



***Fermi* LAT view of the Extragalactic Gamma-ray Sky**

Gino Tosti*

**on behalf of the Fermi-LAT
collaboration**

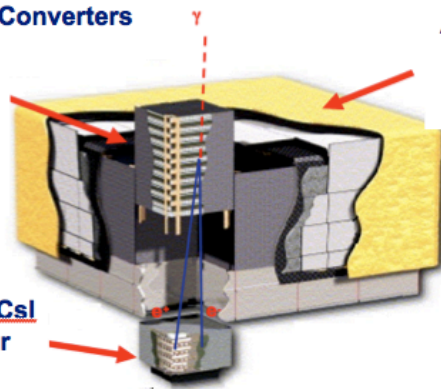
***University & INFN Perugia**

Fermi Survey Mode



Si-strip Tracker + W Converters

- 12 planes 3% r.l. (FRONT)
- 4 planes 12% r.l. (BACK)
- 2 planes with no converter



Anticoincidence Detector
→ segmented scintillator tiles

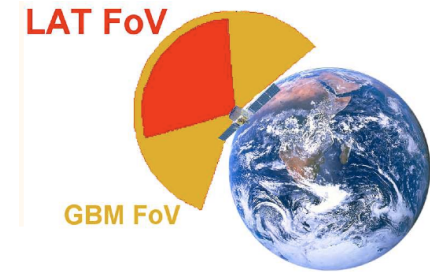
Hodoscopic CsI Calorimeter
→ 1536 logs
→ 8.5 r.l. on axis

Data Acquisition System

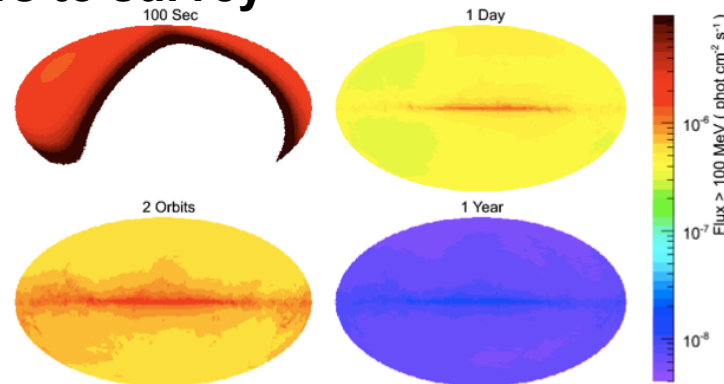
Pair-tracking Telescope

1.8m x 1.8m x 0.72m
3000 kg
4 x 4 modular array
1M channels x 160W

LAT sees 1/5 of the sky at any time
GBM sees entire un-occulted sky



Fermi spends every other orbit rocked either north or south: **3 hours to survey entire sky**

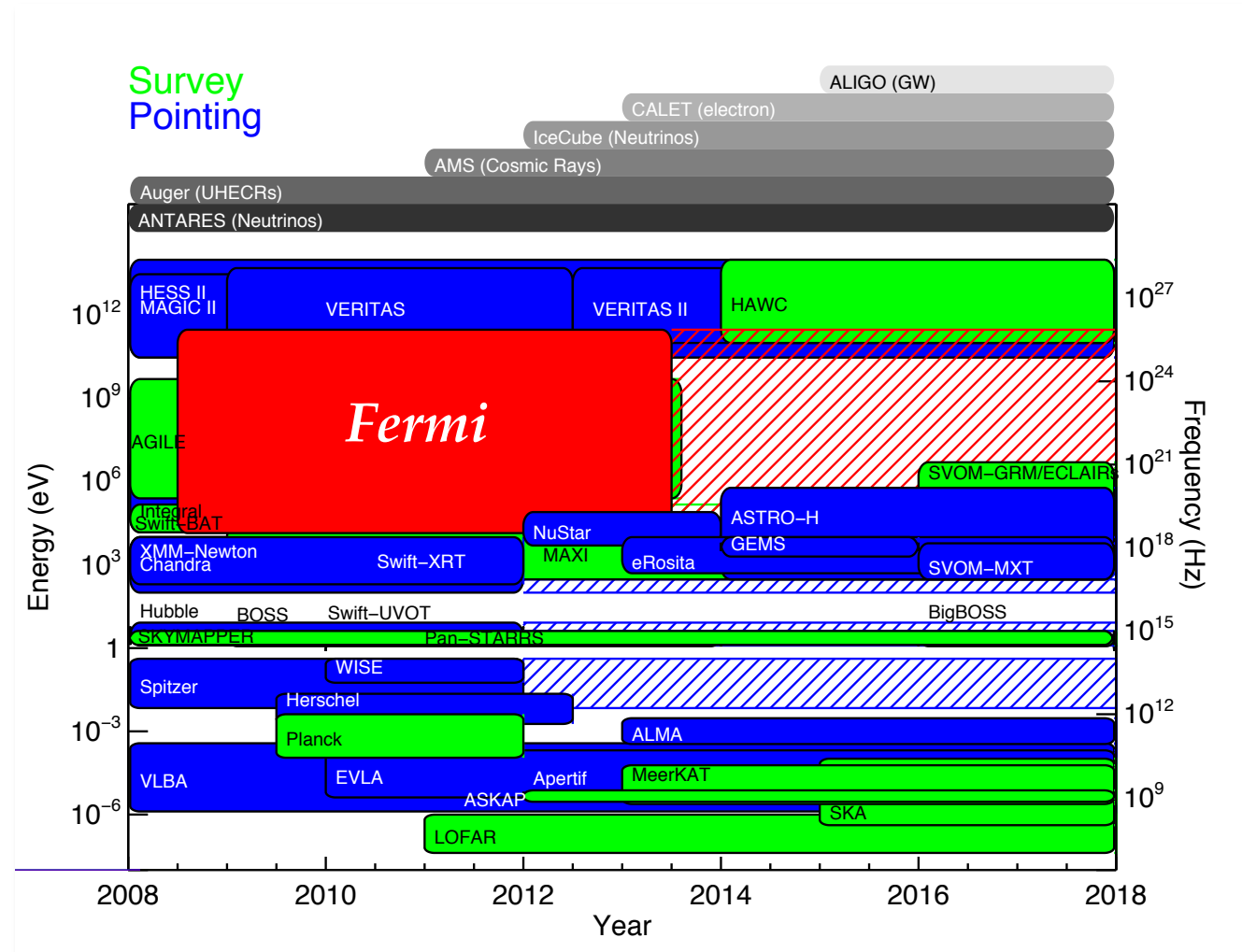


- ✓ ~100 MeV – 300 GeV
- ✓ Large FoV
- ✓ PSF ~45' @ 1GeV
~15' @ 10GeV

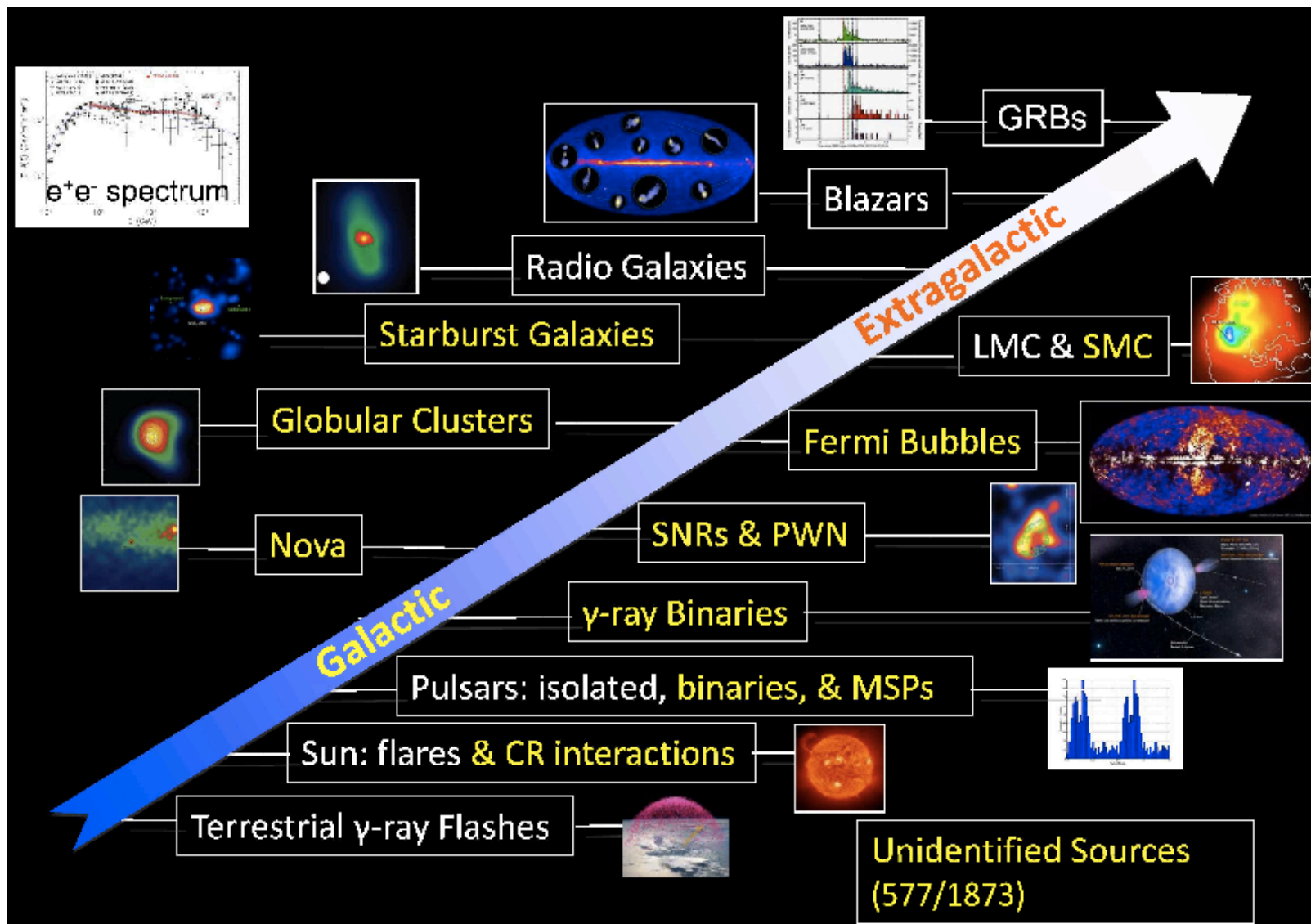
Synergies with Other Observatories



- **Fermi covers a huge interval of the EM spectrum**
 - **Crucial and unique spectral coverage**
- **Complement the large number of upcoming new survey instruments from VHE to radio wavebands**
 - **At the dawn of time domain astrophysics**



Fermi Discoveries Highlight



Fermi Large Area Telescope 2FGL catalog

○ AGN ⊗ AGN-Blazar

□ AGN-Non Blazar

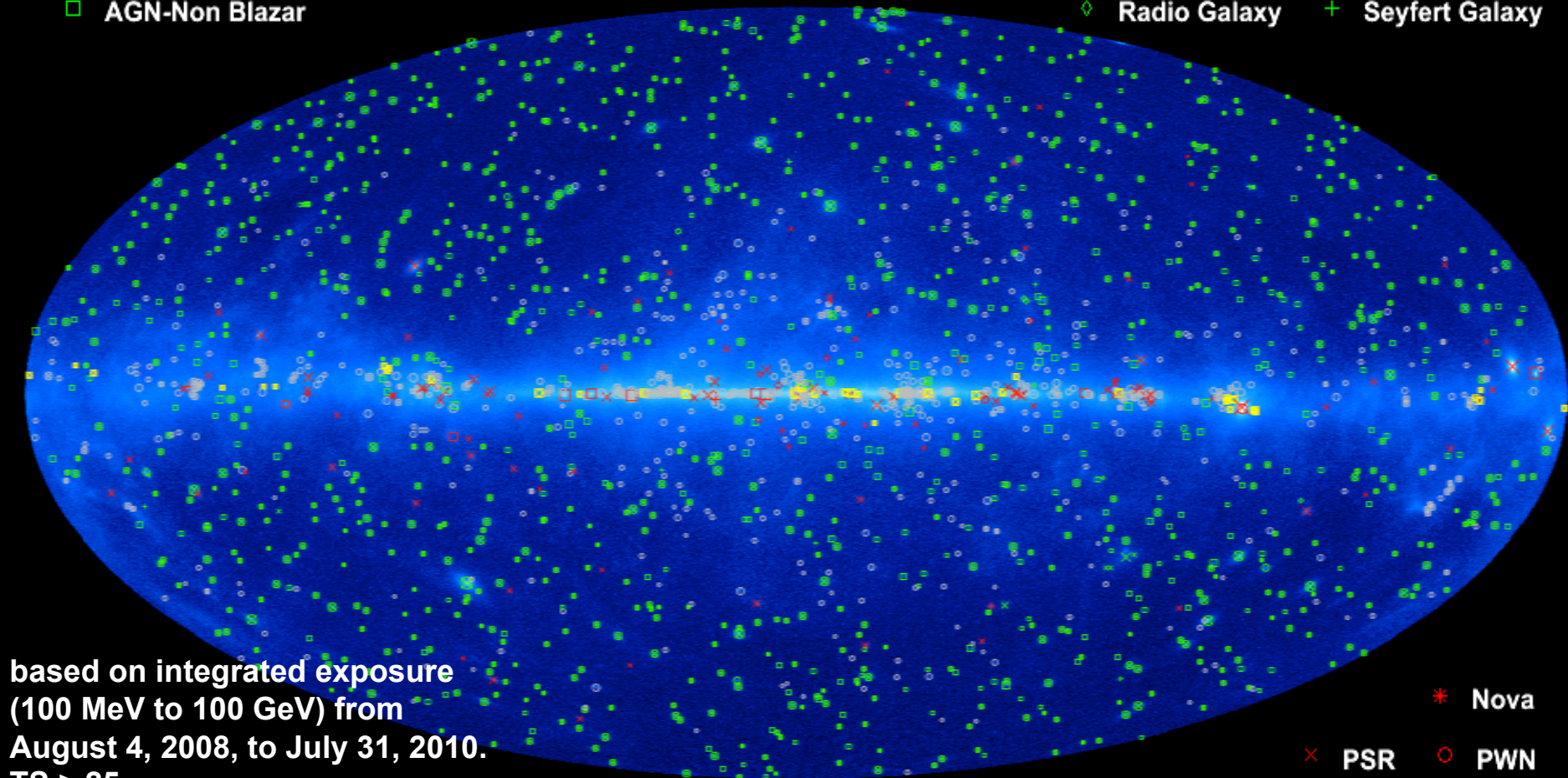
1,873 sources

× Galaxy

* Starburst Galaxy

◇ Radio Galaxy

+ Seyfert Galaxy



based on integrated exposure
(100 MeV to 100 GeV) from
August 4, 2008, to July 31, 2010.
TS > 25

○ Unassociated

□ Possible Association with SNR and PWN

* Nova

× PSR

○ PWN

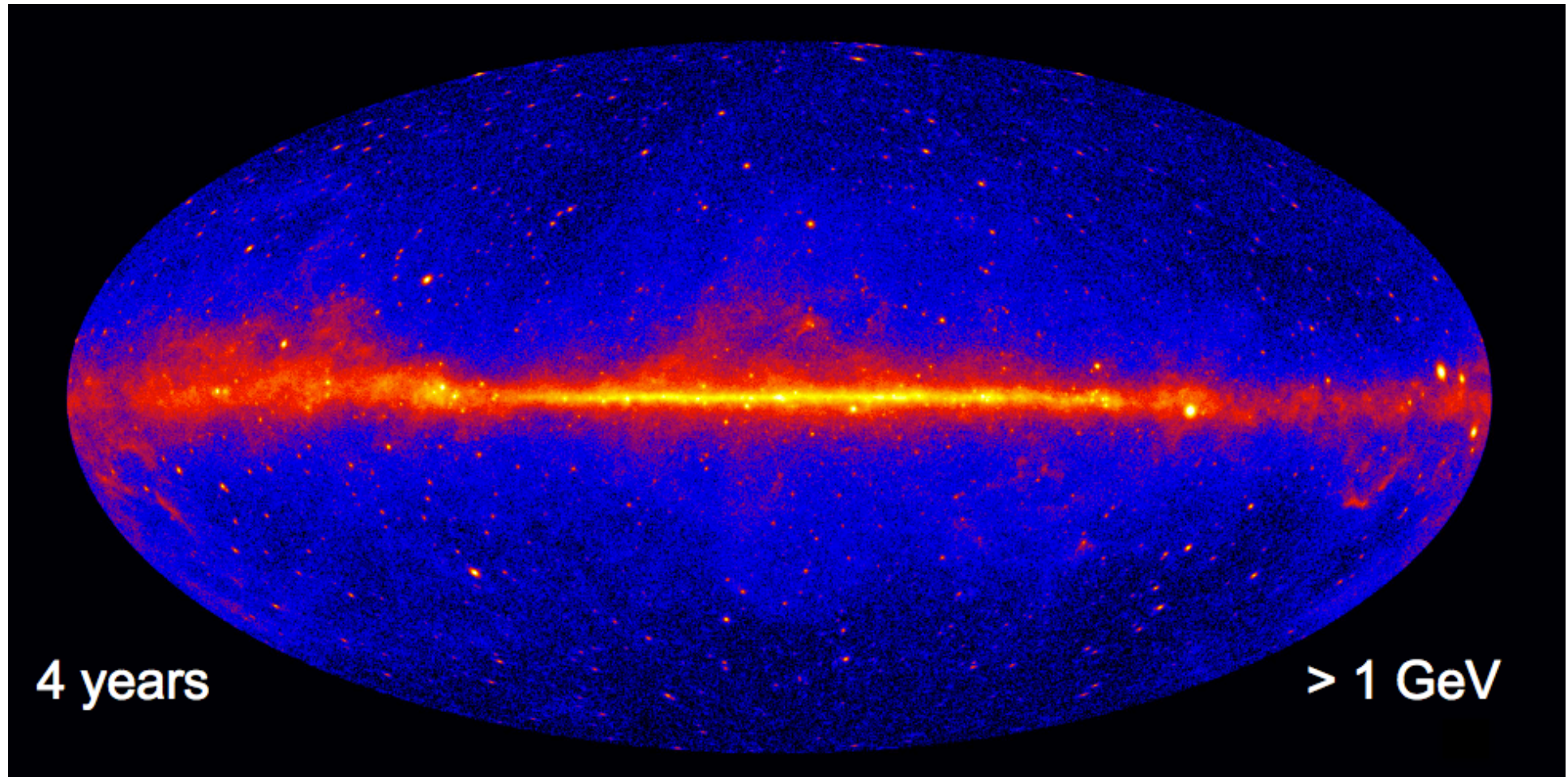
⊗ PSR w/PWN

□ SNR

◇ Globular Cluster

+ HMB

The 3rd Fermi LAT Catalog Sky



The 3rd Fermi LAT Catalog Sky



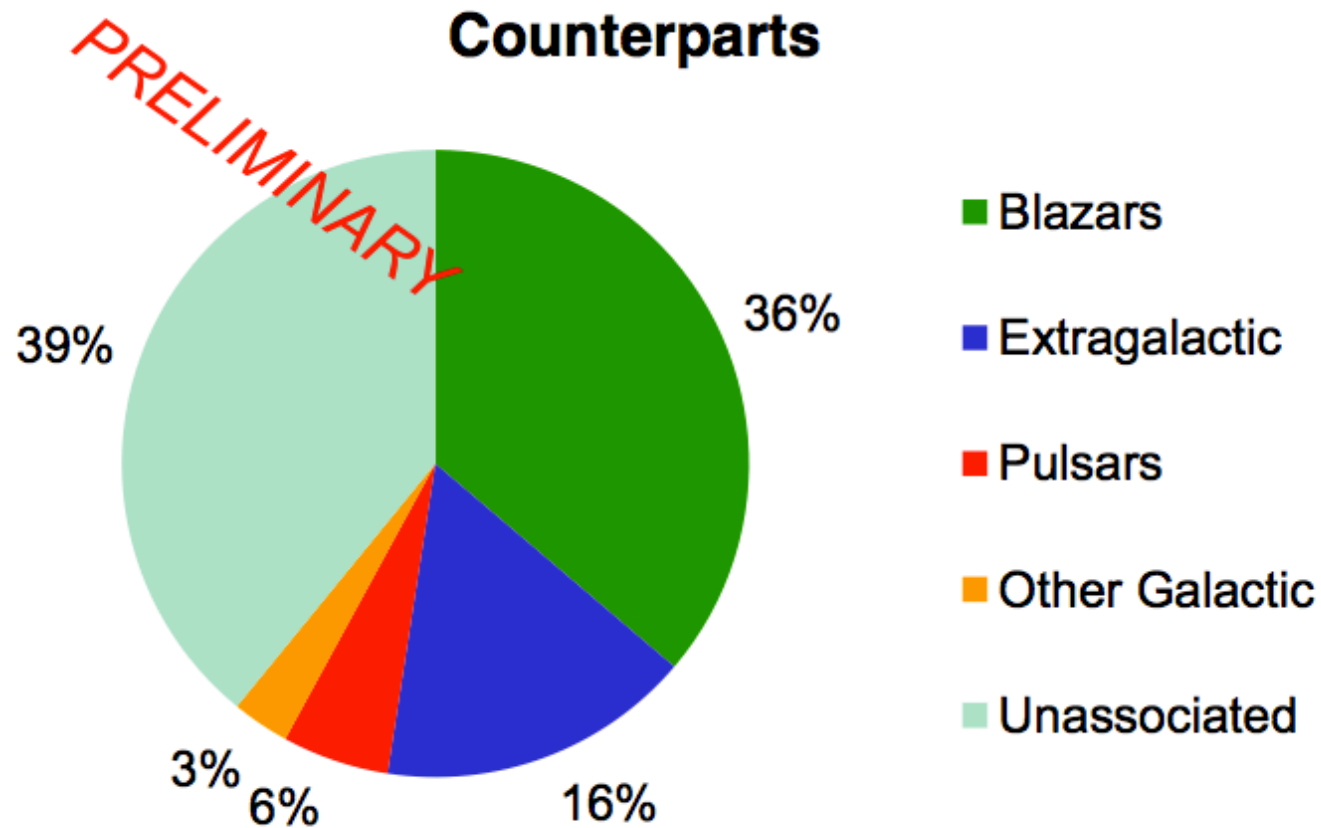
Based on 4 years of reprocessed data

- **Significantly better high-energy PSF → better localization**
- **Upgraded interstellar emission model allows keeping up with better statistics**
- **Significantly deeper than 2FGL, some 2500 sources**
- **Association rate similar to 2FGL**
- **Will be followed by a 5-year (contractual) catalog based on Pass8 (new reconstruction and classification of events) and another improvement of the interstellar emission model**

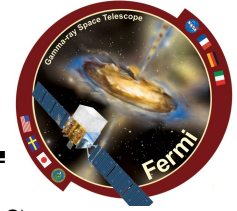
The 3rd Fermi LAT Catalog



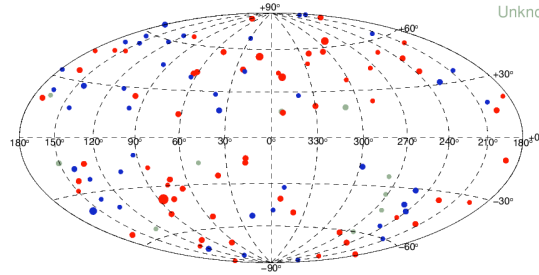
- More than 2500 sources
- Fraction of unassociated sources similar to 2FGL at this point in the process (ultimately 31%)



Blazars dominate the gamma-ray sky



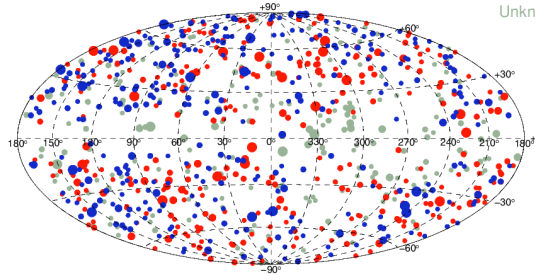
LAT Bright AGN Source List (LBAS)
TS>100, August 2008 – October 2008



3 months:LBAS

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

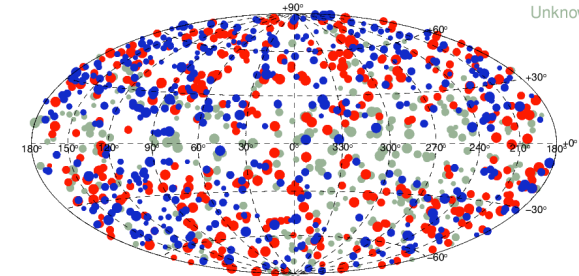
First LAT AGN Catalogue (1LAC)
TS>25, August 2008 – July 2009



1 year:1LAC

Abdo, et al. 2010, ApJ,
715, 429

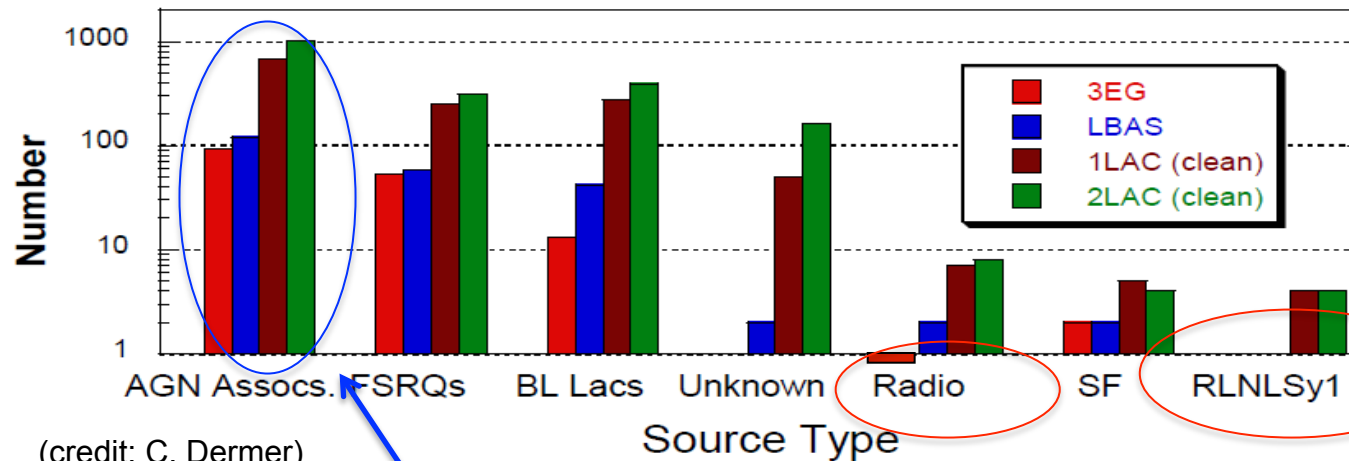
Second LAT Catalogue (2LAC)
TS>25, August 2008 – August 2010



2 years2LAC

Ackermann, M. et al.,
ApJ, 743: 171, 20
December 2011
arXiv:1108.1420

Extragalactic Gamma Ray Galaxies



(credit: C. Dermer)

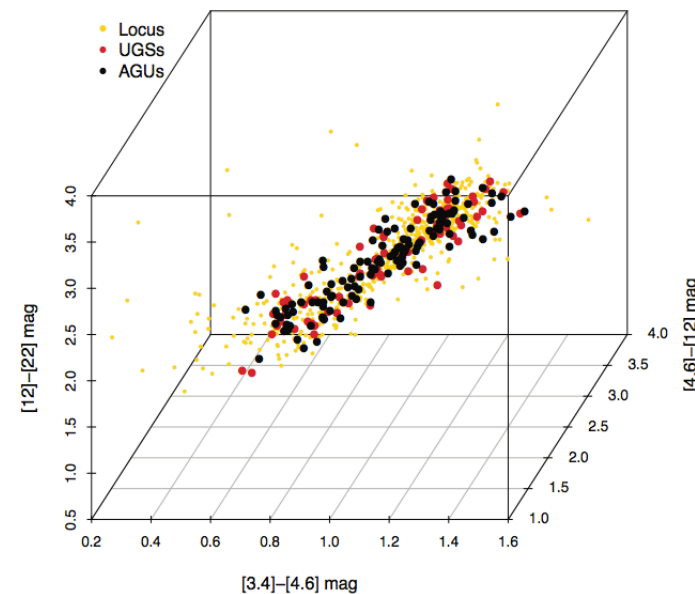
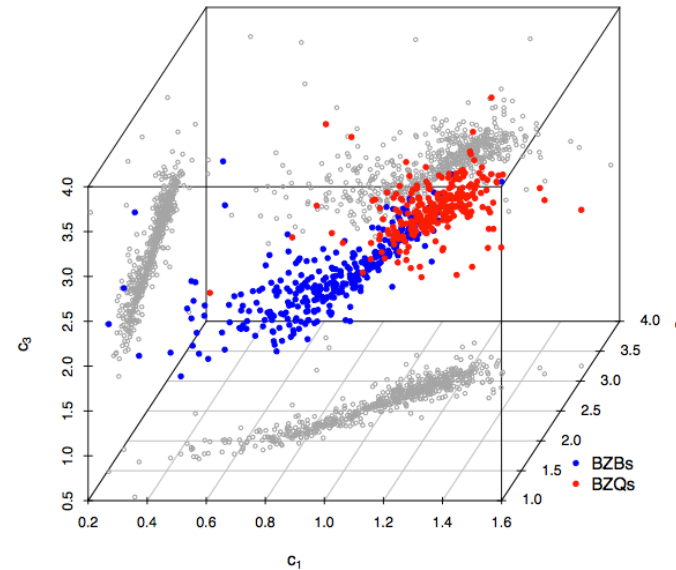
More than 1000 AGN!

See Filippo's Talk

Next:3LAC Catalog



- In the 3-dimensional WISE IR color space γ -ray emitting blazars lie in a distinct region (D'Abrusco et al. 2013) the “locus”.
- Using this method about 150 unidentified gamma-ray sources can be associated with a WISE blazar candidate (Massaro et al. 2013).



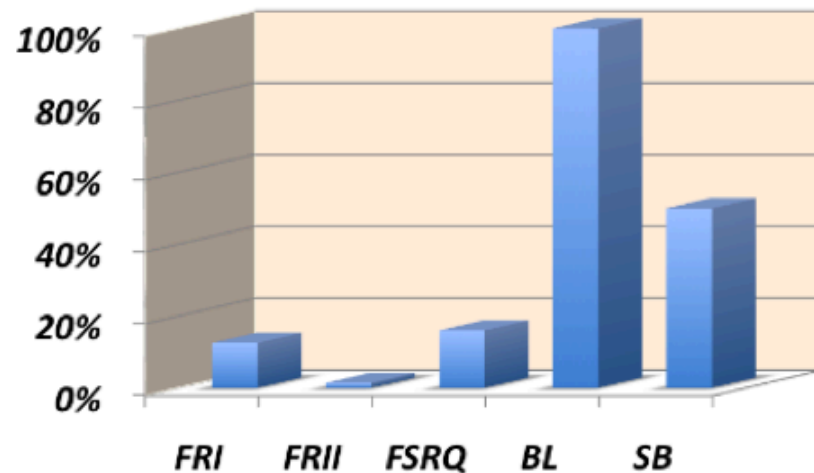
Misaligned AGN



Faint and soft sources

**deficit of FR II sources
(less structured/narrower jets?)**

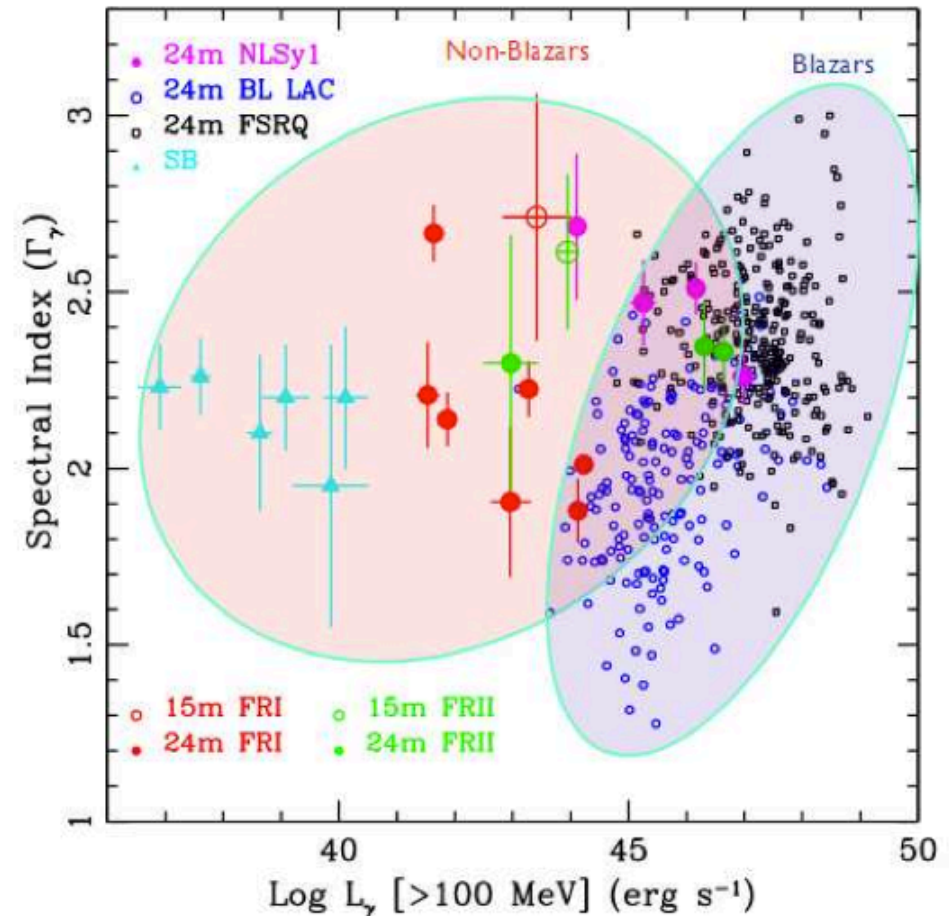
**FR II more variable than FRI
with short and intense flares**



P. Grandi+ 12

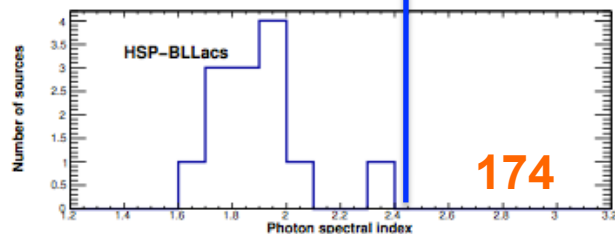
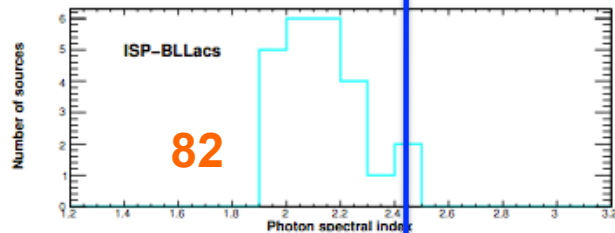
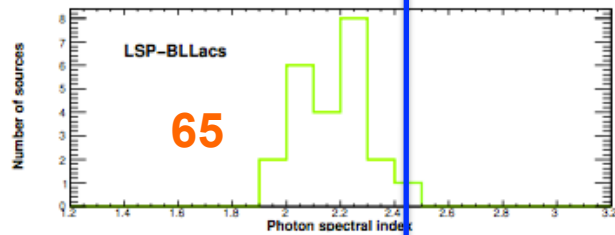
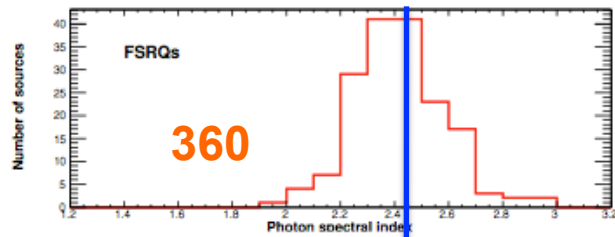
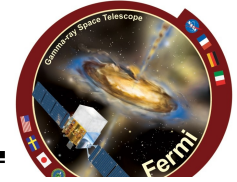
9 FRI radio galaxies (Cen A, 3C120, NGC1275, 3C78, NGC6251, M87, PKS0630, Cen B, Fornax A)

4 FR II-like radio sources (3C111, 3C 207, 3C 380, PKS 0943)



See Anita's Talk

Blazar Class vs Spectral Index



(Ackermann et al. 2011)

tosti@pg.infn.it

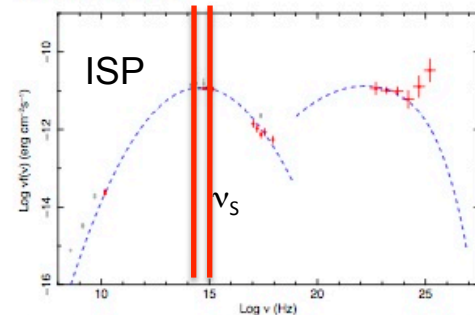
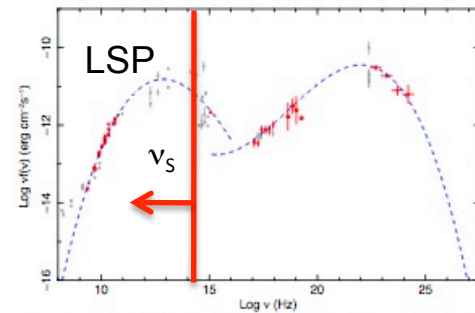
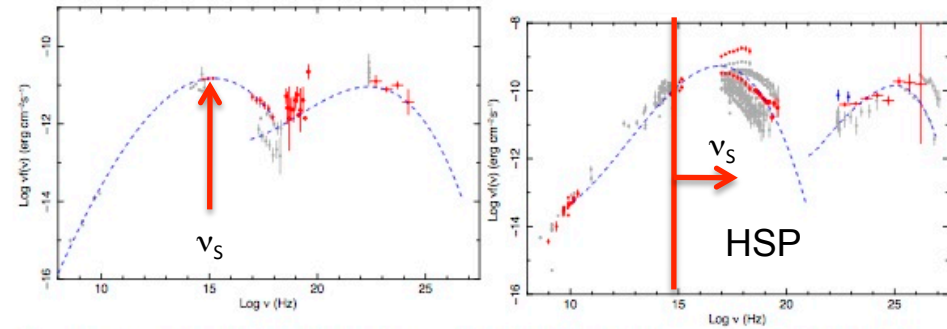
TeV

3

4

4

31



- New Classification based on ν_s
- LSP, ISP, HSP: low-, intermediate-, high-energy peaked blazars, resp.

- LSP: $\log(\nu_s) < 14$
- ISP: $14 < \log(\nu_s) < 15$
- HSP: $\log(\nu_s) > 15$

This classification is now widely used in the Literature.

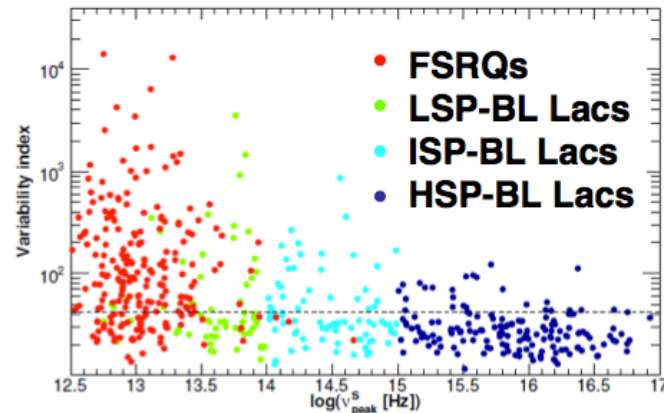
(Abdo et al. 2010)

12

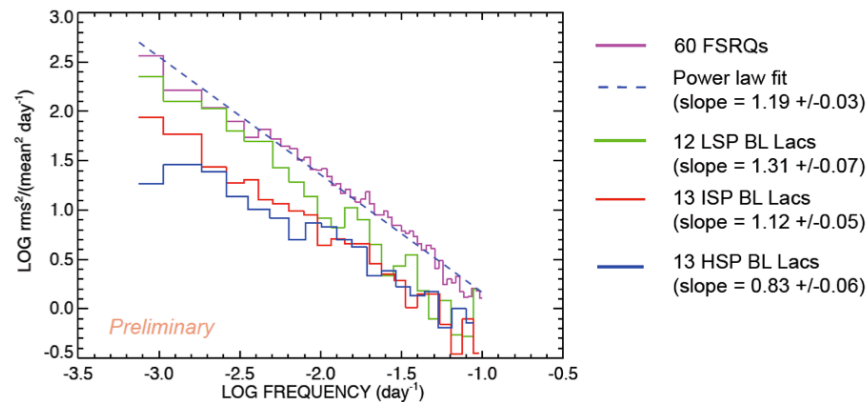
Variability



2LAC



Averaged Power Density Spectra



Produced with 5-day light curves of ~80 brightest LAT blazars
No persistent breaks found in PDS of individual sources

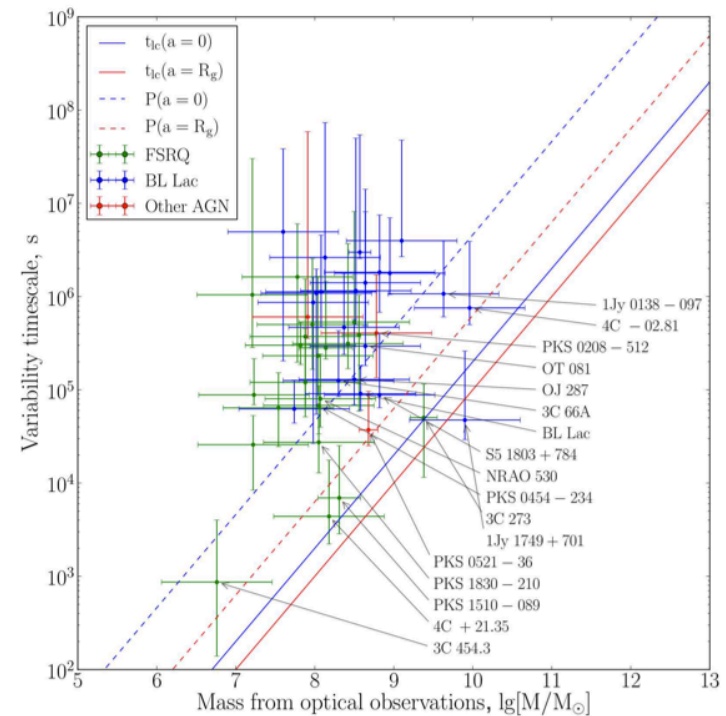


Figure 2. Measured minimal variability timescales versus the mass of the central black hole for the AGNs from table 1. Solid lines represent the light-crossing times for maximally rotating (red) and non-rotating (blue) black holes, dashed lines – the same for the period of the last stable prograde orbit.

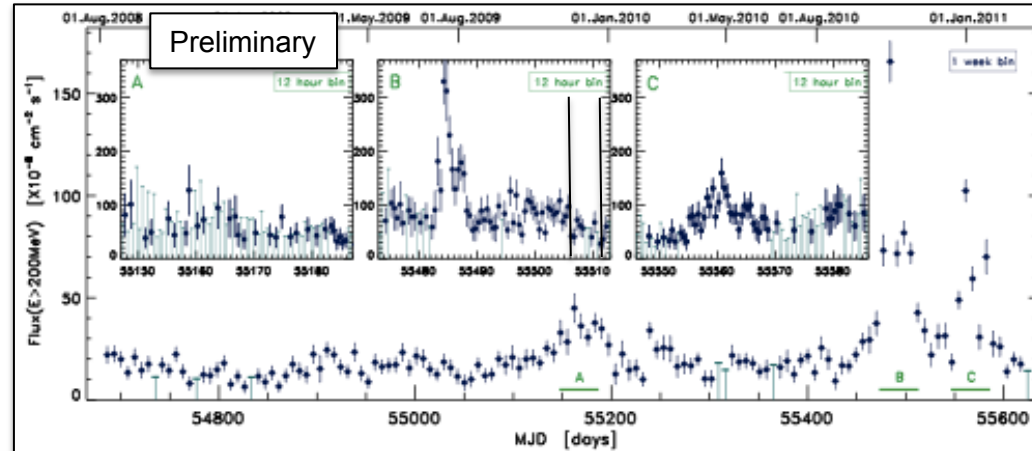
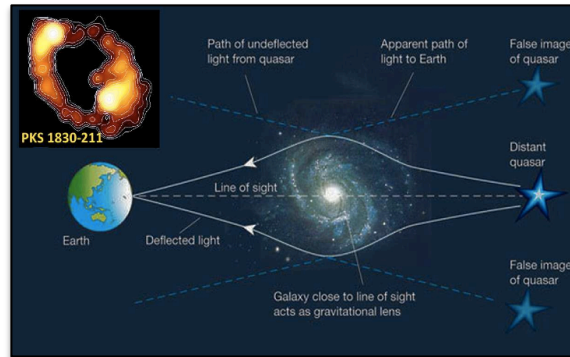
(Vovk & Neronov 2013)

See Stefan's Talk

tosti@pg.infn.it

EWASS Symp. 12 - 11 and 12 July 2013,
Turku, Finland

Gravitationally lensed blazar at gamma rays



PKS1830-211: FSRQ subject to gravitational lens
(measured radio delay ~ 26 days and magnification ratio ~ 1.5)

No evident sign of “echo”
gamma-ray flares caused by lens
Abdo+2013, submitted to ApJ

See Stefano's Talk

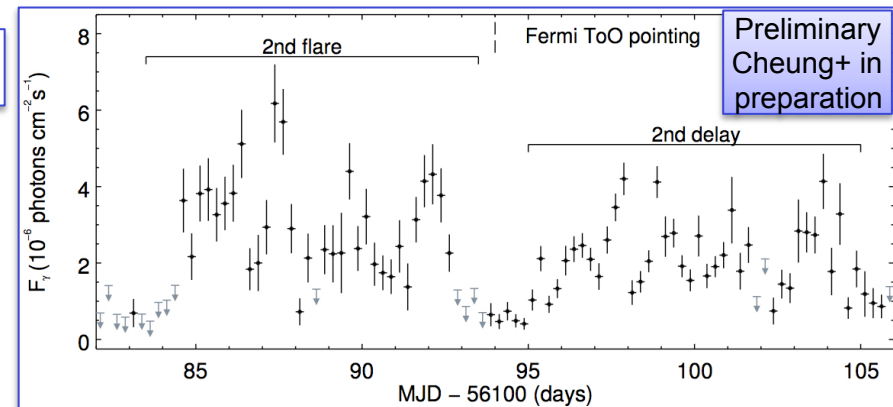
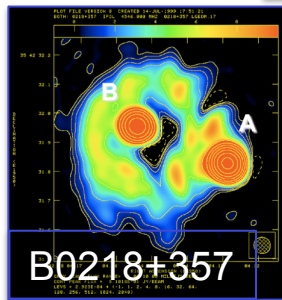
The Astronomer's Telegram

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

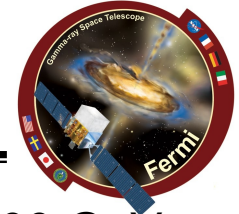
ATel #4411: C. C. Cheung (NRC/NRL), R. Ojha (NASA/GSFC), M. Orienti (Univ. Bologna, INFN-IRA Bologna), D. L. Wood (Pratt/NRL); on behalf of the Fermi Large Area Telescope Collaboration
on 22 Sep 2012; 03:01 UT
Credential Certification: Teddy Cheung (ccheung@milkyway.gsfc.nasa.gov)

Subjects: Gamma Ray, >GeV, AGN, Blazar

Recently, the Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope, observed a re-brightening of the gravitationally lensed blazar S3 0218+35, with the source reaching a peak daily flux ($E > 100$ MeV) of $\sim 2 \times 10^{-6}$ ph $\text{cm}^{-2} \text{s}^{-1}$ on 2012 September 6. The re-brightening was about ten days after a previous gamma-ray peak (ATel #4363, #4361, #4371), consistent with the time delay of 10.5 ± 0.4 days measured between the variations in its two compact radio source images (Biggs et al. 1999, MNRAS, 304, 349).

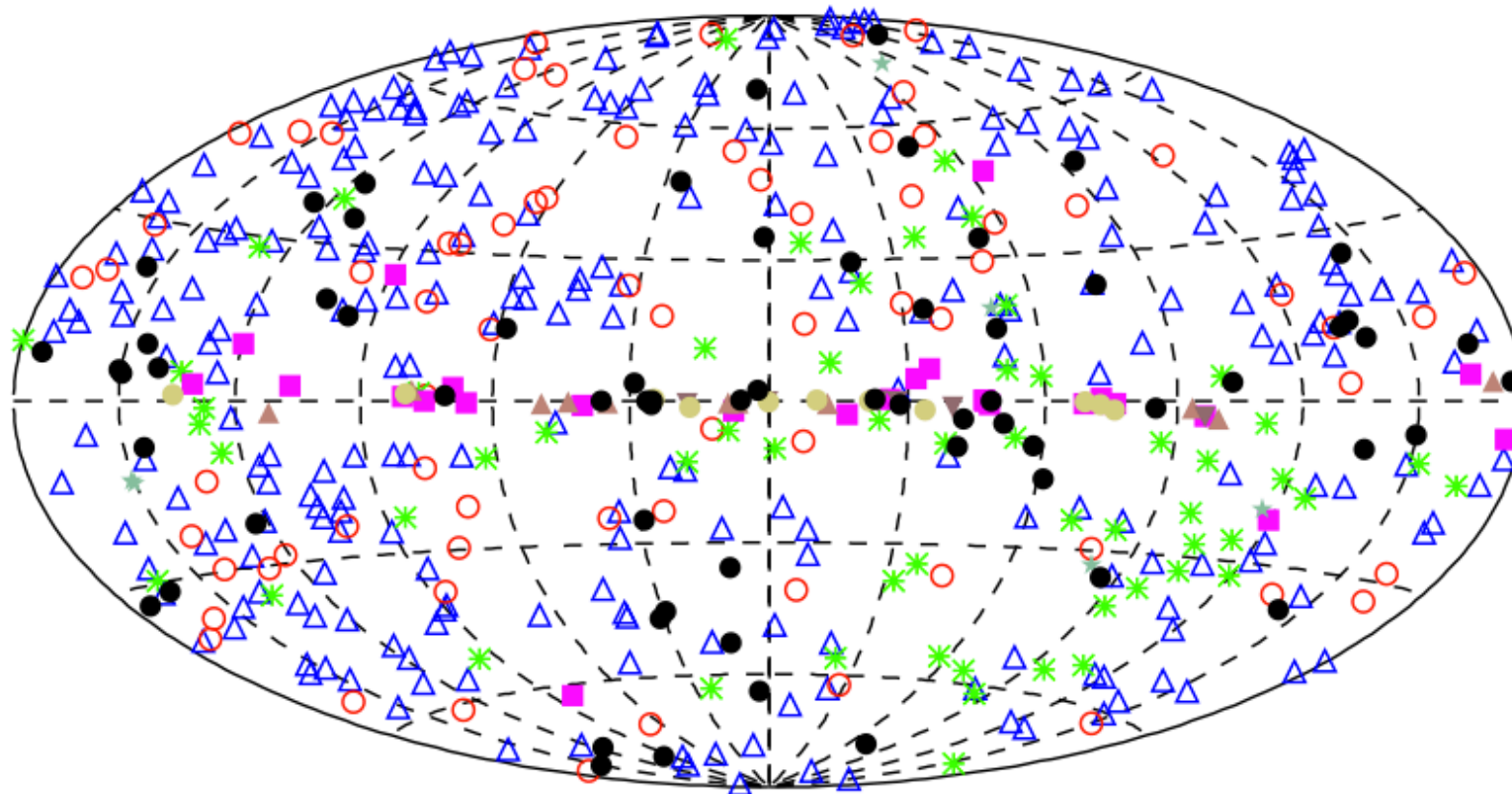


The >10 GeV Sky: 1FHL Catalog



Ackermann et al, arXiv:1306.6772

3-year Data; 10-500 GeV



△	BL Lac	○	FSRQ	✱	AGNs of unknown type
■	PSR	▲	SNR	▼	PWN
●	Other Galactic objects	★	Other (non-beamed) Extragalactic objects	●	No association

The >10 GeV Sky: 1FHL Catalog



Ackermann et al, arXiv:1306.6772

Table 4. LAT 1FHL Sources by Class

Class Description	Identified Designator	Number	Associated Designator	Number	Total Number	Fraction of full catalog [%]
Blazar of the BL Lac type	BZB	7	bzb	252	259	50.4
Blazar of the FSRQ type	BZQ	13	bzq ^a	58	71	13.8
Active galaxy of uncertain type	AGU	1	agu	57	58	11.3
Pulsar, identified by pulsations above 10 GeV	HPSR	20	...	...	20	3.9
Pulsar, identified by pulsations in LAT (excluding HPSR)	PSR	6	...	...	6	1.2
Pulsar, no pulsations seen in LAT yet	...	...	psr	1	1	0.2
Supernova remnant	SNR	6	snr	5	11	2.1
Pulsar wind nebula	PWN	3	pwn	3	6	1.2
Unclear whether SNR or PWN	...	...	spp	6	6	1.2
Radio galaxy	RDG	1	rdg	4	5	1.0
High-mass binary	HMB	3	hmb	0	3	0.6
Normal galaxy	GAL	1	gal	0	1	0.2
Star forming region	SFR	1	sfr	0	1	0.2
LBV star	LVB	0	lvb	1	1	0.2
Unassociated source	...	...	...	65	65	12.6

^a1FHL J1312.8+4827, classified here as bzq, may in fact be a narrow-line Seyfert 1 galaxy (Sokolovsky et al., *submitted*).

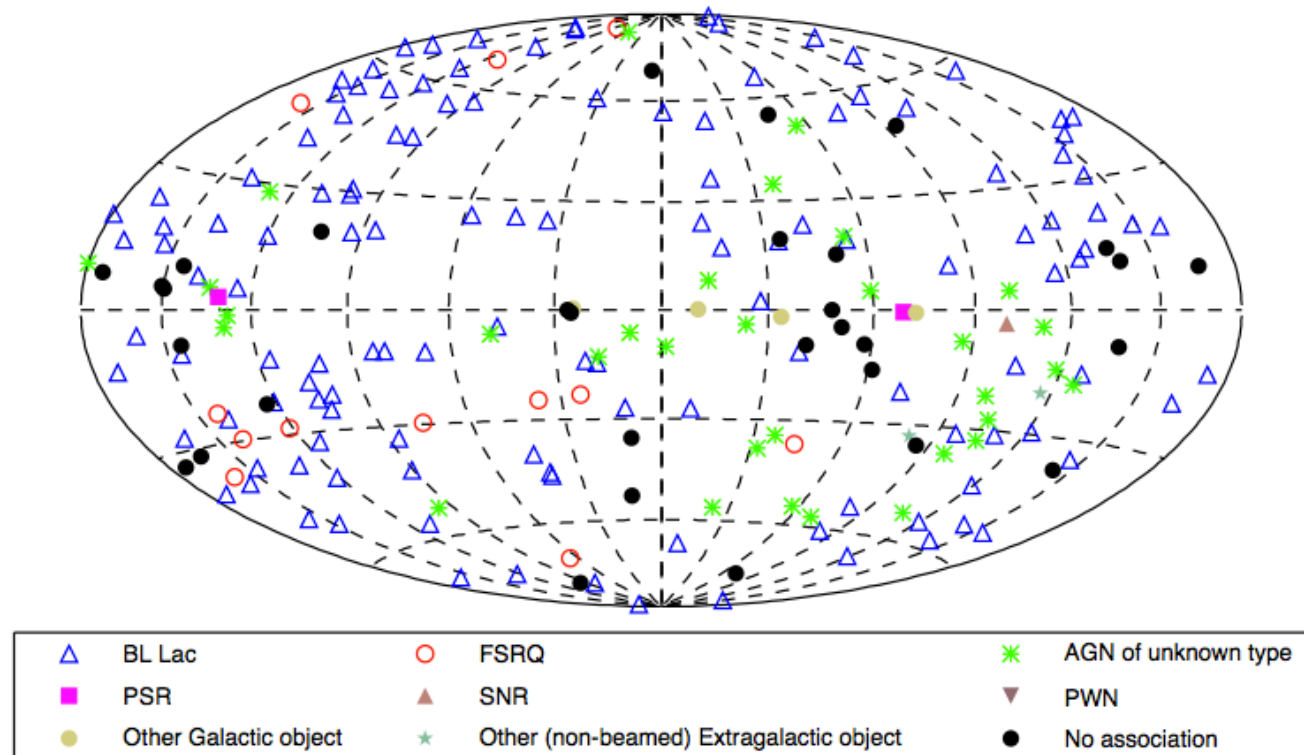
52 sources not in previous Fermi-LAT catalogs

84 sources have associations with known VHE sources (about 2/3 of all the known VHE emitters).

1FHL candidates for VHE detection



213 VHE Candidates: 129 BL Lacs, 12 FSRQs, 32 AGUs, 2 PSRs, 3 SPP, 1 SNR (SNR G260.4–03.4), 1 LVB star (Eta Carinae), 1 radio galaxy (PKS 0625–35), 1 Galaxy (LMC), and 31 unassociated sources.



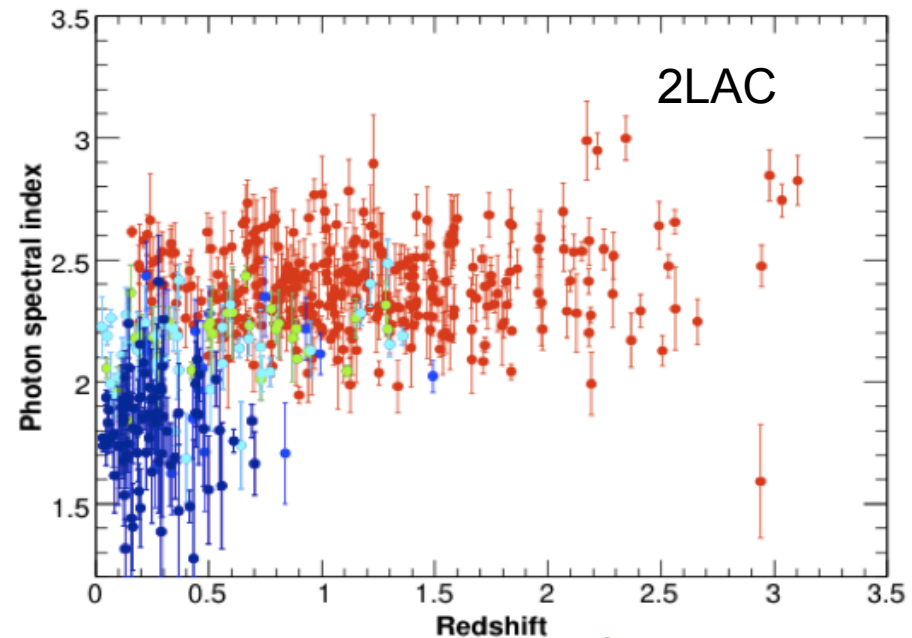
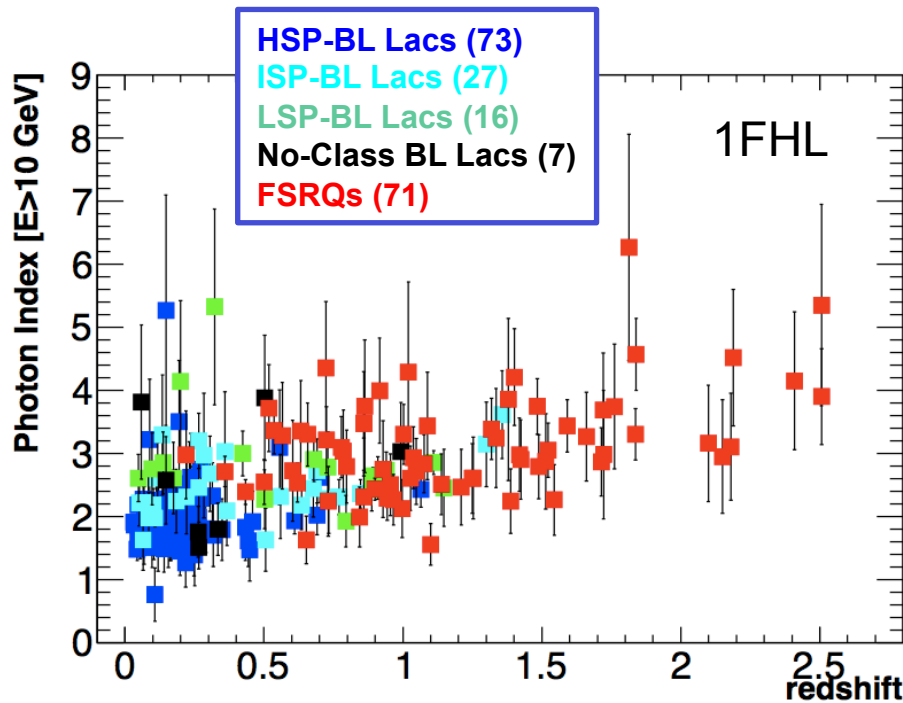
Ackermann et al, arXiv:1306.6772

Extragalactic background light attenuation in Fermi LAT data?



- Fermi 1FHL source List:
 - sources get softer with increasing redshift
 - possibly due to attenuation on optical/UV photons of EBL

» Such trend is less clear with photon index from E>100MeV (2LAC paper)



See Anita's Talk



IR radiation
Hot Dust

Broad Line
Region clouds

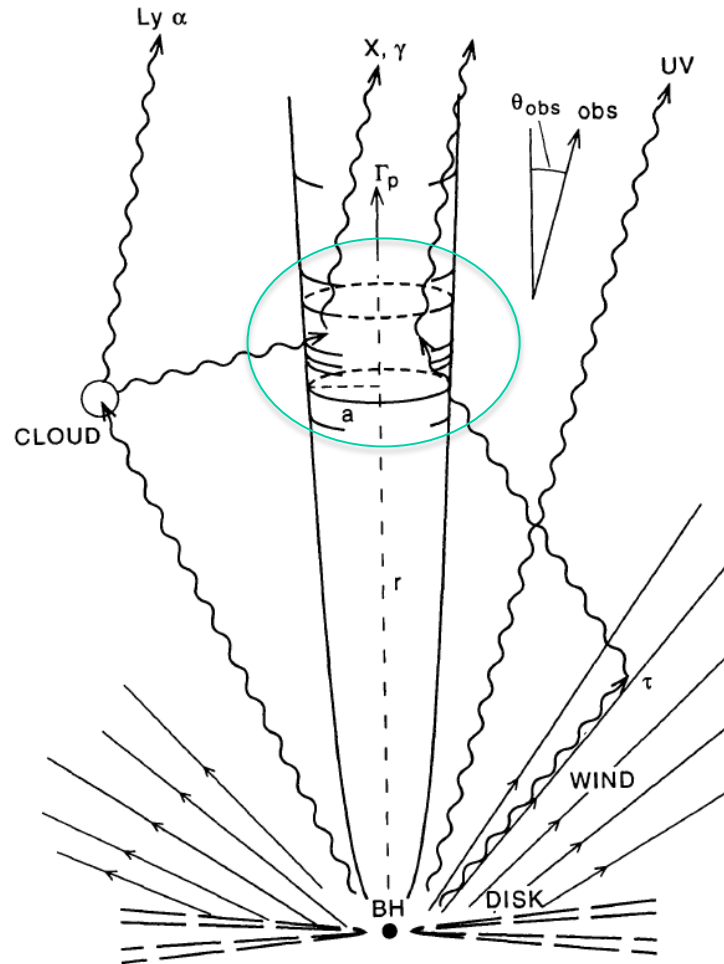
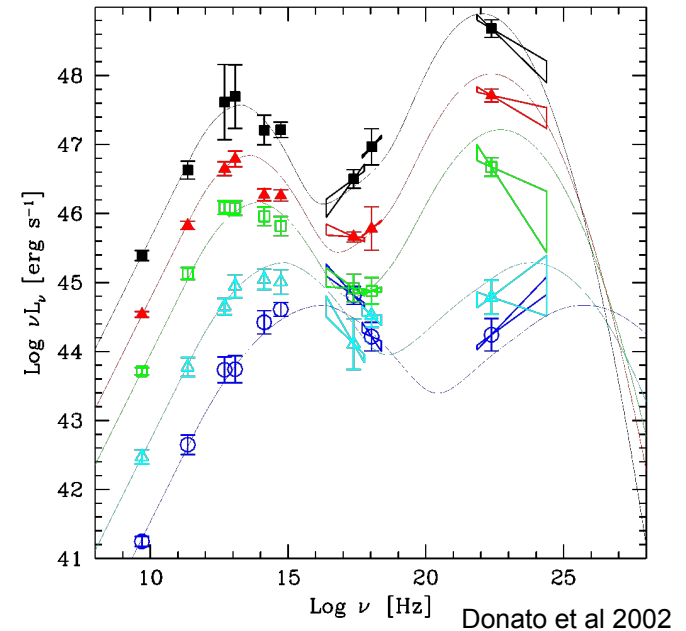


FIG. 2.—Geometry of the source. The radiating region, denoted by short cylinder of dimension a , moves along the jet with pattern Lorentz factor Γ_p . Underlying flow moves with Lorentz factor Γ , which may be different.

Sikora et al. 1994



See Markus's Talk

MW campaign on PKS 2155-304



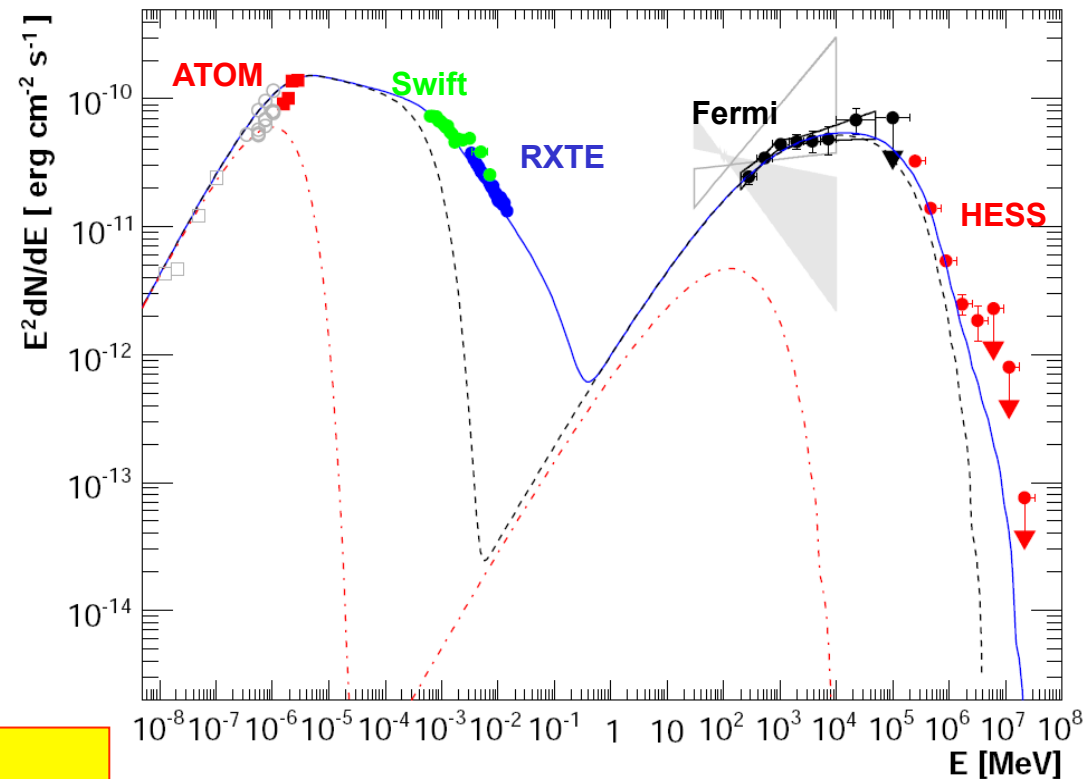
PKS 2155-304: BLLac-HSP, $z=0.116$

First simultaneous
SED including GeV-TeV data

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
usually used to model the SEDs of BL Lacs

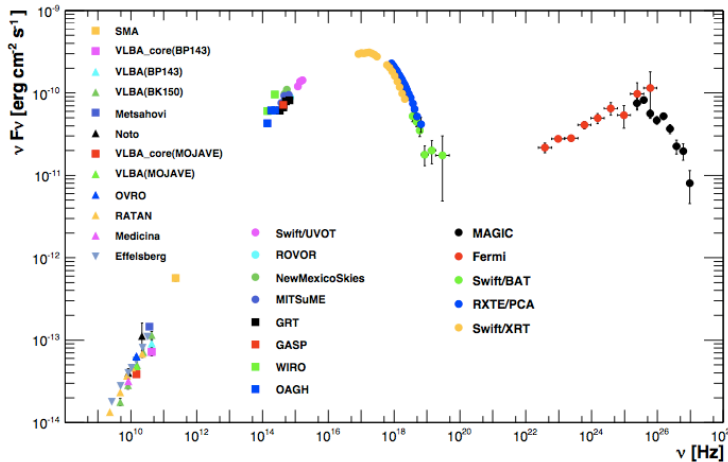


(Aharonian, F. et al. 2009, ApJL, 696 L150)

GeV-TeV Connection: MKN 421



[Abdo et al. 2011 (Fermi-LAT + MAGIC)]



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

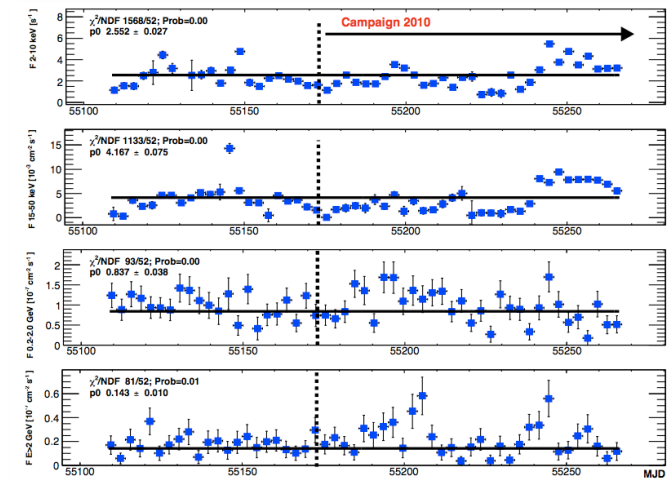
During this campaign, Mrk 421 showed a low activity at all wavebands

Extensive multiwavelength campaign on MKN 421 (from 2009 Jan. 19 to 2009 Jun. 1)

SED emerging from this is the most **complete and accurate representation of the low/quiescent state of Mrk421.**

Two scenarios are proposed:

Hadronic and Leptonic

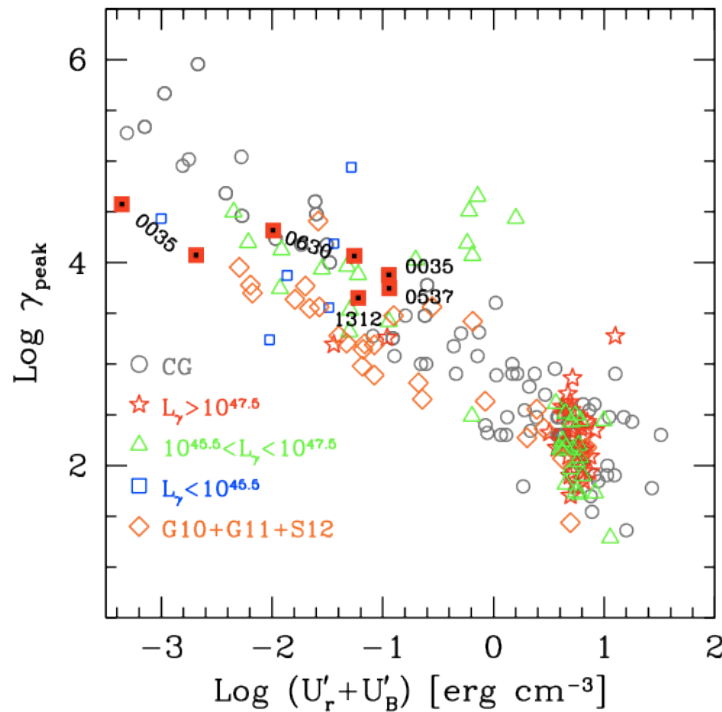


Multi-frequency light curves (X-ray:RXTE/ASM, Soft-Gamma: Swift-BAT, Gamma-ray: Fermi-LAT)

Origin of Blazar Sequence:

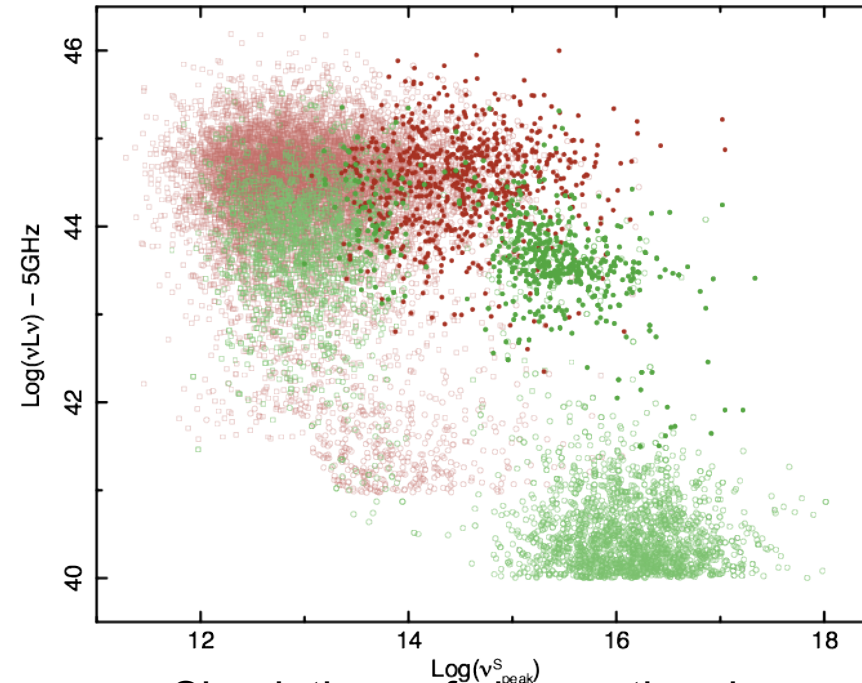


Physical ?



Ghisellini et al. 1998-2012

Selection bias ?



Simulations of observational biases

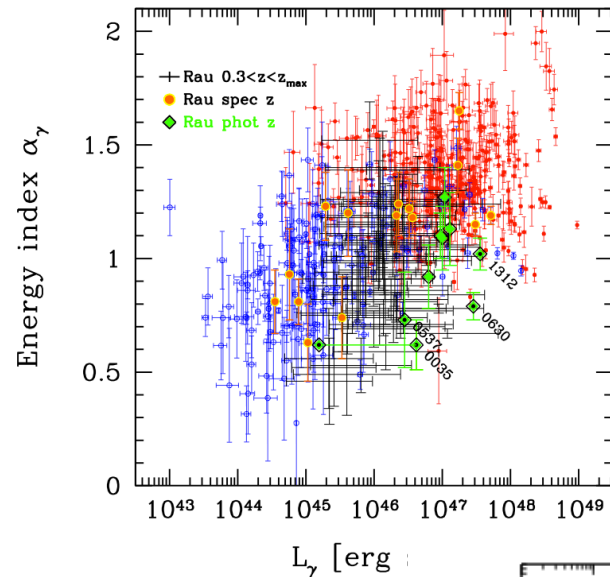
Giommi, Padovani et al. 2012

Problem of many Fermi BL Lacs with no redshift (but see Shaw et al. 2013 and Ajello et al. 2013 submitted)

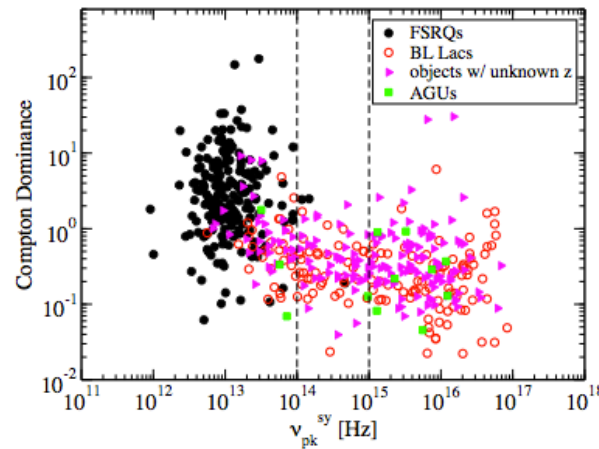
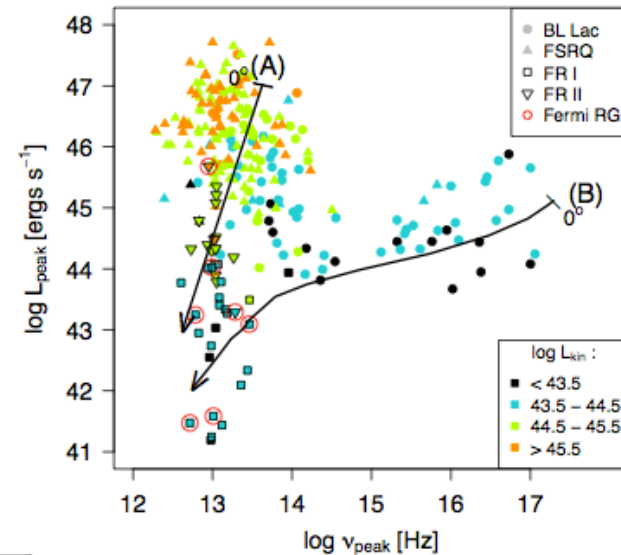
Modern view of the Blazar Sequence



Ghisellini et al 2009,2012
sequence of accretion rates.



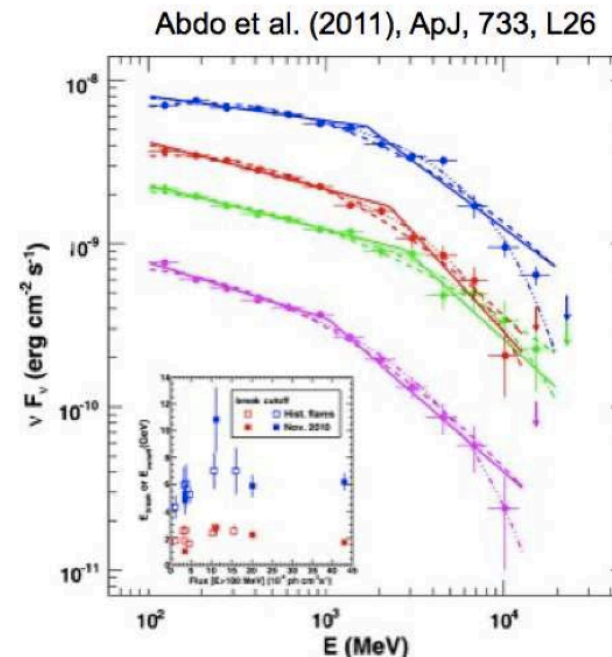
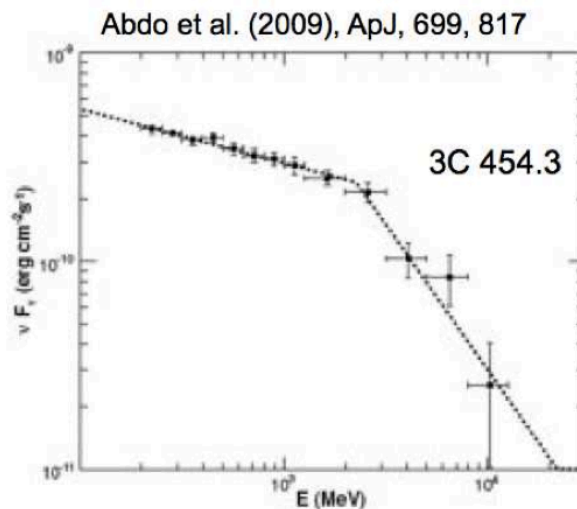
Meyer et al 2011 – different structure
of the jet in FSRQ/FR II and BLLac/FR I



Finke 2012 – this correlation is quasi
Independent from redshift; u_{ext} , B, beaming



- Spectral departure from a pure power-law \sim few GeV have been found in the γ -ray spectra of many LSP FSRQs and BL Lacs, most prominently in the extremely bright 3C454.3.
 - γ - γ attenuation from He II line photons (Poutanen et al. 2010, 2011)
 - intrinsic electron spectral breaks (Abdo et al 2009, ApJ 699, 817)



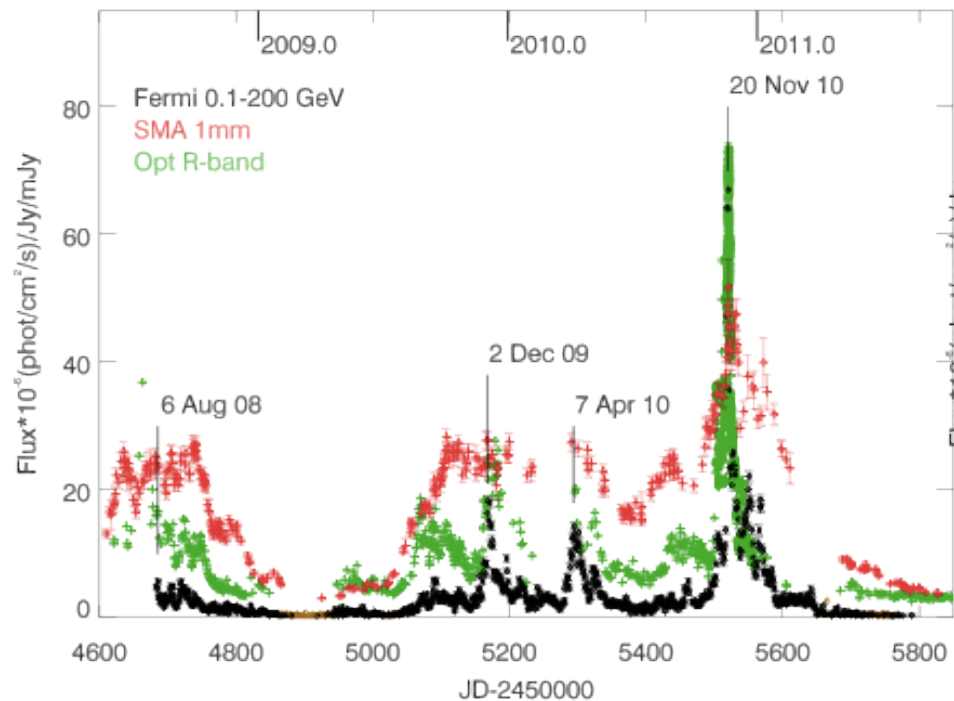
See Boris's Talk

Locating the blazar zone at large distance

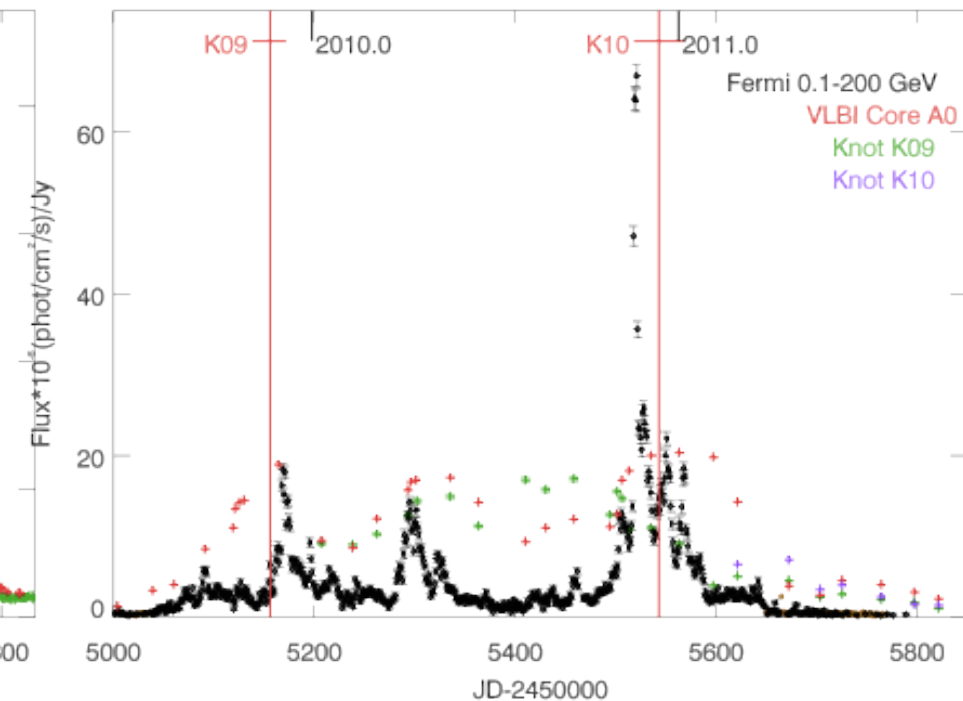


3C 454.3

Simultaneous flares



Knots passage through core



Jorstad 2011, Marscher et al 2011-2012

Radio/Gamma Co-spatial, transparent to radio

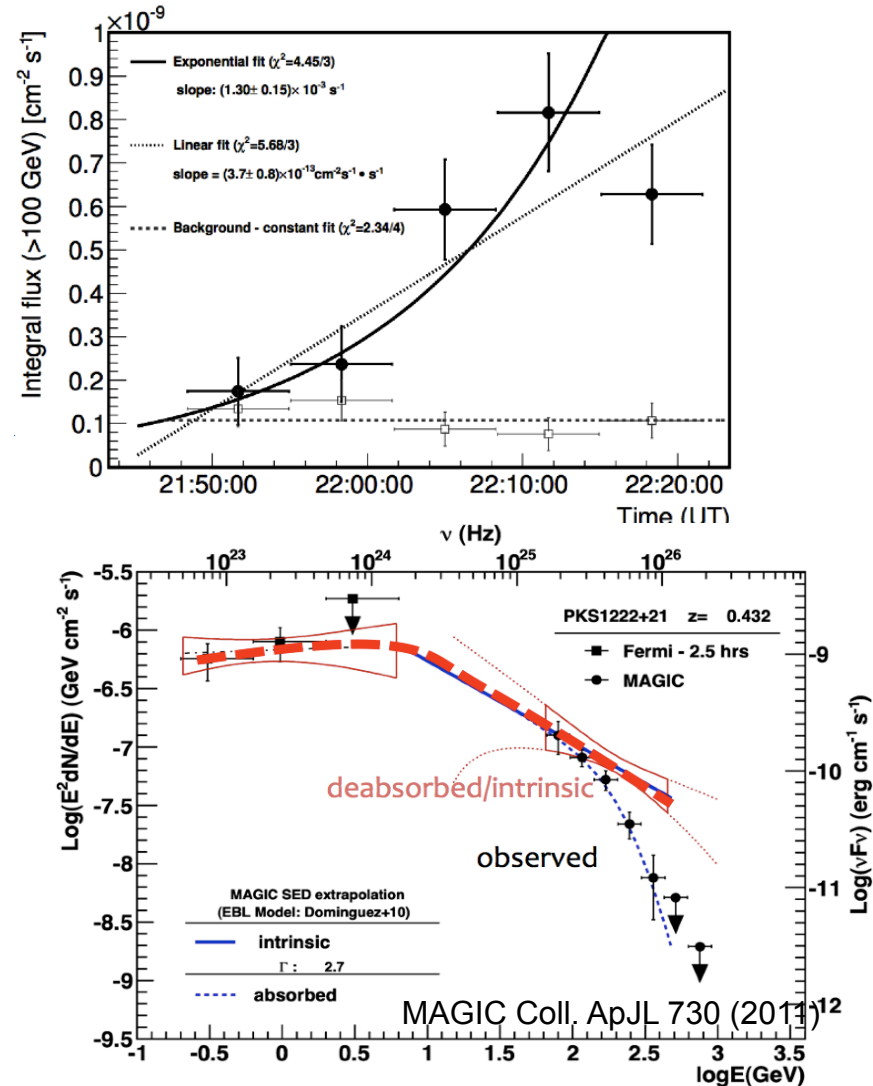
Flares: 43 positives, 13 negatives (34 Fermi blazars)

Location of the blazar zone: Fast Variability



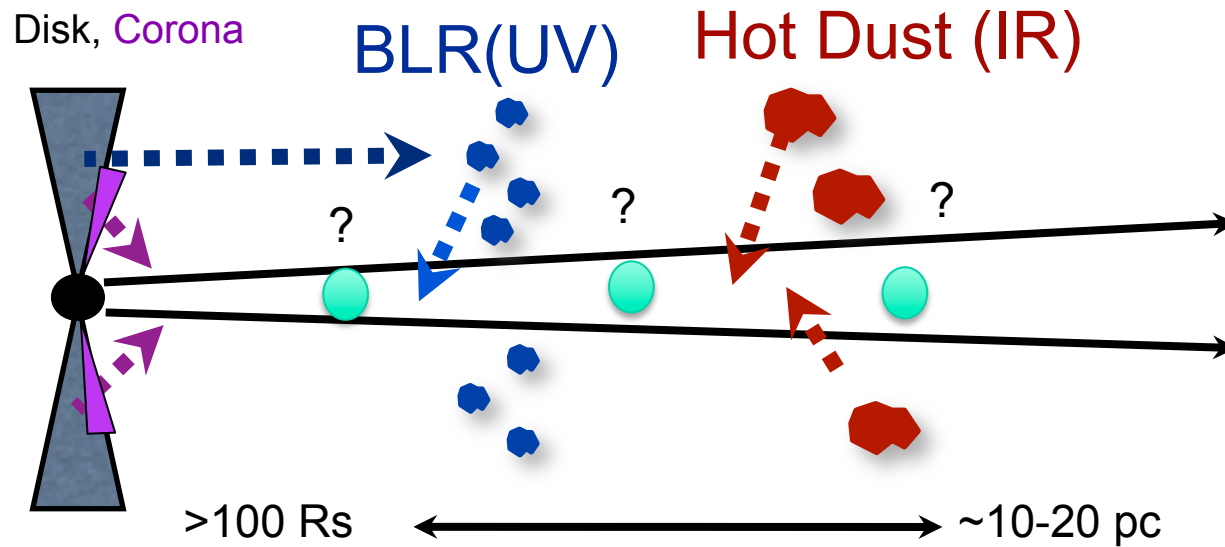
- Very fast variability observed by MAGIC in the FSRQ PKS 1222+216(4C +21.35)
- Doubling flux scale 9 minutes approx
→ Very compact emission region (no $E > 50$ GeV ph could escape if source inside the BLR)

Single spectral component from 2 to 400 GeV
cutoff excluded at $E < \sim 130$ GeV





1) Location of the emitting region



2) One-zone leptonic model crises?

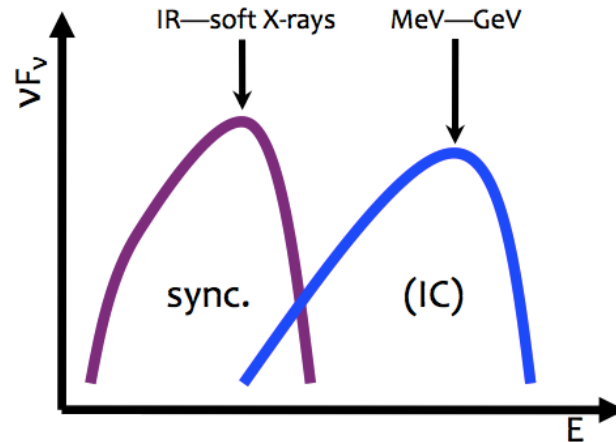
Summary



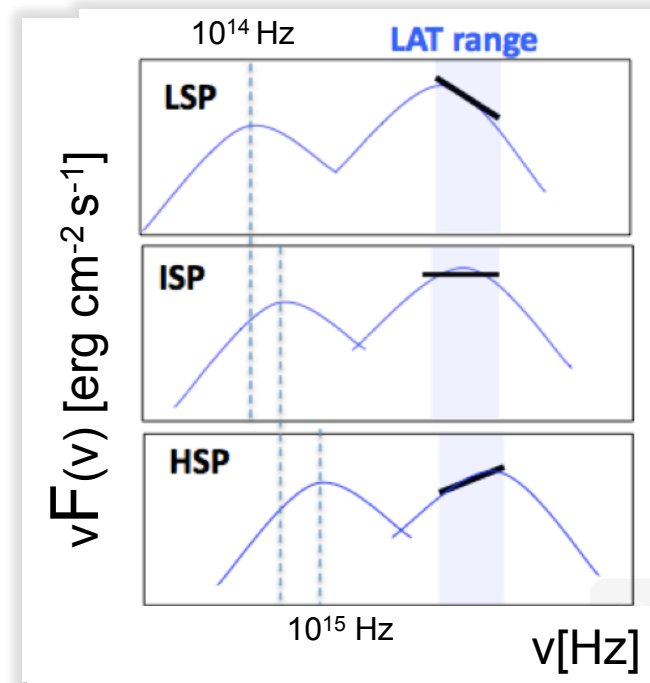
- More than 1000 blazars are now detected also in the MeV- GeV band
- Many **new non-blazars sources** have been detected (Radio galaxies, NRLSy1, NGC 1275, etc.)
- Baseline catalog of possible TeV source candidates to be investigated with the present and future VHE facilities
- AGN Physics:
 - Investigation of blazar **spectral properties** (correlation of photon index with blazar class, spectral breaks) and **variability time scales** (observed ranging from sub-day to several months)
 - Some cases with evidence for large distances gamma-ray emission regions from BH although the location of the gamma-ray emitting region in the jet is still ambiguous
 - Radio-to-gamma-ray SEDs are forcing us to look for models beyond the standard one-zone leptonic models
 - Many multifrequency studies have provided time-resolved SEDs and interband (radio, optical, X-ray, TeV) temporal correlation

BACKUP SLIDES

Blazar Emission processes



SED with two broad bumps:
Synchrotron and **IC** in **leptonic** models.
 Also **hadronic** scenarios have been considered (e.g. Mannheim, Boettcher, Reimer, Dermer).

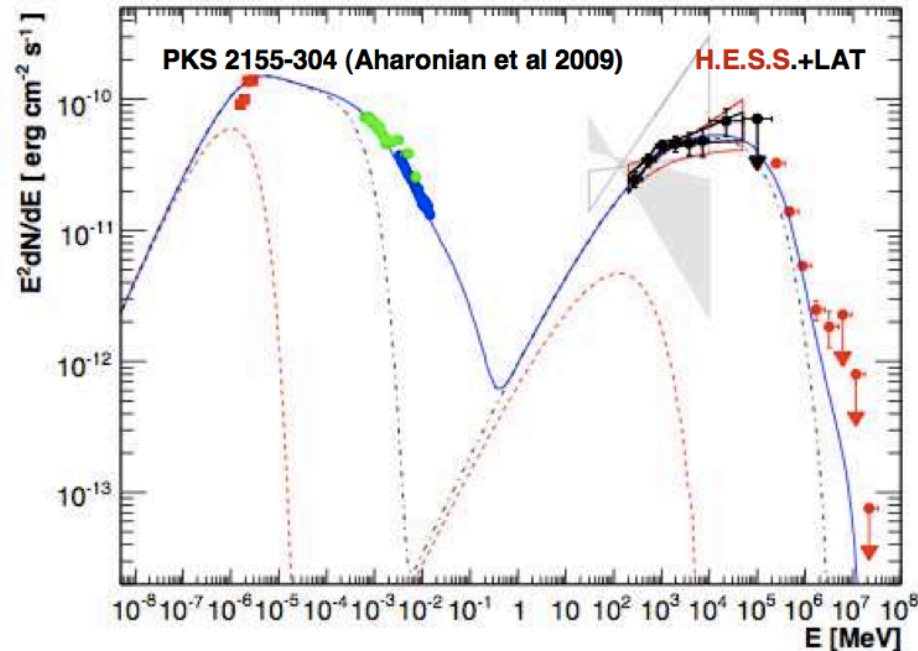


2FGL catalog



Type	Number	Percentage of total
Active Galactic Nuclei	832	44%
Candidate Active Galactic Nuclei	268	14%
Unassociated	594	32%
Pulsars (pulsed emission)	86	5%
Pulsars (no pulsations yet)	26	1%
Supernova Remnants/Pulsar Wind Nebulae	60	3%
Globular Clusters	11	< 1%
Other Galaxies	7	< 1%
Binary systems	4	< 1%
TOTAL	1888	100%

GeV-TeV Connection: PKS 2155-304



- One of few cases with SED modeled with **one-zone SSC**
- Indication of a correlation between Optical and VHE
- Anticorrelation between X-ray fluxes and Fermi-LAT spectral indices

