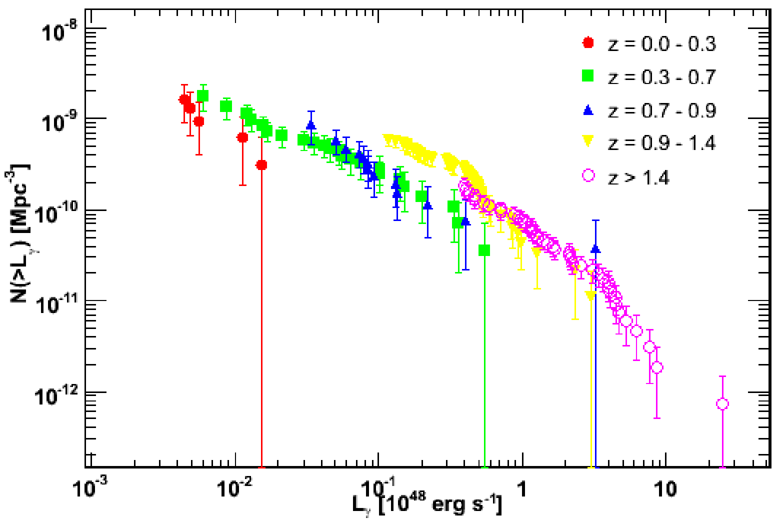
Population studies



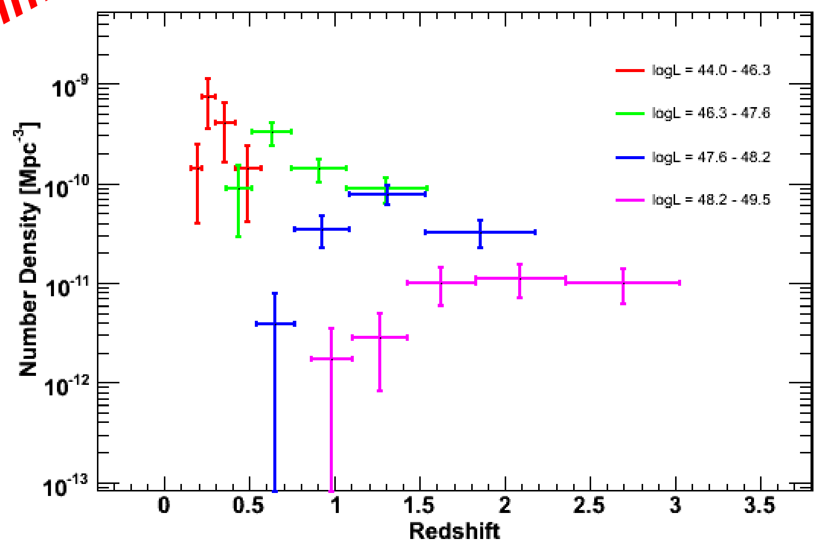
• Log N- Log S presents a flattening around $F[E>100\ \mathrm{MeV}]=6.7 \times 10^{-8}$ ph cm^{-2}s^{-1}

• FSRQ densities peak at a redshift which increases with increasing luminosity (i.e. LDDE behavior)

M. Ajello's talk



Preliminary



Spectral properties in the γ-ray band

SED-based classification

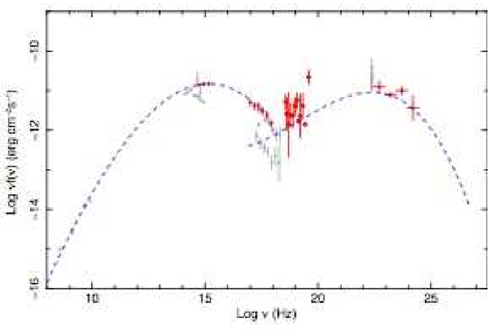
P. Giommi's talk, Posters P5-188, 1-29, S.Cutini et al.

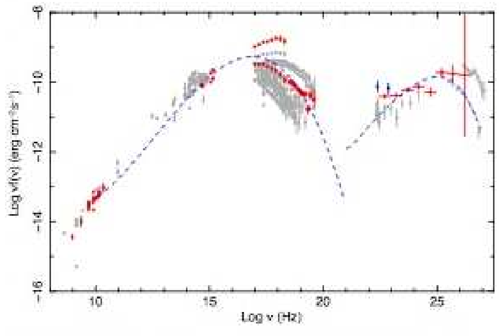
- **Simultaneous Swift data enabled the determination of ν_{syn} for 48 LBAS sources**

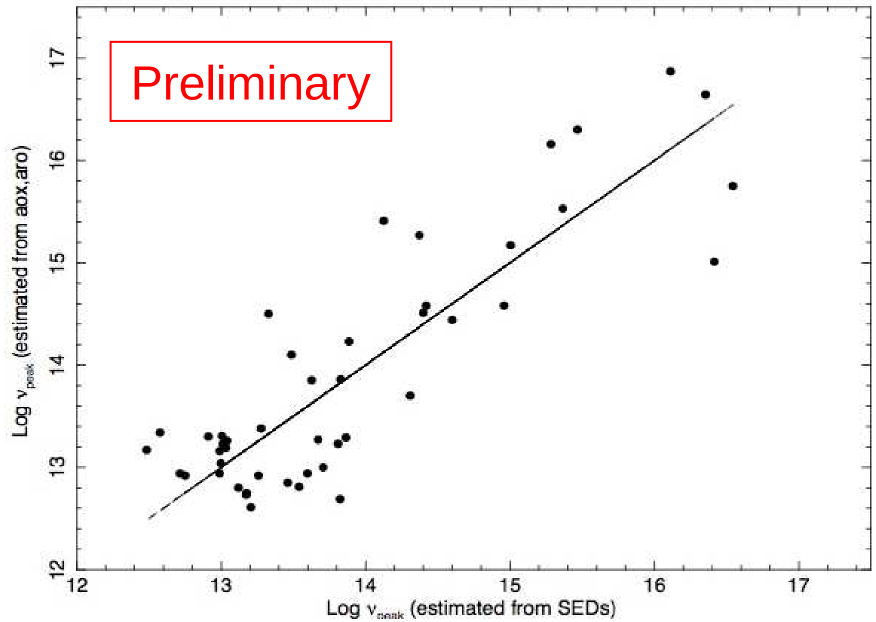
- **Calibration of relation with ν_{syn} estimated from α_{ox}, α_{ro}**

- **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: $\log(\nu_{syn}) > 15$**

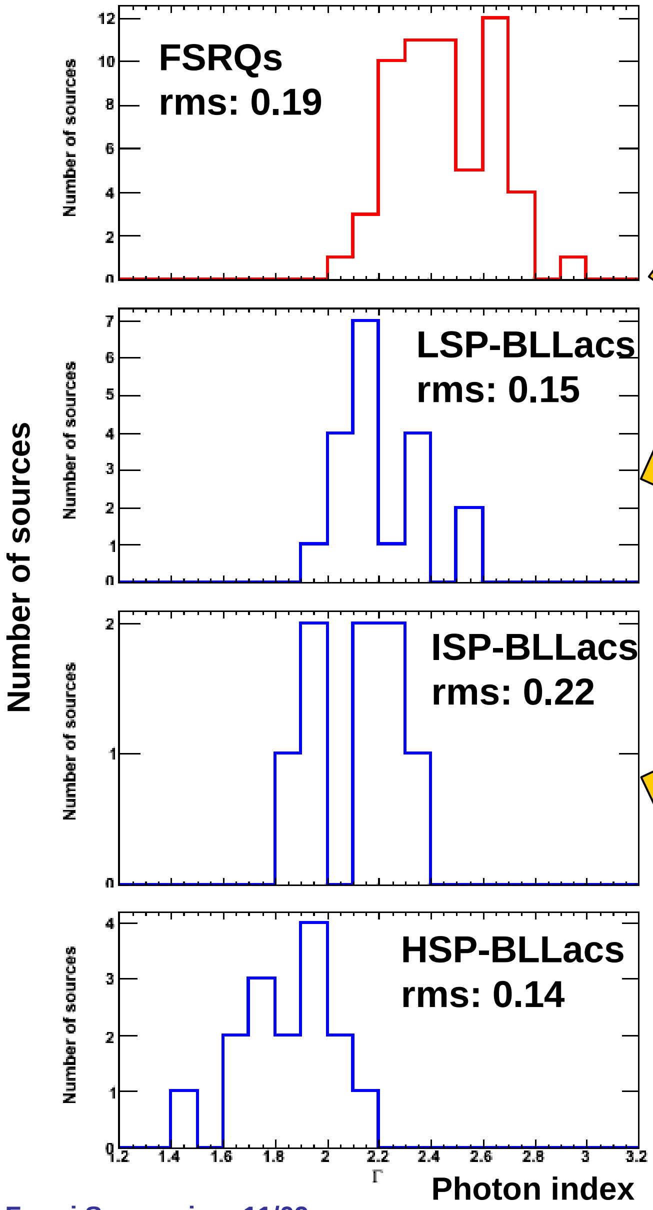
  with ν_{syn} in Hz







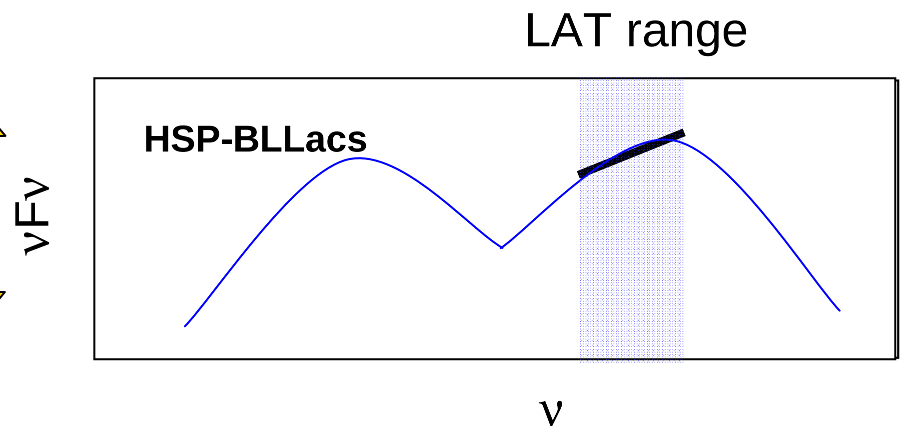
Photon index distributions in LBAS



Preliminary

(Poster P1-21, L. Escande et al.)

Photon index determined with the first 6-month data set

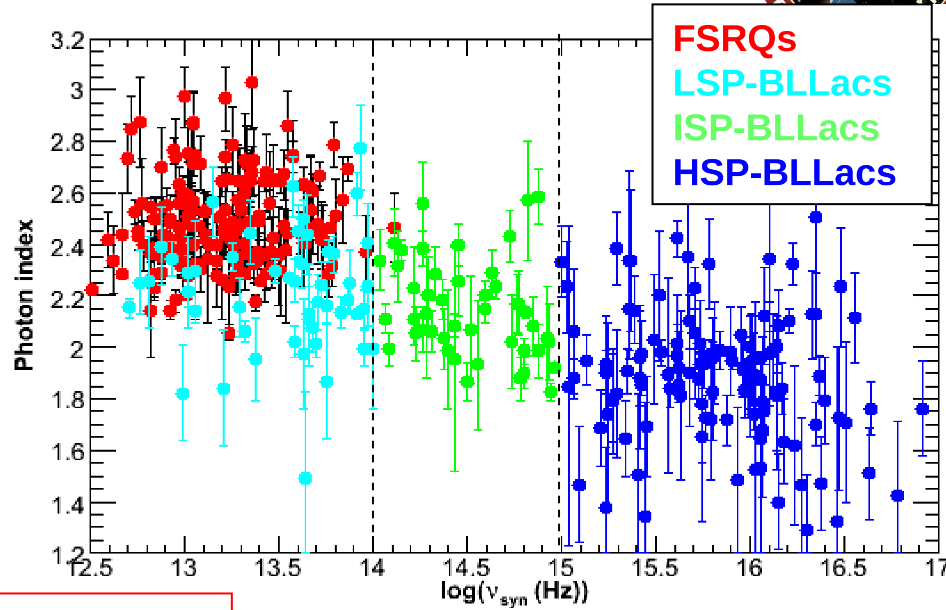


- **Strong correlation between photon index and blazar class**
- **Narrow distributions point to a small numbers of parameters driving the blazar SEDs**

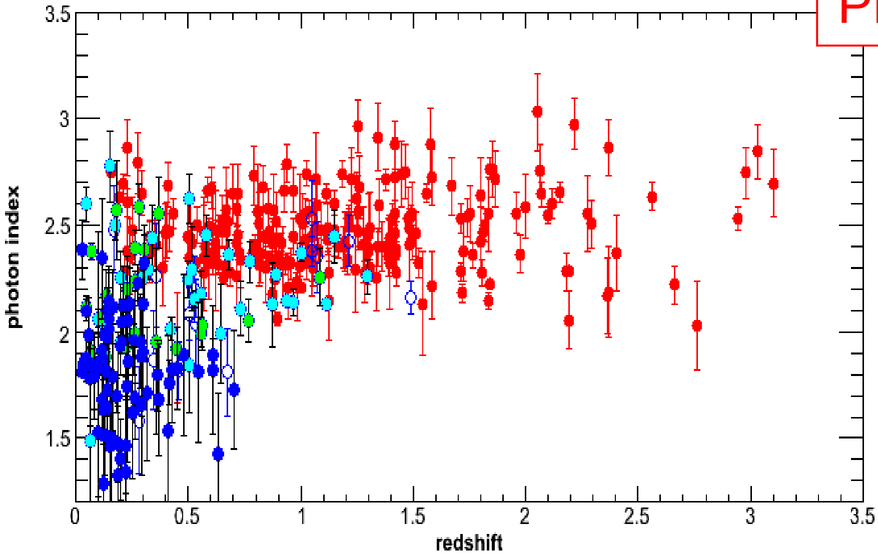
Photon index vs ν_{syn}, Lγ, redshift

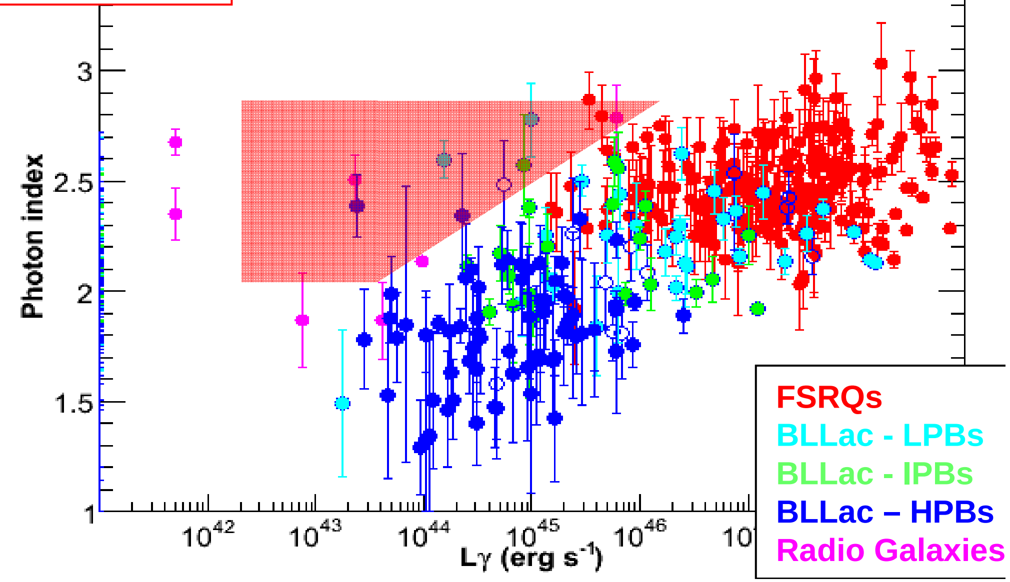
- **All (but one) FSRQs in 1LAC are LPBs**
- **Most BLLacs are HSPs**

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



Preliminary



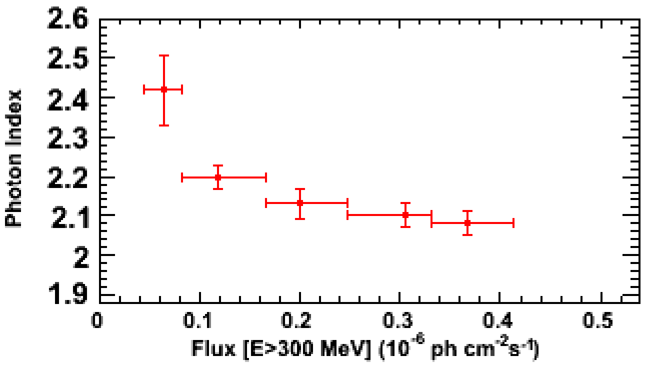


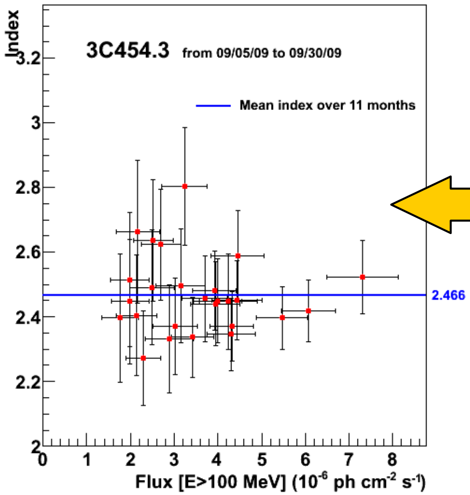
Relative constancy of photon index

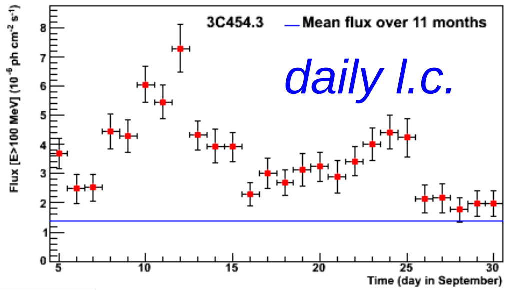
(Poster P1-21, L. Escande et al.)

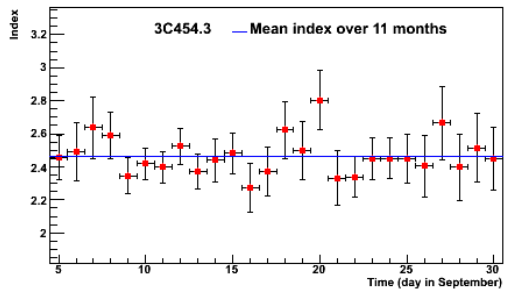
Preliminary

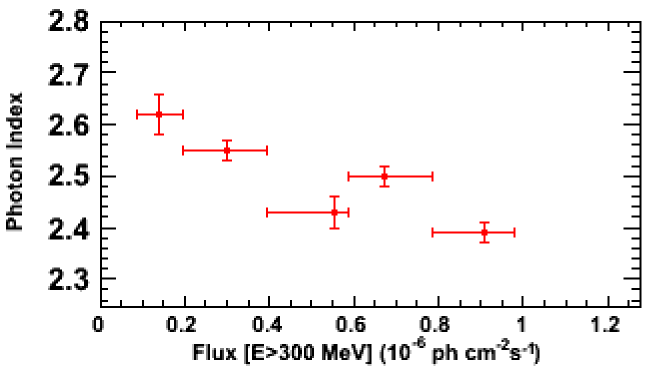
weekly l.c.

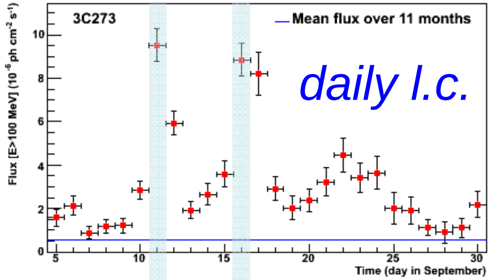


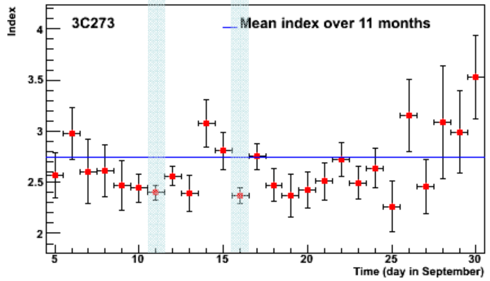


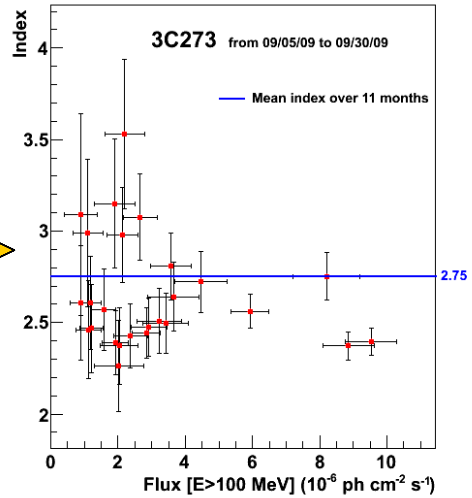












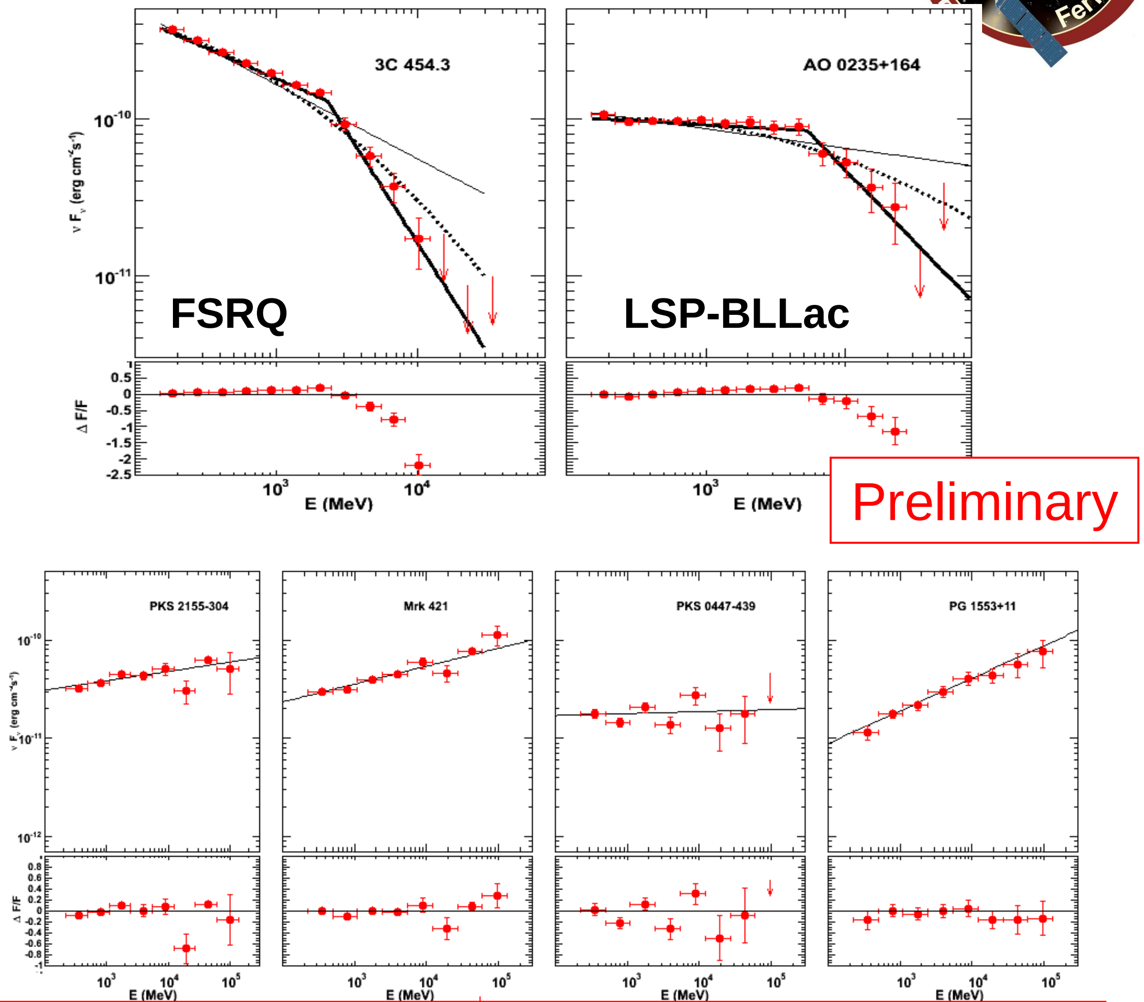
« Harder when brighter » effects observed but moderate variations ($\Delta\Gamma$ <0.3) seem to be the rule

Process stabilizing the spectral shape?

Benoit Lott

Non-power law spectra

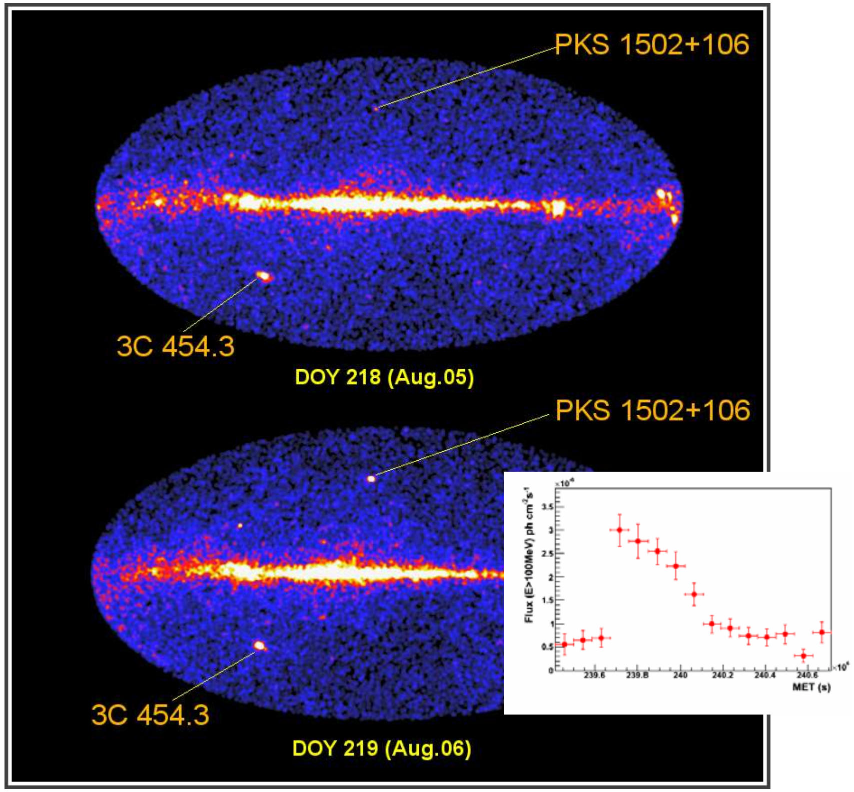
- **General feature in FSRQs and many LSP-BLLacs**
- **Absent in HSP-BLLacs**
- **Broken power law model seems to be favored**
- **$\Delta\Gamma \sim 1.0 > 0.5 \rightarrow$ not from radiative cooling**
- **Possible explanations:**
  - **feature in the underlying particle distribution**
  - **Klein-Nishina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

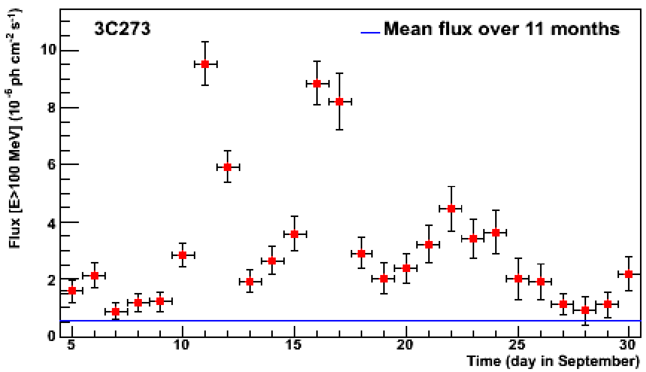


Challenge for modelers to account for the break and the relative constancy of spectral index with time

Temporal properties in the γ-ray band

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

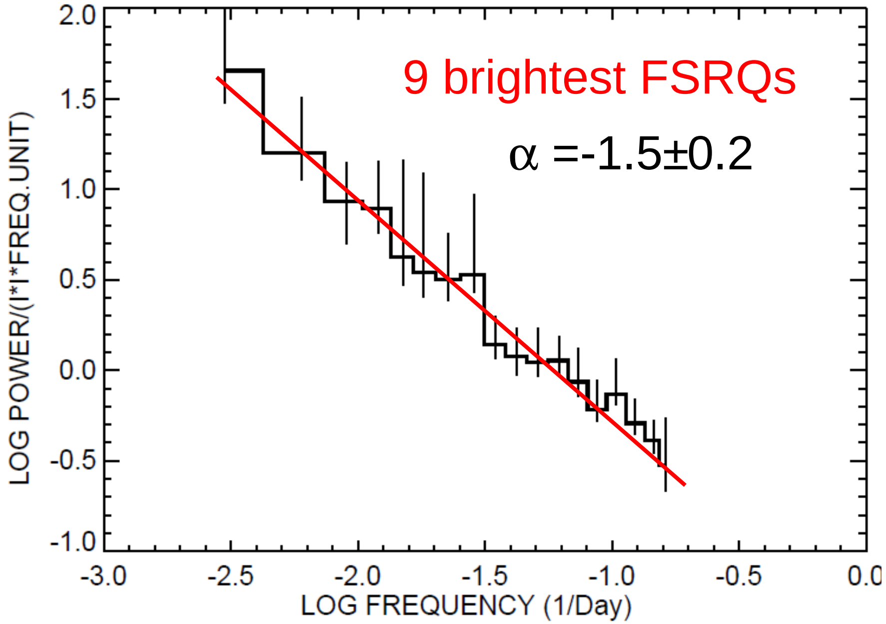
Poster P5-203, S. Ciprini et al.

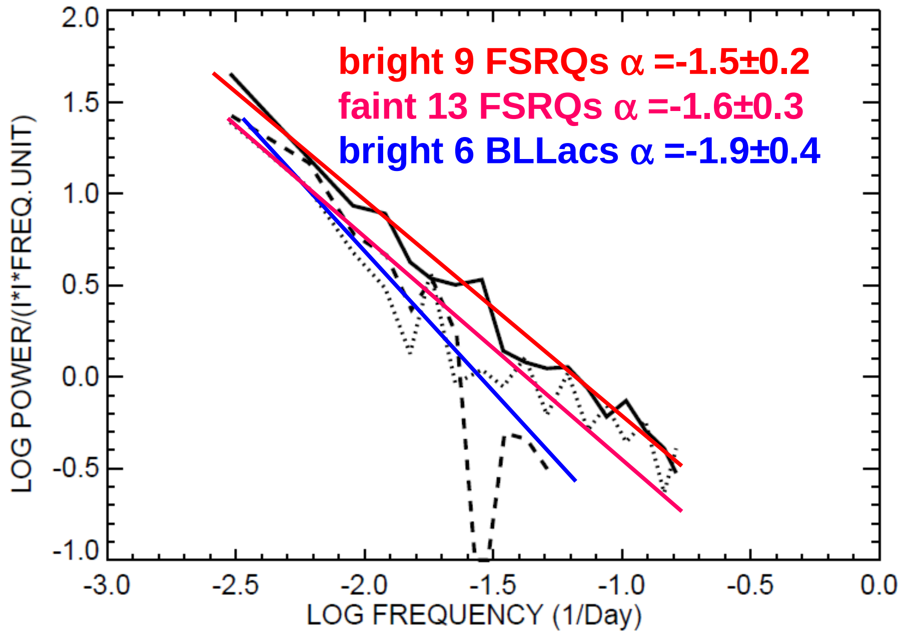
Power Density Spectrum

- $1/f^{-\alpha}$ 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





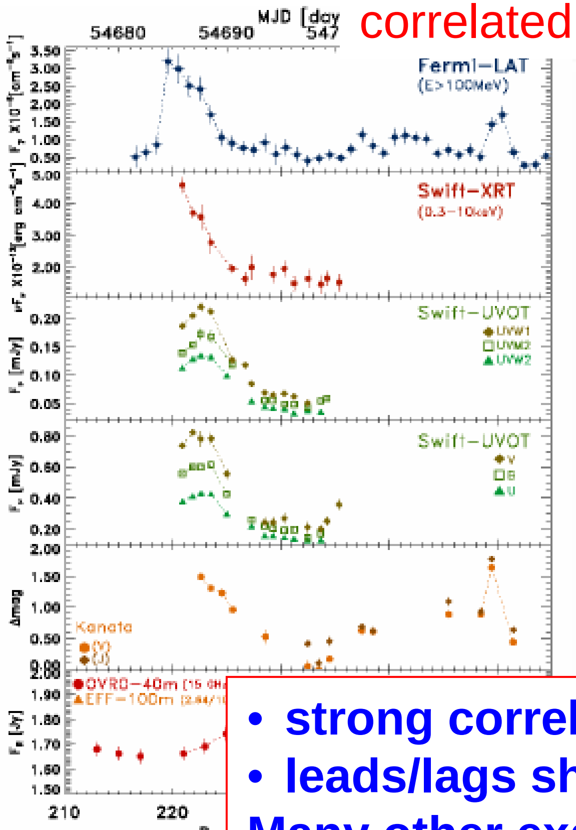
No significant difference in PDS shape between BLLacs and FSRQs but a tendency for the former to be slightly steeper. BLLacs have also a lower fractional variability.

Multi-frequency studies

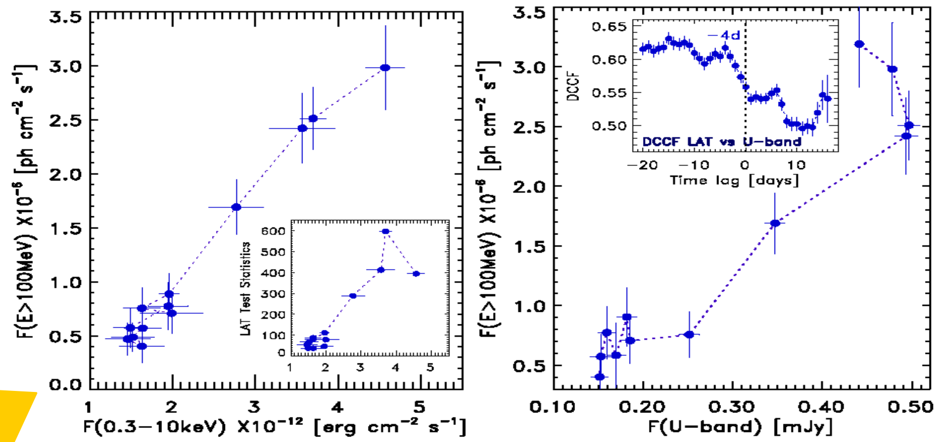
MW opportunities:
Poster P5-199, D. Thompson

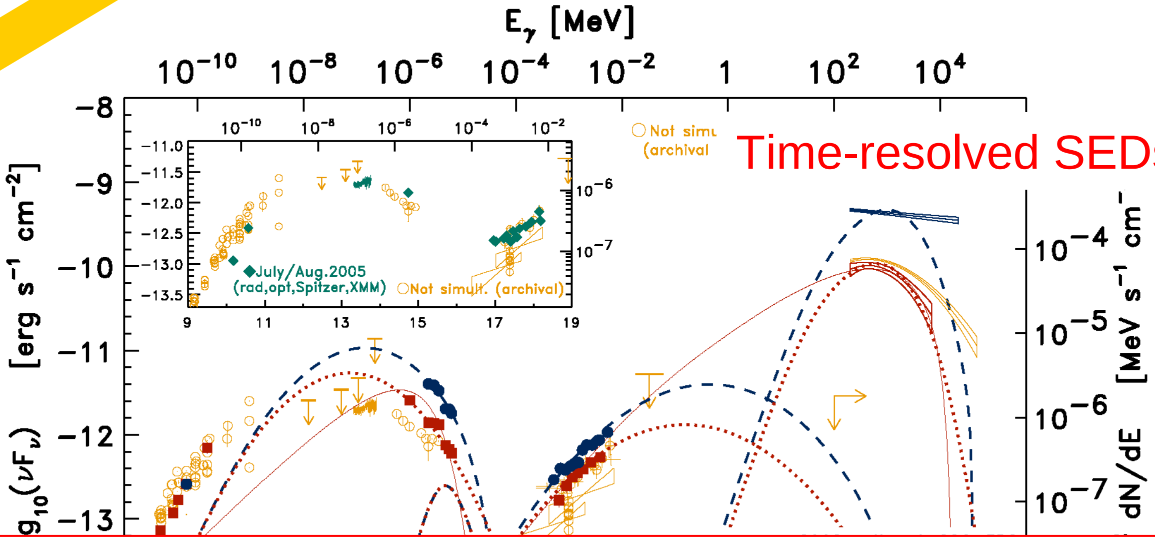
Multiwavelength data for PKS1502+106

- 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





Time-resolved SEDs

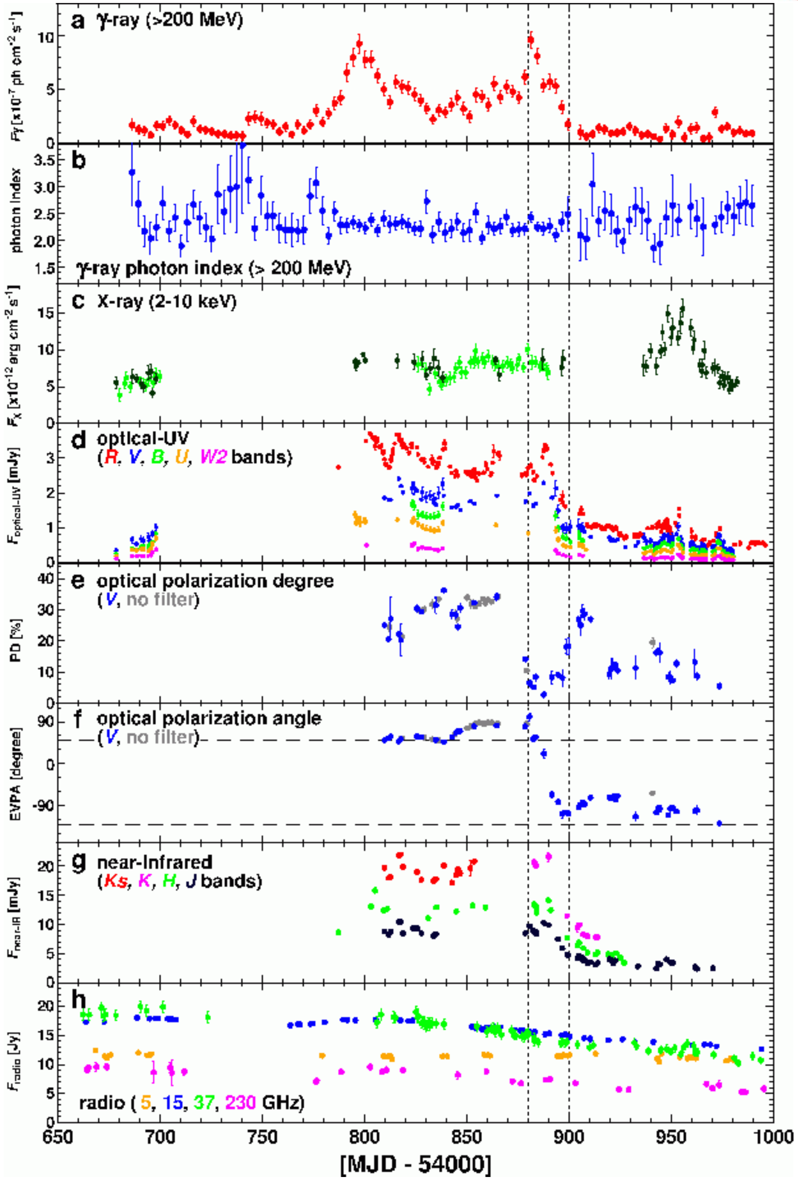
- **strong correlated variability indicates co-spatiality of emission**
- **leads/lags shed light into electron dynamics/geometry**

Many other examples, ***see S. Wagner's talk, SMARTS poster P1-39***

Multi-wavelength campaign on 3C279

Preliminary

- 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



M. Hayashida's talk

The GeV-TeV connection

MW campaigns on

- **Mkn421, Mkn501, 1ES 1959+650 *(Poster P1-53, D. Paneque et al., P1-17, A. Konopelko et al.)***
- **PKS 2155-304 (*Poster P1-24, D. Sanchez et al.*)**
- **3C 66A (w. Veritas)**
- **PKS 1424+240 (w. Veritas, *poster P1-15, A. Furniss et al.*)**
- **RGB J0710+591 (w. Veritas, *poster P1-30, P.Fortin et al.)***
- **PKS2005-489 (w. HESS, *poster P1-35, S. Kaufmann et al.)***

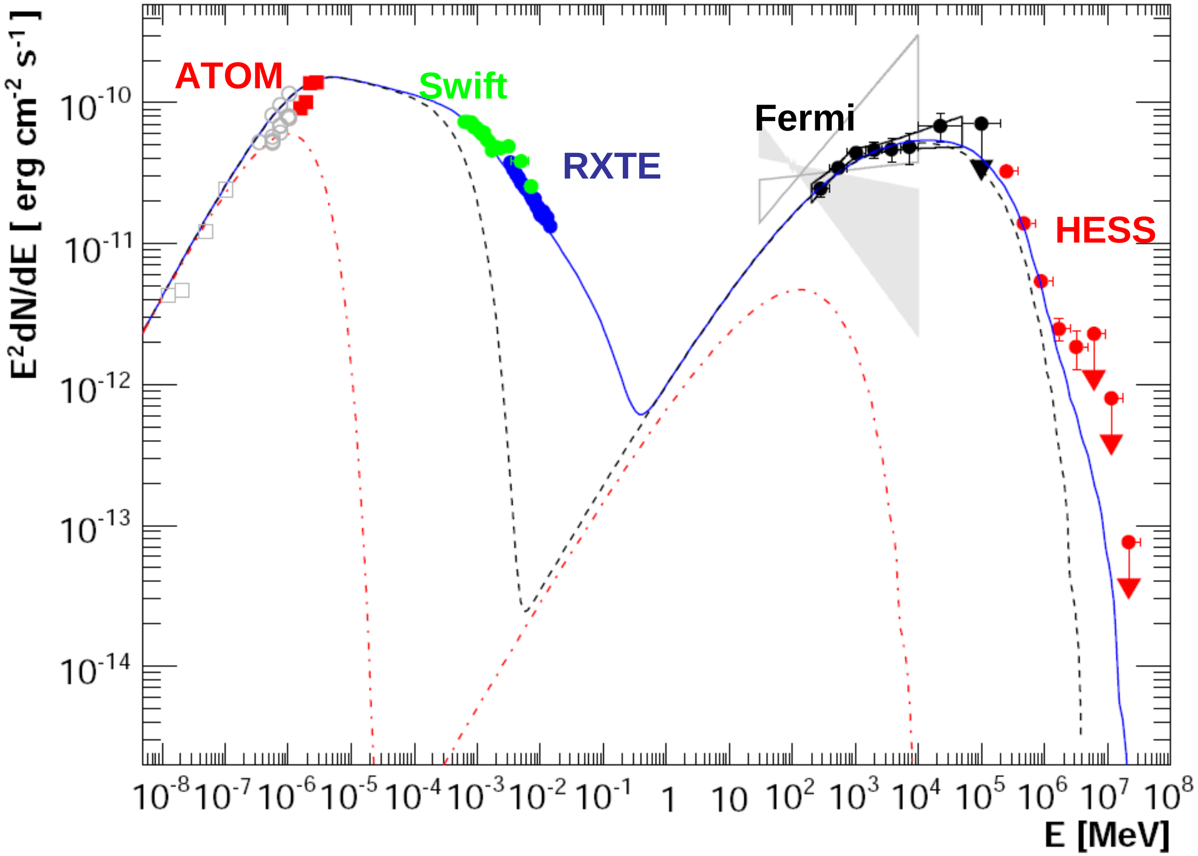
and more….

Enormous set of data!

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

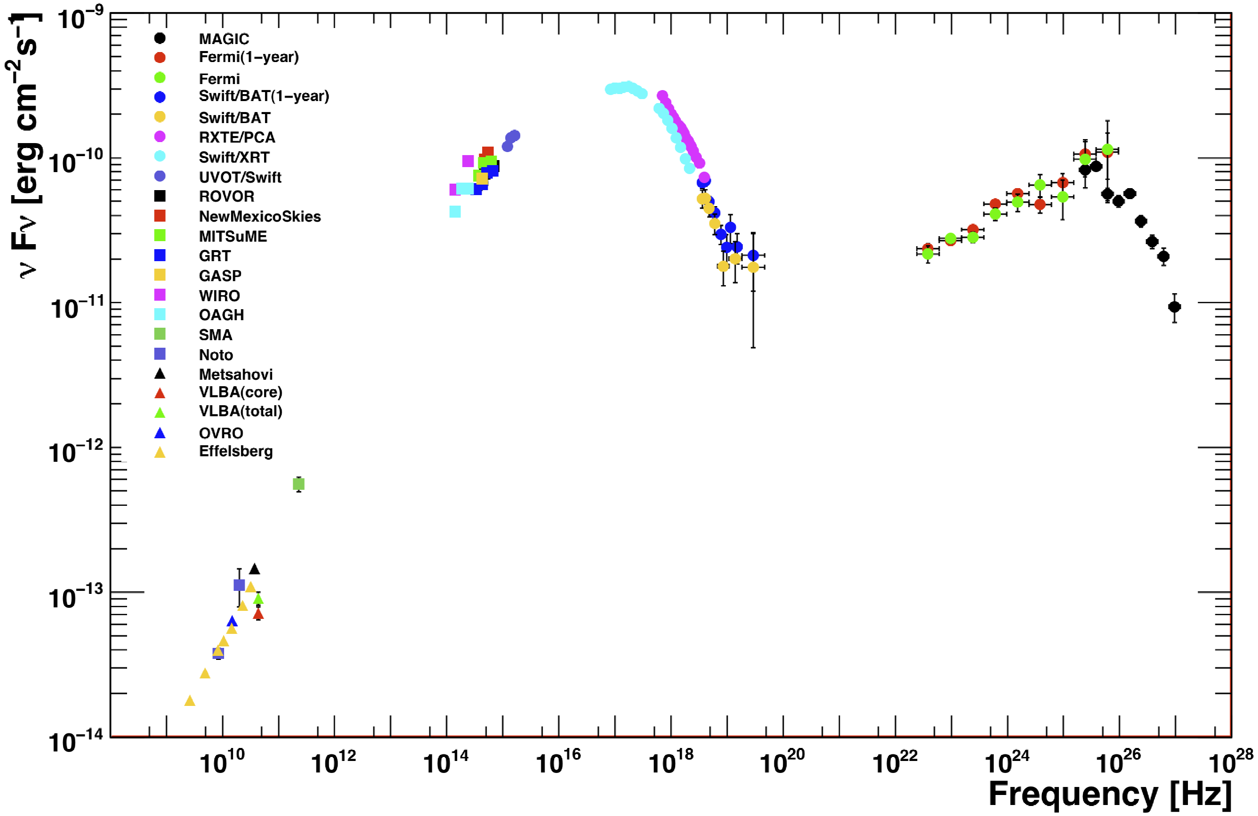
Challenge simple SSC models



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

Poster P1-53, D. Paneque et al.

Preliminary

The GeV-TeV connection

21/28 TeV AGNs detected by Fermi-LAT (5.5 months of data), now 25/30

- **mostly BLLacs, mostly HSPs**
- **2 RGs: Centaurus A, M87**

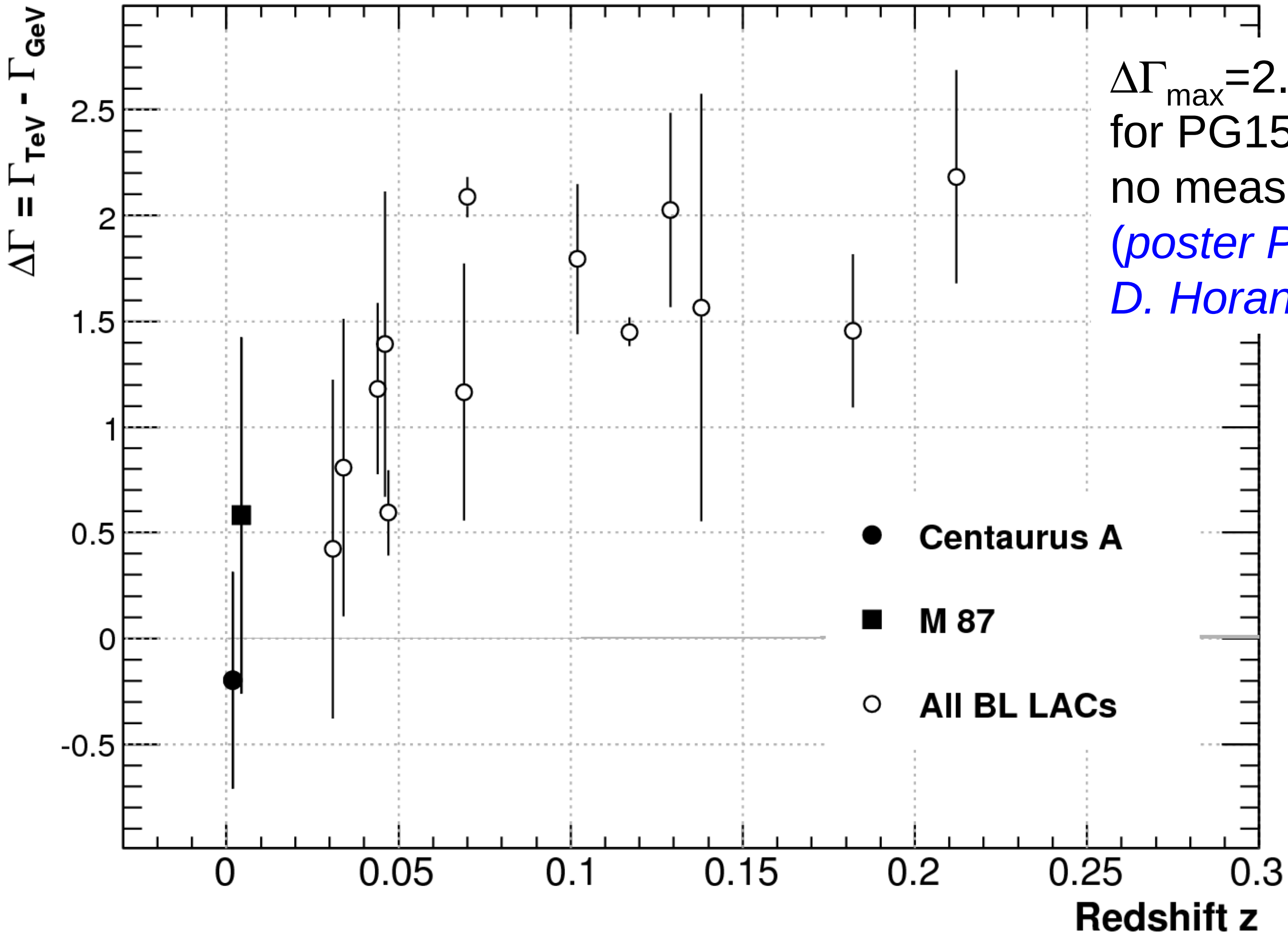
arXiv:0910.4881 (Poster P1-18 S. Fegan et al.)

Name	TS	Parameters of fitted power-law spectrum: Flux (>200 MeV) $F \pm \Delta F_{\rm stat} \pm \Delta F_{\rm sys}$	Parameters of fitted power-law spectrum: Photon Index $\Gamma \pm \Delta\Gamma_{\rm stat} \pm \Delta\Gamma_{\rm sys}$	Decorr. energy	Highest energy photons: $1^{\rm st}$	Highest energy photons: $5^{\rm th}$	Probability of constant flux: 10 day	Probability of constant flux: 28 day
	[1]	$[10^{-9}{\rm cm}^{-2}{\rm s}^{-1}]$	[1]	[GeV]	[GeV]	[GeV]	[1]	[1]
3C 66A	2221	$96.7 \pm 5.82 \pm 3.39$	$1.93 \pm 0.04 \pm 0.04$	1.54	111^{a}	54	< 0.01	< 0.01
RGB J0710+591	42	$0.087 \pm 0.049 \pm 0.076$	$1.21 \pm 0.25 \pm 0.02$	15.29	74	4	0.98	0.94
S5 0716+714	1668	$79.9 \pm 4.17 \pm 2.84$	$2.16 \pm 0.04 \pm 0.05$	0.82	63	9	< 0.01	< 0.01
1ES 0806+524	102	$2.07 \pm 0.38 \pm 0.71$	$2.04 \pm 0.14 \pm 0.03$	1.54	30	4	0.05	< 0.01
1ES 1011+496	889	$32.0 \pm 0.27 \pm 0.29$	$1.82 \pm 0.05 \pm 0.03$	1.50	168	32	0.54	0.50
Markarian 421	3980	$94.3 \pm 3.88 \pm 2.60$	$1.78 \pm 0.03 \pm 0.04$	1.35	801	155	0.06	0.02
Markarian 180	50	$5.41 \pm 1.69 \pm 0.91$	$1.91 \pm 0.18 \pm 0.09$	1.95	14	2	0.98	0.54
1ES 1218+304	147	$7.56 \pm 2.16 \pm 0.67$	$1.63 \pm 0.12 \pm 0.04$	5.17	356	31	0.53	0.06
W Comae	754	$41.7 \pm 3.40 \pm 2.46$	$2.02 \pm 0.06 \pm 0.05$	1.13	26	18	0.01	< 0.01
3C 279	6865	$287 \pm 7.13 \pm 10.2$	$2.34 \pm 0.03 \pm 0.04$	0.59	28	21	< 0.01	< 0.01
PKS 1424+240	800	$34.35 \pm 2.60 \pm 1.37$	$1.85 \pm 0.05 \pm 0.04$	1.50	137	30	< 0.01	0.16
H 1426+428	38	$1.56 \pm 1.05 \pm 0.29$	$1.47 \pm 0.30 \pm 0.11$	8.33	19	3	0.83	0.39
PG 1553+113	2009	$54.8 \pm 3.63 \pm 0.85$	$1.69 \pm 0.04 \pm 0.04$	2.32	157	76	0.40	0.54
Markarian 501	649	$22.4 \pm 2.52 \pm 0.13$	$1.73 \pm 0.06 \pm 0.04$	2.22	127	50	0.57	0.18
1ES 1959+650	306	$25.1 \pm 3.49 \pm 2.83$	$1.99 \pm 0.09 \pm 0.07$	1.60	75	21	0.91	0.29
PKS 2005-489	246	$22.3 \pm 3.09 \pm 2.14$	$1.91 \pm 0.09 \pm 0.08$	1.01	71	8	0.86	0.97
PKS 2155-304	3354	$109 \pm 4.45 \pm 3.18$	$1.87 \pm 0.03 \pm 0.04$	1.13	299	46	< 0.01	< 0.01
BL Lacertae	310	$51.6 \pm 5.81 \pm 12.2$	$2.43 \pm 0.10 \pm 0.08$	0.85	70	4	0.61	0.23
1ES 2344+514	37	$3.67 \pm 2.35 \pm 1.62$	$1.76 \pm 0.27 \pm 0.23$	5.28	53	3	0.76	0.46
M 87	31	$7.56 \pm 2.70 \pm 2.24$	$2.30 \pm 0.26 \pm 0.14$	1.11	8	1	0.43	0.57
Centaurus A	308	$70.8 \pm 5.97 \pm 5.80$	$2.90 \pm 0.11 \pm 0.07$	0.47	6	4	0.38	0.97

Most of the bright TeV blazars have been in low states since Fermi launched. Low variability in the GeV range.

Search for new TeV emitters *(poster P5-190, P. Fortin et al.)*

Difference between GeV-TeV photon indices vs redshift



$\Delta\Gamma_{max}$=2.5
for PG1553+113
no measured z
(poster P1-20,
D. Horan et al.)

Warning: non-simultaneous data!

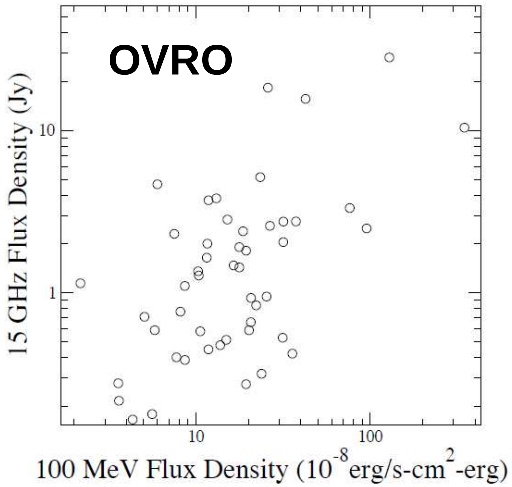
Poster P1-18, S. Fegan et al.

Radio- γ-ray connection

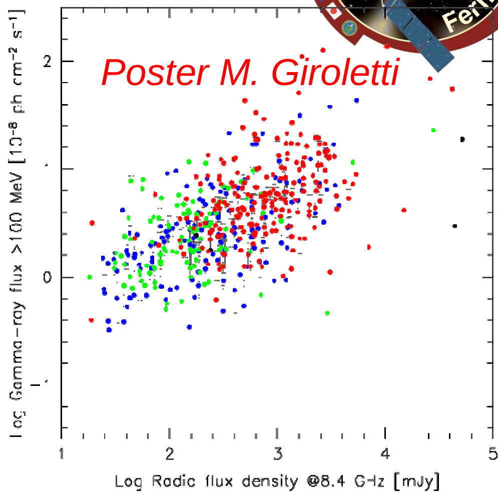
Investigation of correlations between

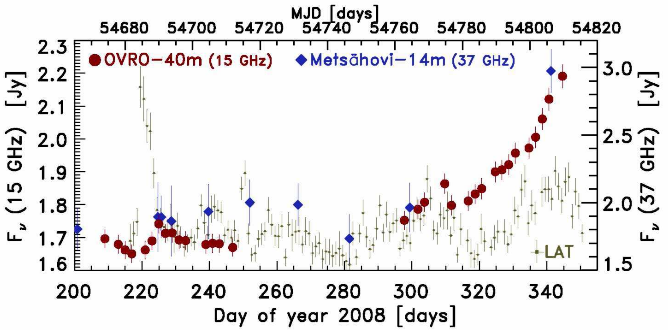
γ-ray and radio correlated variability
γ-ray and radio luminosities
γ-ray luminosity and jet properties
γ-ray flares and ejection of new radio components

Preliminary



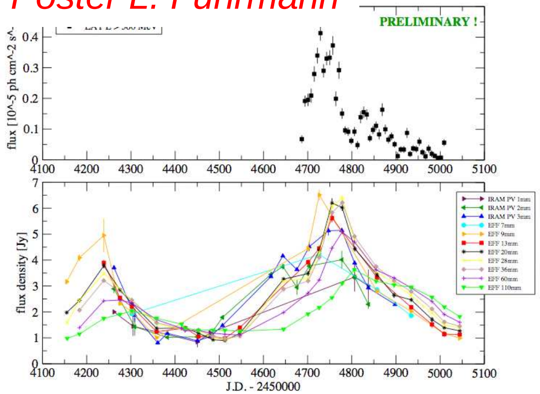
Poster M. Giroletti

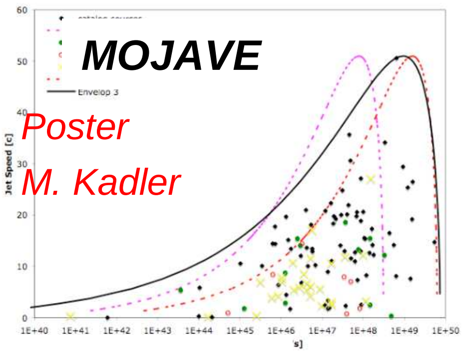




Effelsberg &

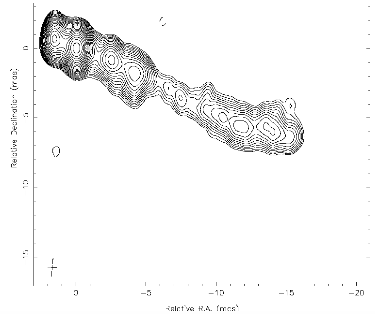
Poster L. Fuhrmann



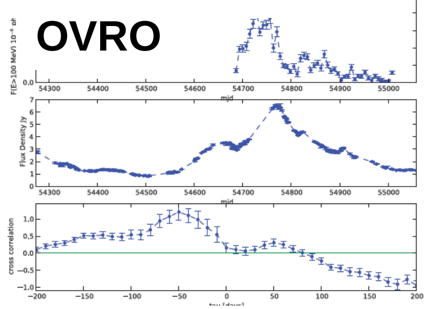


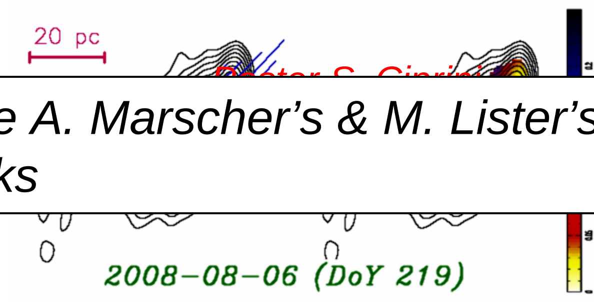
Poster M. Kadler

Poster Chin-Shin Chang



Poster W. MaxMoerbec



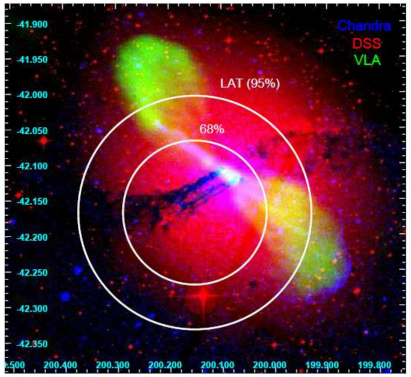


see A. Marscher's & M. Lister's talks

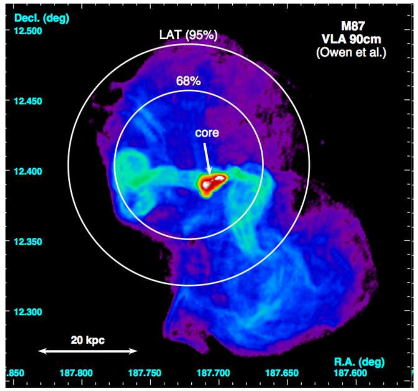
Non-blazar sources

Radio (non-blazar) Galaxies

- **Cen A** *(Poster P1-14, J. Finke et al.)*
  - nearest radio galaxy, FRI, D=3.7 Mpc, seen by EGRET and HESS
  - Fermi-LAT detection. Γ: 2.71 ± 0.09, TS=318
  - two-zone SSC model required to reproduce whole SED



- **M 87** *(Poster P1-49, W. McConville et al.)*
  - giant radio galaxy, FR1, D=16Mpc
  - detected by HESS, VERITAS, MAGIC
  - Γ : 2.26 ± 0.13, $F_{8:}$ 2.45 ± 0.6, TS=108
  - No indication of variability over 11 months
  - good fit of SED with one-zone SSC (e from sub-pc core)



- **NGC 1275** *(Poster P1-33, J. Kataoka et al.)*
  - "cooling core" cluster
  - detected by COS-B, not by EGRET
  - LAT flux 6x larger than EGRET upper limit
  - « short-term» variability points to an AGN

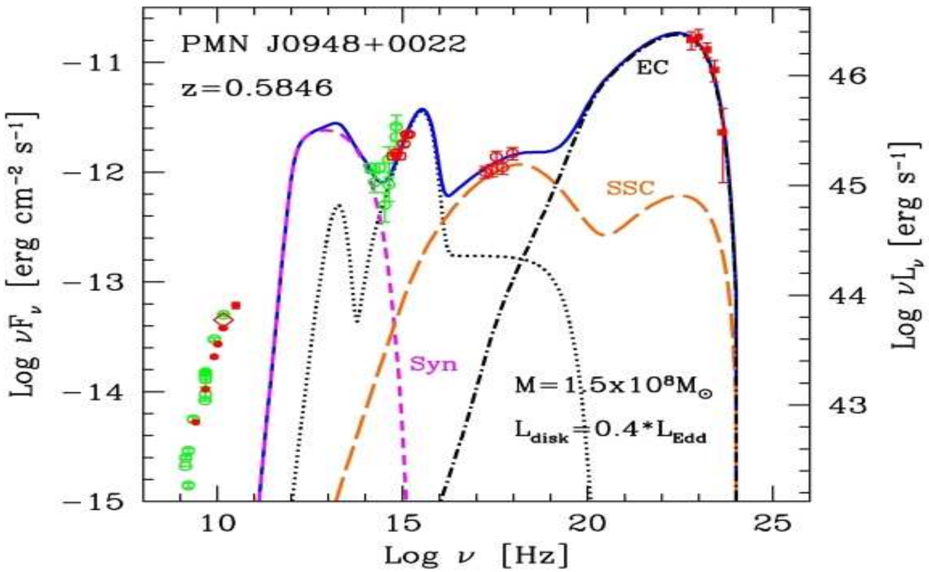
+ 7 other radio galaxies *(E.Cavazzuti's talk)*

Radio (non-blazar) Galaxies

Other class?

- **PMN J0948+0022, Narrow-line, radio loud Sy1** ***(contact: L. Foschini)***
  - **SED similar to FSRQ, less powerful**
  - **Radio emission is strongly variable and with flat spectrum, suggests Doppler boosting, now confirmed by LAT**
  - **More similar sources detected**

  Abdo, A. A. et al. 2009, ApJ, 699, 976



Limits on Galaxy clusters

Extragalactic Background Light

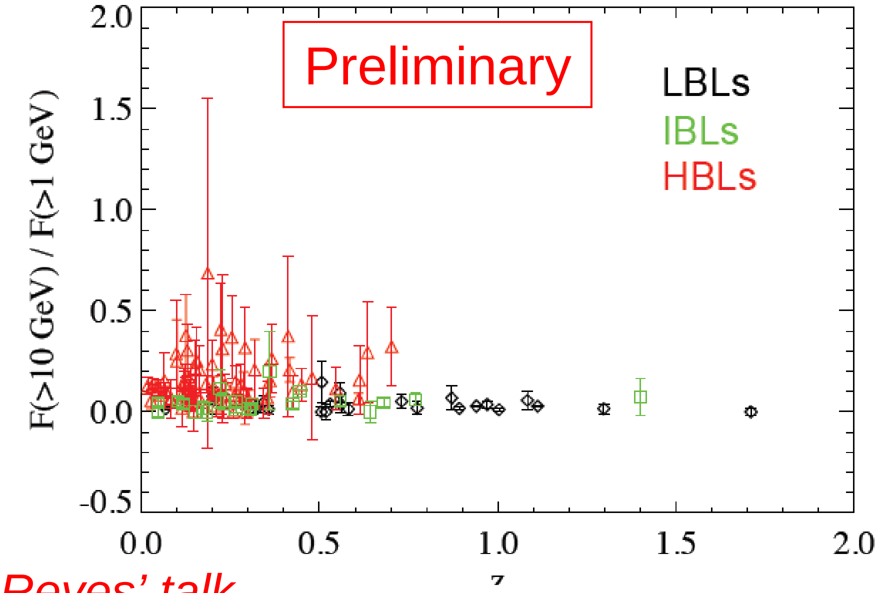
Fermi Gamma-ray Space Telescope

Extragalactic Background Light (EBL)

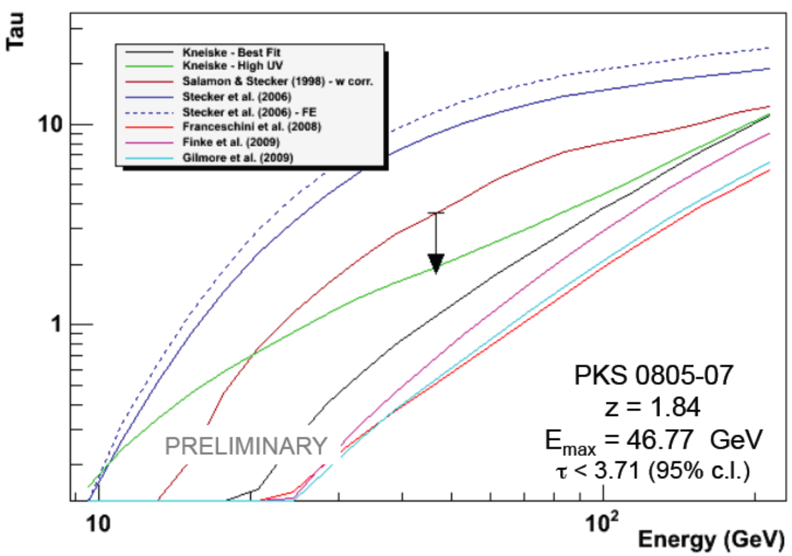
- **LAT-detected blazars at high z have soft spectra, many exhibiting breaks**

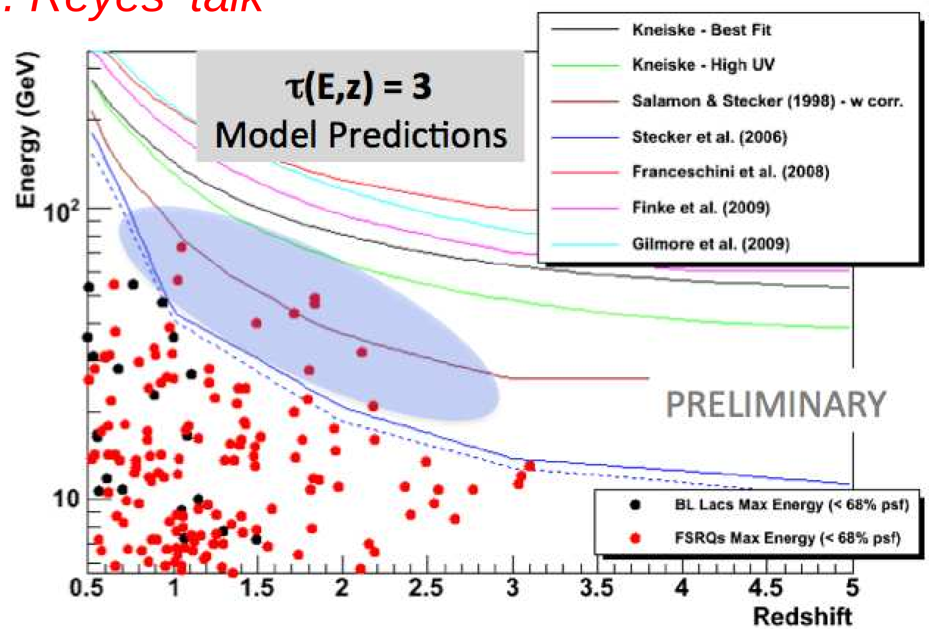
- **Little-constraining results provided by initially planned method based on** $\frac{F(E > 10\,GeV)}{F(E > 1\,GeV)}$ **ratio**

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



See L. Reyes' talk





Summary

- Fermi has discovered hundreds of new sources, proving that blazars dominate the extragalactic sky :
  - BLLacs (x~20 wrt EGRET), many being HSPs
  - FSRQs (x~5 wrt EGRET)
  - majority of TeV AGNs.

making detailed population studies possible.

- Important spectral properties (correlation of photon index with blazar class, spectral breaks, relative constancy of photon index with flux) have been observed.

- 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.

- Many new non-blazars sources have been detected (Radio galaxies, NRLSy1, Cen A giant radio lobes).
- Constraints on EBL opacity have been obtained.

A lot of novel features and correlations to digest, but ultimately a better understanding of gamma-ray emitting AGNs will emerge.