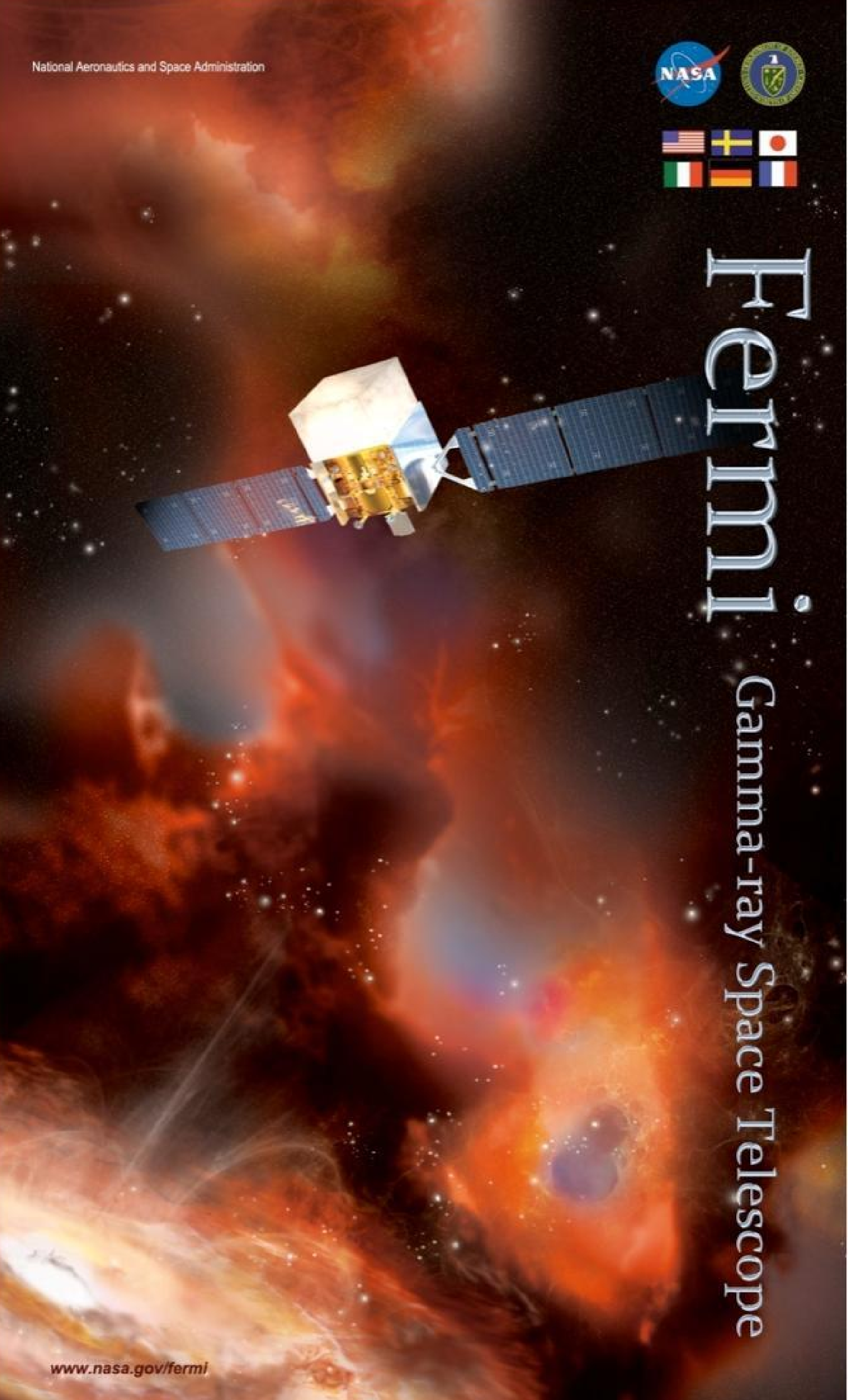


Fermi AGN and the GeV—TeV connection

Stephen FEGAN

Ecole Polytechnique
CNRS / IN2P3 / LLR

Outline

- Brief characteristics of LAT
- AGN (Blazars) in the LAT
- GeV—TeV studies of AGN
  - Multi-wavelength campaigns
  - Non-simultaneous studies
- The LAT as a flare detection tool
- New AGN targets for TeV instruments
- Conclusions

Fermi & LAT characteristics

- *Energy range:* 20MeV to 300GeV
- *Energy resolution:* 15% – 100MeV to 10GeV
- *Collecting area:* 9,500 cm^2
- *Field of view:* 2.4sr (104° cone)
- *Angular resolution:* 0.6°@1GeV, 0.15°@10GeV
- *Observation mode:* sky survey, rocking 35° N/S
- *Orbital period:* 95 minutes
- *Full sky view:* 3 hrs (~uniform in 55 days)

LAT bright AGN sample (LBAS)

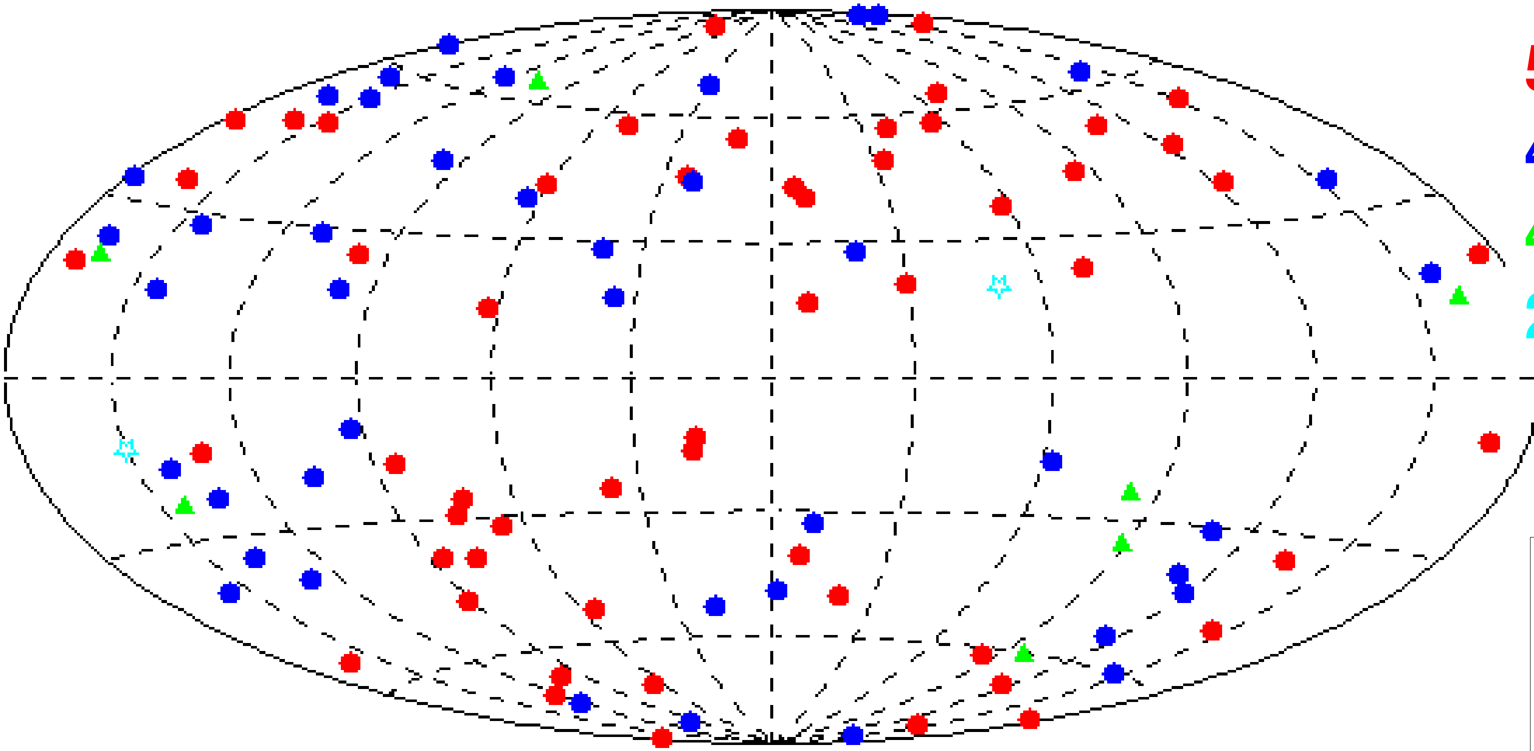
The Astrophysical Journal, 700:597–622, 2009 July 20
doi:10.1088/0004-637X/700/1/597

BRIGHT ACTIVE GALACTIC NUCLEI SOURCE LIST FROM THE FIRST THREE MONTHS OF THE *FERMI* LARGE AREA TELESCOPE ALL-SKY SURVEY

A. A. Abdo[1,57], M. Ackermann[2], M. Ajello[2], W. B. Atwood[3], M. Axelsson[4,5], L. Baldini[6], J. Ballet[7], G. Barbiellini[8,9], D. Bastieri[10,11], B. M. Baughman[12], K. Bechtol[2], R. Bellazzini[6], R. D. Blandford[2], E. D. Bloom[2], E. Bonamente[13,14], A. W. Borgland[2], A. Bouvier[2], J. Bregeon[6], A. Brez[6], M. Brigida[15,16], P. Bruel[17], T. H. Burnett[18], G. A. Caliandro[15,16], R. A. Cameron[2], P. A. Caraveo[19], J. M. Casandjian[7], E. Cavazzuti[20], C. Cecchi[13,14], E. Charles[2], A. Chekhtman[21,1], A. W. Chen[19], C. C. Cheung[22], J. Chiang[2], S. Ciprini[13,14], R. Claus[2], J. Cohen-Tanugi[23], S. Colafrancesco[20], W. Collmar[24], L. R. Cominsky[25], J. Conrad[4,26,27,58], L. Costamante[2], S. Cutini[20], C. D. Dermer[1], A. de Angelis[28], F. de Palma[15,16], S. W. Digel[2], E. do Couto e Silva[2], P. S. Drell[2], R. Dubois[2], D. Dumora[29,30], C. Farnier[23], C. Favuzzi[15,16], S. J. Fegan[17], E. C. Ferrara[22], J. Finke[1,57], W. B. Focke[2], L. Foschini[31], M. Frailis[28], L. Fuhrmann[32], Y. Fukazawa[33], S. Funk[2], P. Fusco[15,16], F. Gargano[16], D. Gasparrini[20], N. Gehrels[22,34], S. Germani[13,14], B. Giebels[17], N. Giglietto[15,16], P. Giommi[20], F. Giordano[15,16], M. Giroletti[35], T. Glanzman[2], G. Godfrey[2], I. A. Grenier[7], M.-H. Grondin[29,30], J. E. Grove[1], L. Guillemot[29,30], S. Guiriec[36], Y. Hanabata[33], A. K. Harding[22], R. C. Hartman[22], M. Hayashida[2], E. Hays[22], S. E. Healey[2], D. Horan[17], R. E. Hughes[12], G. Jóhannesson[2], A. S. Johnson[2], R. P. Johnson[3], T. J. Johnson[22,34], W. N. Johnson[1], M. Kadler[37,38,39,40], T. Kamae[2], H. Katagiri[33], J. Kataoka[41], M. Kerr[18], J. Knödlseder[42], M. L. Kocian[2], F. Kuehn[12], M. Kuss[6], J. Lande[2], L. Latronico[6], M. Lemoine-Goumard[29,30], F. Longo[8,9], F. Loparco[15,16], B. Lott[29,30], M. N. Lovellette[1], P. Lubrano[13,14], G. M. Madejski[2], A. Makeev[21,1], E. Massaro[43], M. N. Mazziotta[16], W. McConville[22,34], J. E. McEnery[22], S. McGlynn[4,26], C. Meurer[4,27], P. F. Michelson[2], W. Mitthumsiri[2], T. Mizuno[33], A. A. Moiseev[38,34], C. Monte[15,16], M. E. Monzani[2], E. Moretti[8,9], A. Morselli[44], I. V. Moskalenko[2], S. Murgia[2], P. L. Nolan[2], J. P. Norris[45], E. Nuss[23], T. Ohsugi[33], N. Omodei[6], E. Orlando[24], J. F. Ormes[45], M. Ozaki[46], D. Paneque[2], J. H. Panetta[2], D. Parent[29,30], V. Pelassa[23], M. Pepe[13,14], M. Pesce-Rollins[6], F. Piron[23], T. A. Porter[3], S. Rainò[15,16], R. Rando[10,11], M. Razzano[6], S. Razzaque[1,57], A. Reimer[2], O. Reimer[2], T. Reposeur[29,30], L. C. Reyes[47], S. Ritz[22,34], L. S. Rochester[2], A. Y. Rodriguez[48], R. W. Ro
H. F.-W. Sadrozinski[3], D. Sanchez[17], A. Sander[12], P. M. Saz Parkinson[3], J. D. Sc
T. L. Schalk[3], A. Sellerholm[4,27], C. Sgrò[6], M. S. Shaw[2], D. A. Smith[29,30], P. D. Smith[12], G. Spa
J.-L. Starck[7], M. S. Strickman[1], D. J. Suson[50], H. Tajima[2], H. Takahashi[33], T. Takahashi[46], T. T
J. B. Thayer[2], J. G. Thayer[2], D. J. Thompson[22], L. Tibaldo[10,11], D. F. Torres[52,48], G. Tosti[13,1
Y. Uchiyama[2], T. L. Usher[2], N. Vilchez[42], M. Villata[54], V. Vitale[44,55], A. P. Waite[2], B. L. W
T. Ylinen[56,4,26], and M. Ziegler[3]

ApJ, 700, 597 (2009)
Contact authors:
B. Lott (CNRS/IN2P3)
G. Tosti (INFN)

LAT bright AGN sample (LBAS)



58 FSRQ
42 BL Lac
4 Uncertain type
2 Radio galaxies

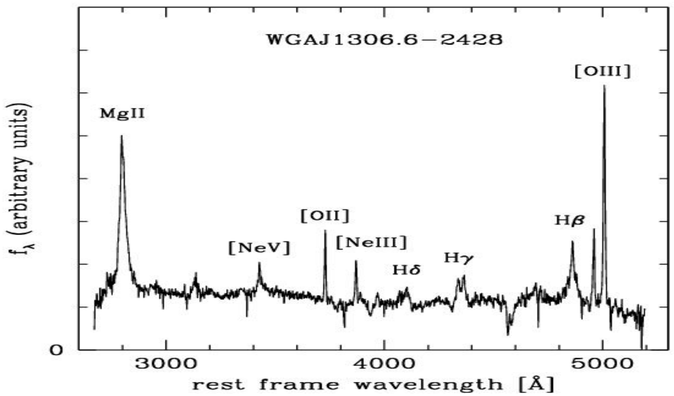
Also: NL Seyfert 1
PMN J0948+0022
ApJ 699, 976 (2009)

- 132 bright Fermi sources (0FGL) outside the plane, with |b| > 10°
- 106 associated with known AGNs at 90% confidence level (LBAS)
- Sample is 40% BL Lac, 55% FSRQ (vs 23% BL Lac for EGRET)

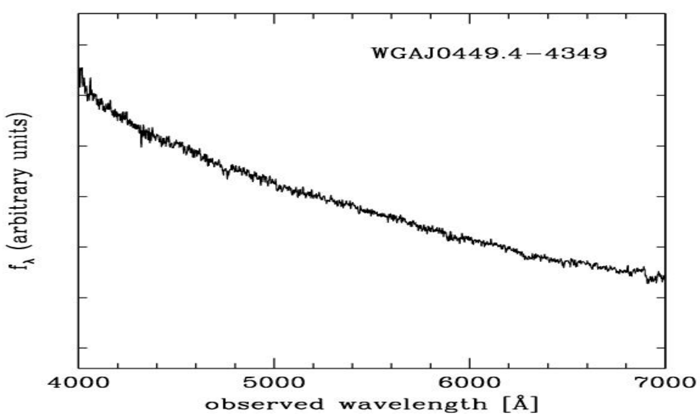
Two classes of blazar

Blazars are sub-classed into two types:

- Flat spectrum radio quasars (*FSRQs*)
  - Strong emission lines
  - High power
  - EGRET detected many FSRQs in its lifetime out to a redshift beyond 2



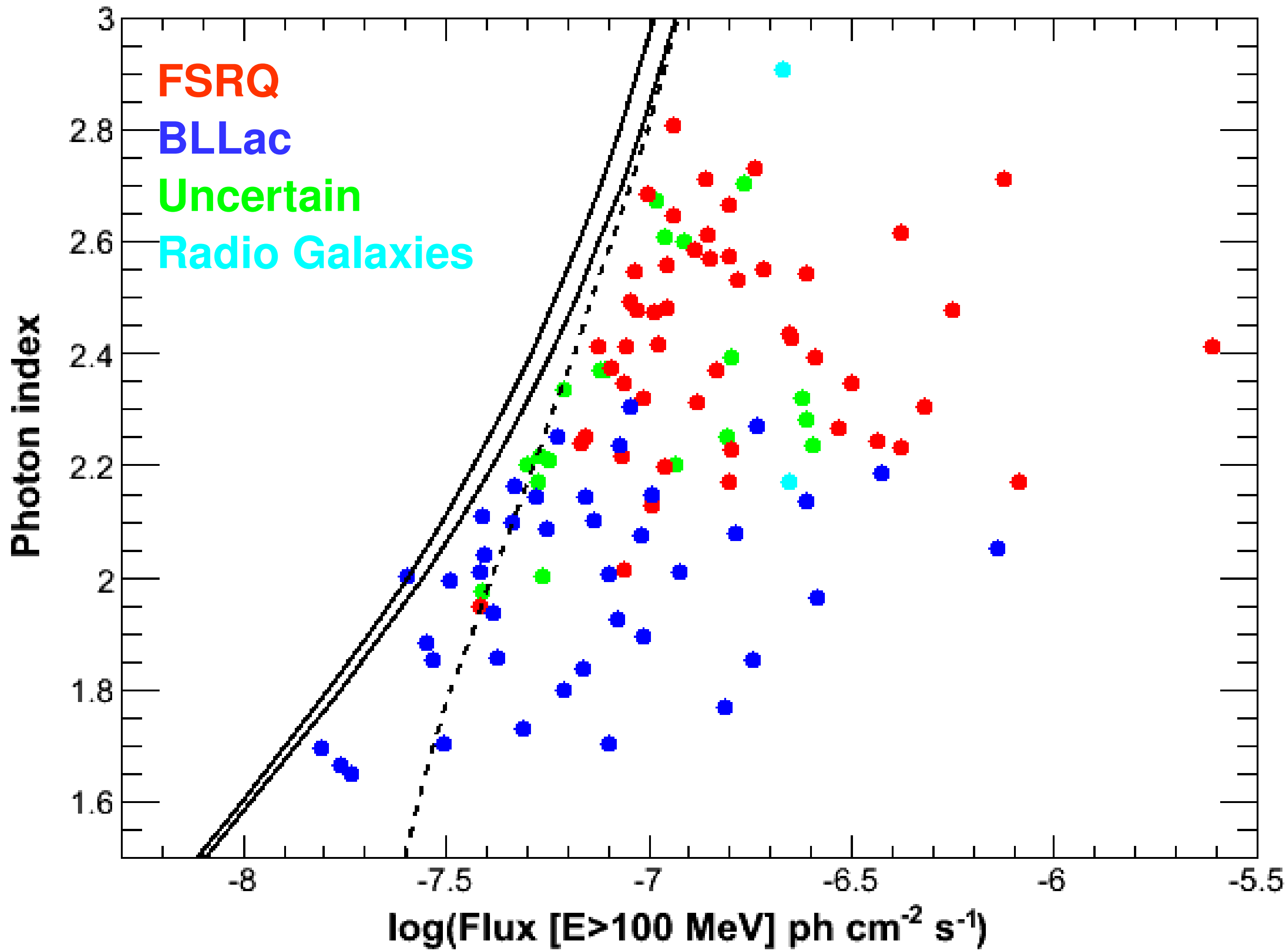
- BL Lacertae type objects (*BL Lacs*)
  - Almost featureless spectra
  - Lower overall power than FSRQs but often with higher energy emission
  - EGRET detected 14 BL Lac, generally at lower redshifts, z<1



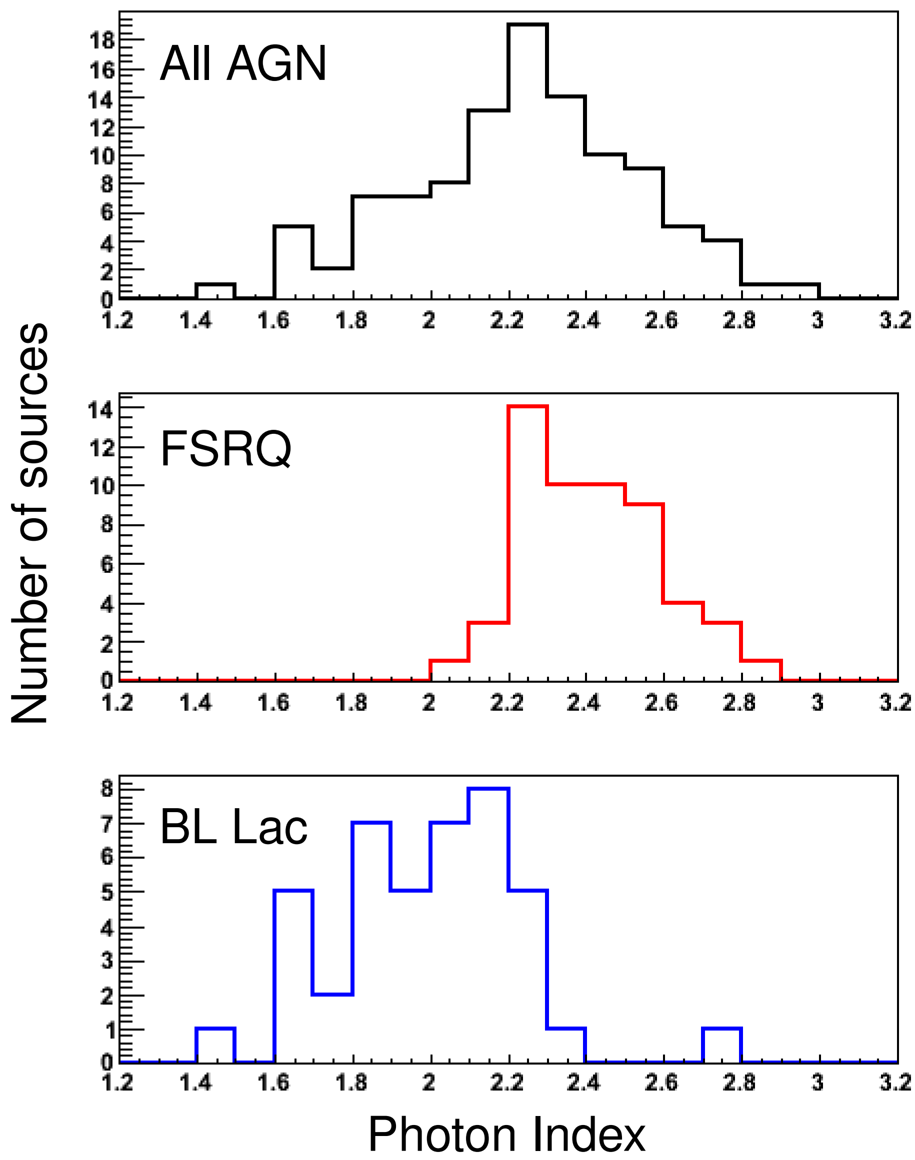
Flux vs spectral index

TS=100
b=20, 80 deg.

TS=100
b= 20 deg.
E< 3 GeV



Power-law index distributions



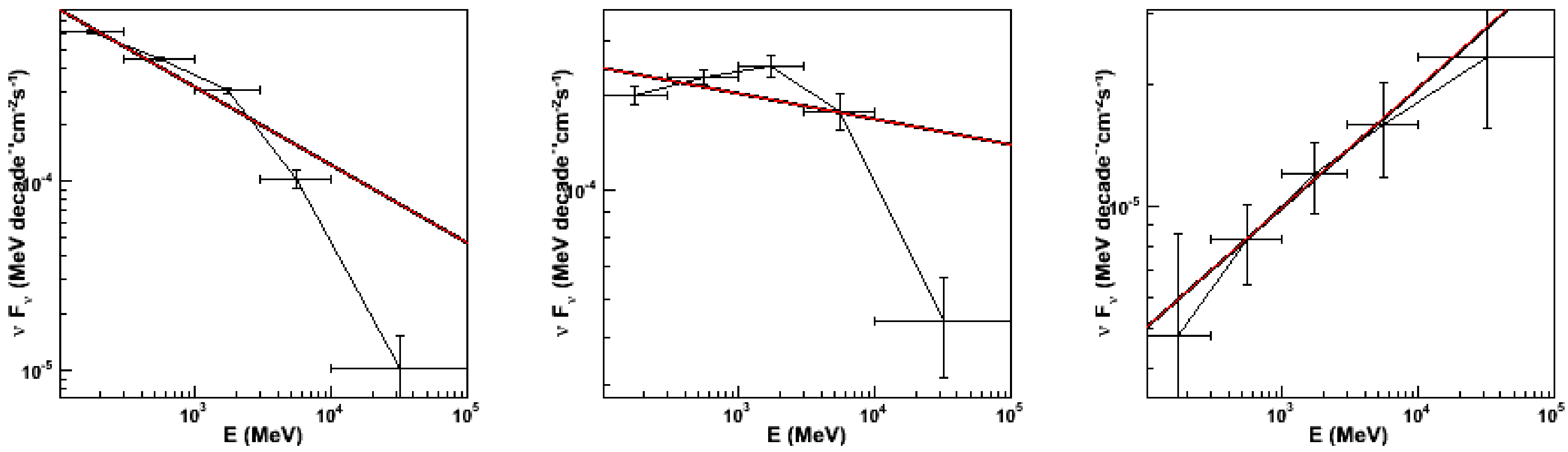
The spectral indexes of detected detected FSRQs and BL Lacs are drawn from different distributions.

FSRQs: softer, LAT is detecting falling edge of emission

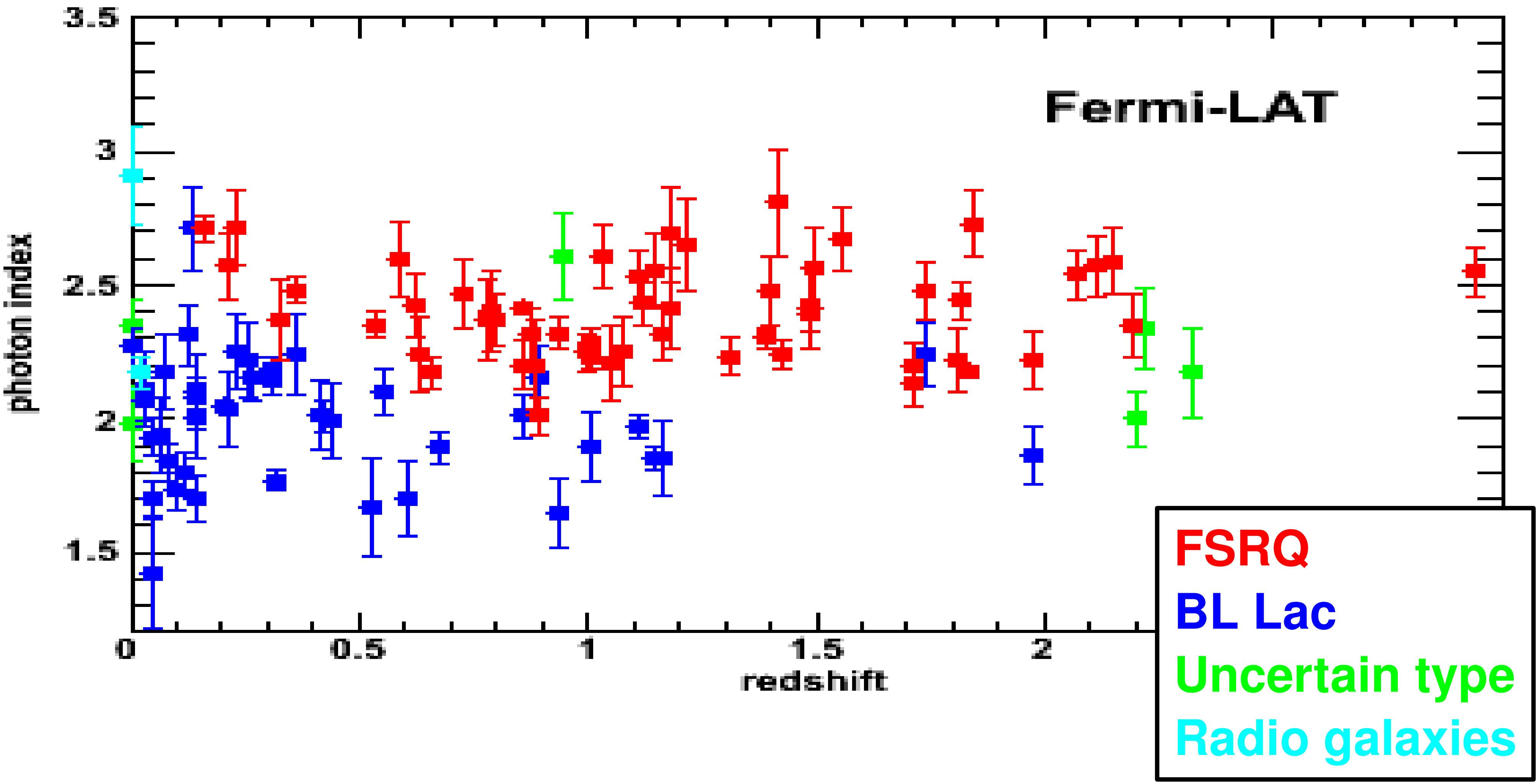
BL Lacs: harder, LAT is detecting photons closer to the peak of emission

Power-law fits

3C454.3 (FSRQ) **AO 0235+165 (Int. BL)** **Mkn501 (HBL)**



Redshift distributions



Source evolution

- $\langle V/V_{max} \rangle$ test is a simple and robust test for evolution in a population
- V is co-moving volume to the known redshift of each detected source
- V_{max} is the total CMV within which a similar source could be detected
- $\langle V/V_{max} \rangle$ should be 0.5 for non-evolving source population

Sample	#objects	$<V/V_{max}>$
FSRQs	58	0.645±0.043
BL Lacs	42	0.475±0.046
All with z>0	92	0.512±0.031

LBAS sample summary

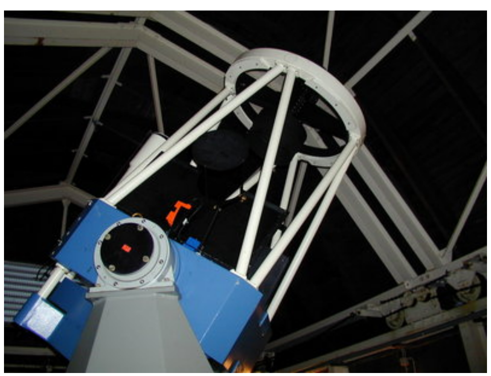
	FSRQ	*BL Lac*
• *Number*	58	42
• *Flux*	Higher	Lower
• *Index*	Softer (>2)	Harder (~2)
• *Distance*	Further	Nearer
• *Evolution*	Positive (3σ)	None

Studies of GeV—TeV blazars

- Simultaneous multi-wavelength observations
  - Single source state allows detailed modeling ✓
  - Modeling correlations between different bands ✓
  - "Simultaneous" observations with Fermi free! ✓
  - "Timescales" not matched for weaker sources ✗
  - Take time to revisit 28 detected TeV blazars ✗
- Fermi and non-simultaneous TeV observations
  - TeV spectra available for 28 blazars ✓
  - State not "guaranteed" to be same – can study this effect somewhat ✗

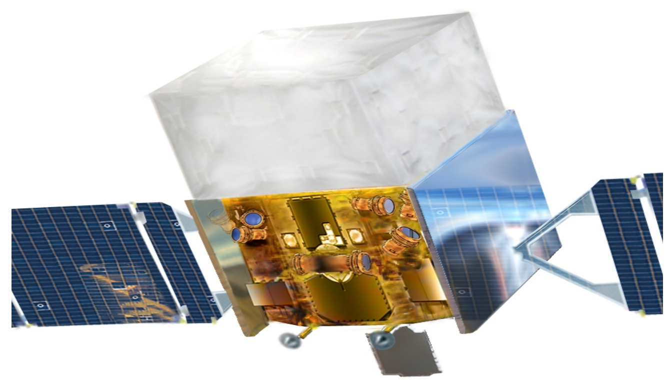
PKS 2155-304

- Well-known TeV BL Lac, from which extreme variability has been detected by H.E.S.S.
- Multi-wavelength observations made with *Fermi*, H.E.S.S., RXTE, Swift and ATOM
- 12 days of observations in August 2008

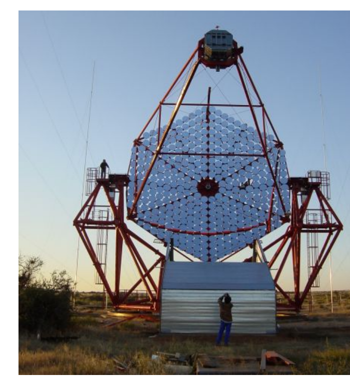


ATOM – Optical
106 pointings

RXTE + Swift
0.5 – 10keV
75ks + 6.4ks



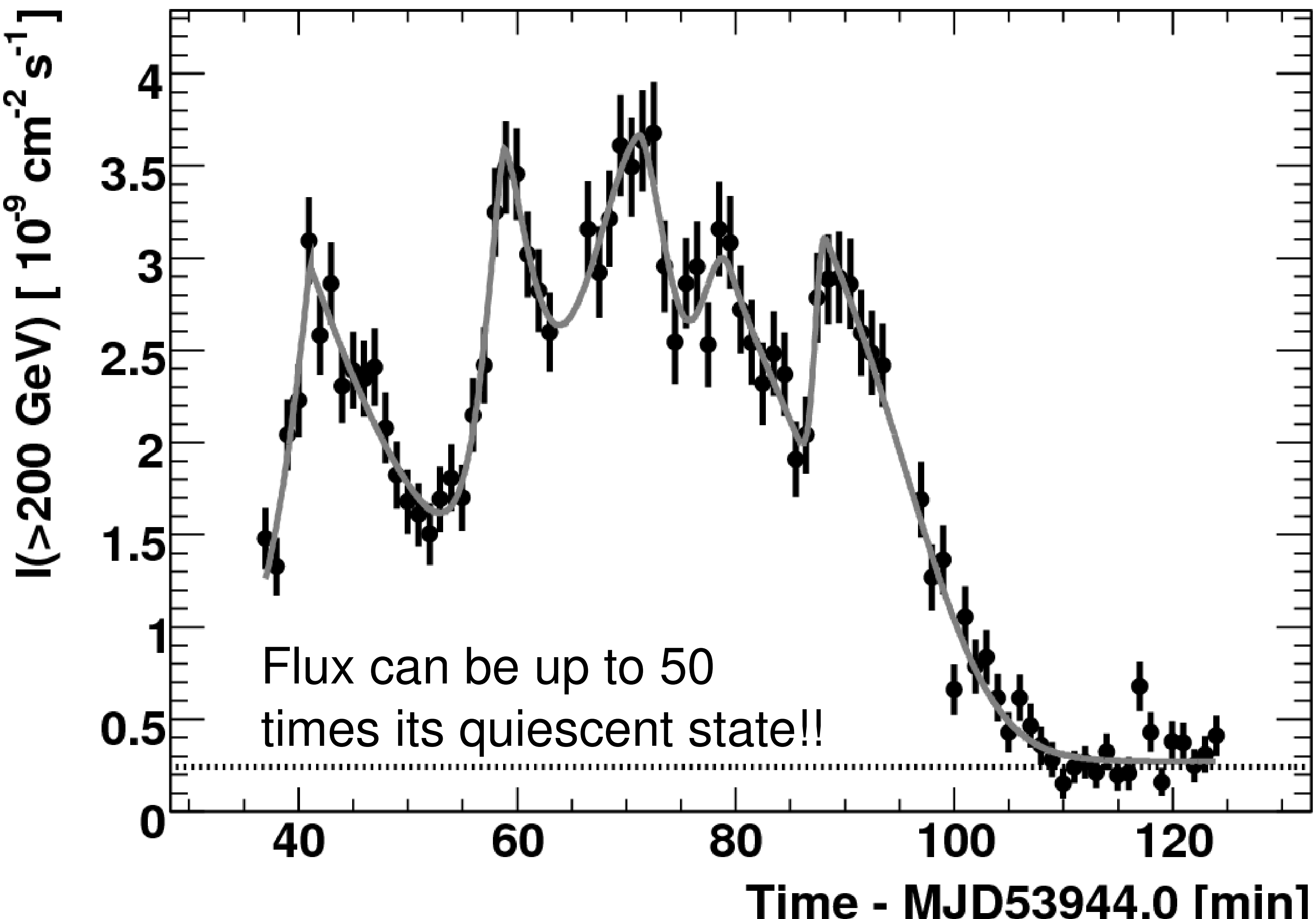
Fermi/LAT
0.2-300 GeV
7.7×10^{8} cm^{2}



H.E.S.S.
0.2-10 TeV
32.9 hours

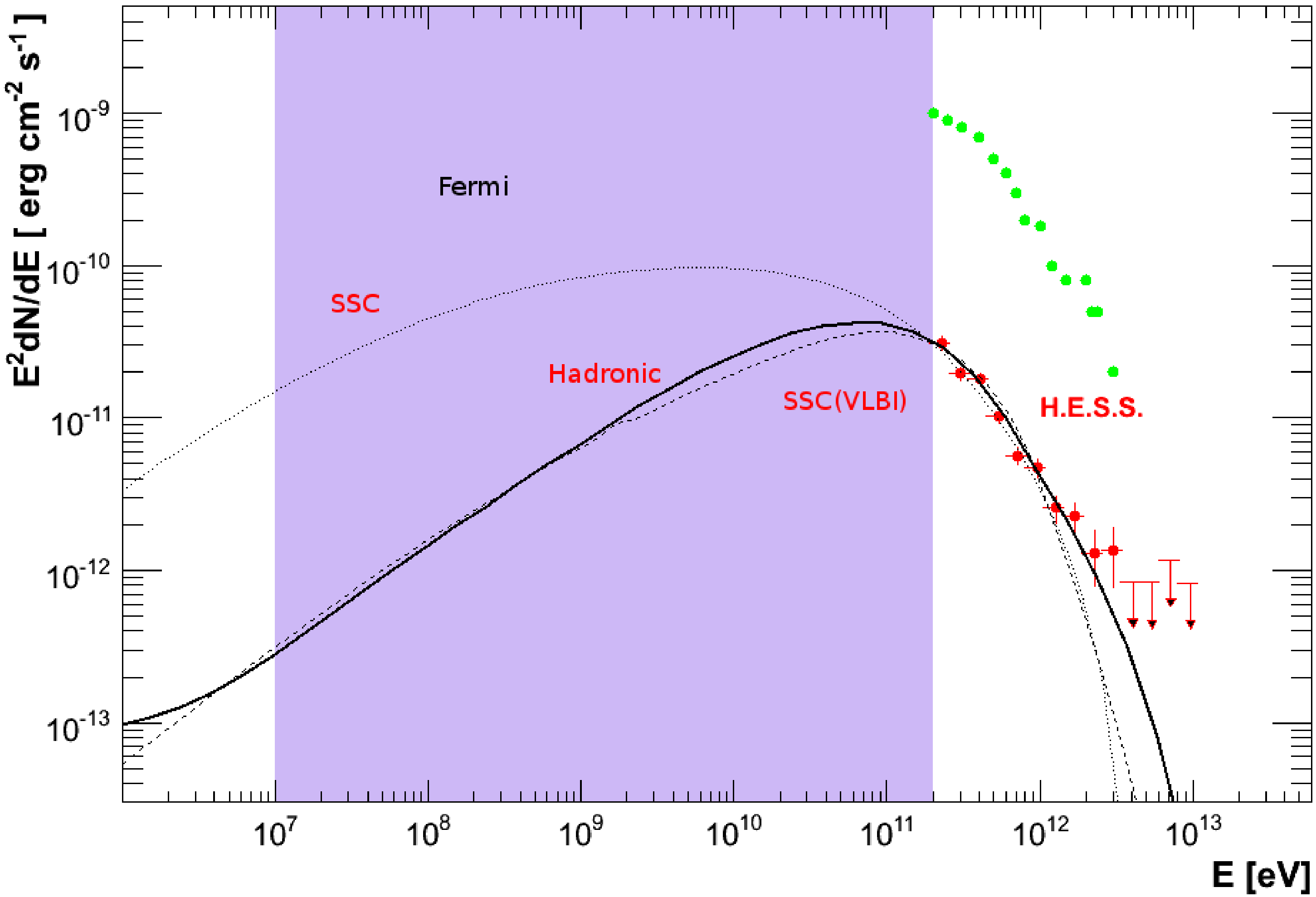
(From: D. Sanchez)

Historical VHE flux states



(From: D. Sanchez)

Historical VHE spectra



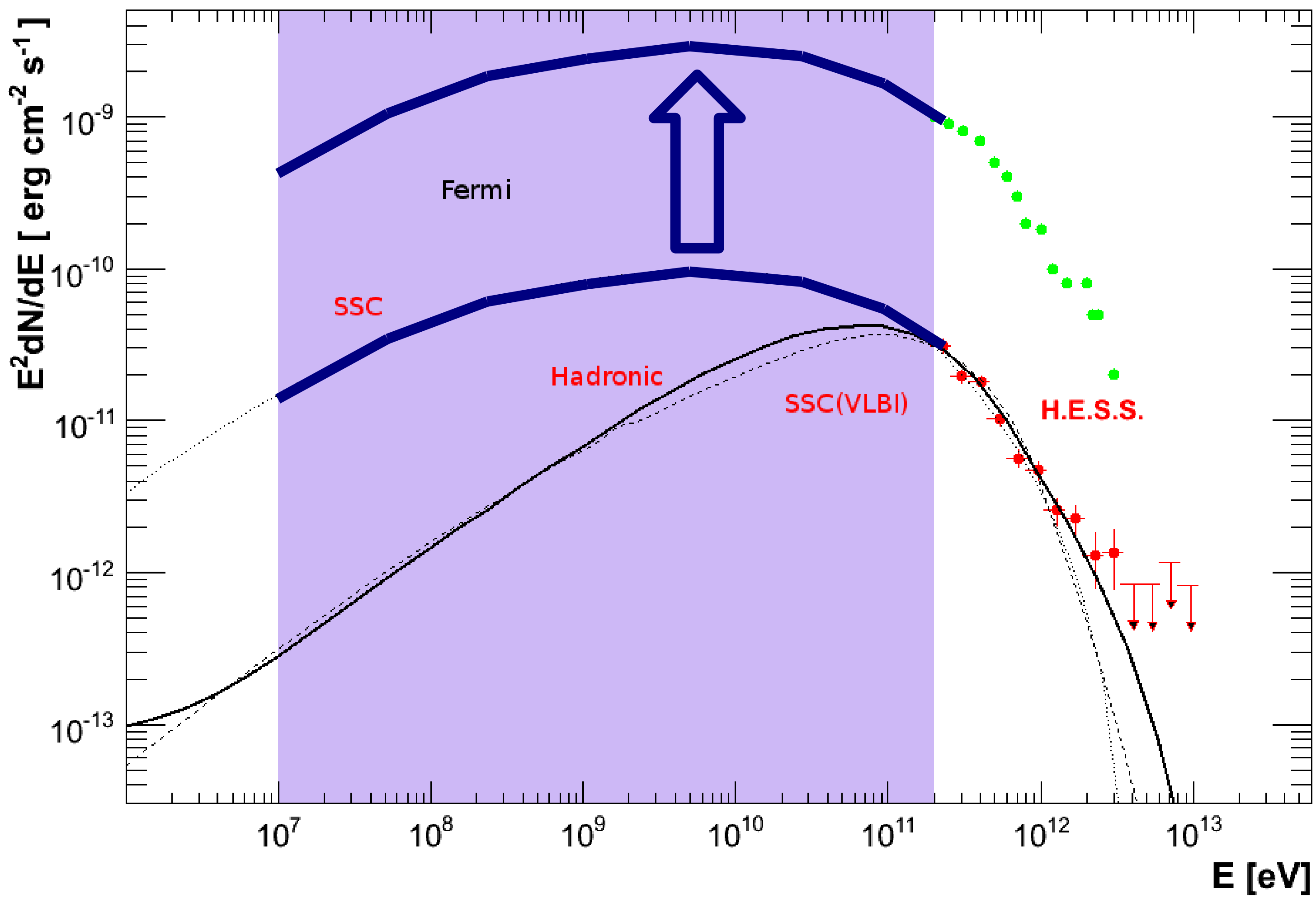
H.E.S.S. Spectrum is soft, with Γ=-3.3

Peak in emission is likely in the *Fermi* energy range

Simultaneous observations can measure full I.C. emission peak regardless of flux state

(From: D. Sanchez)

Historical VHE spectra



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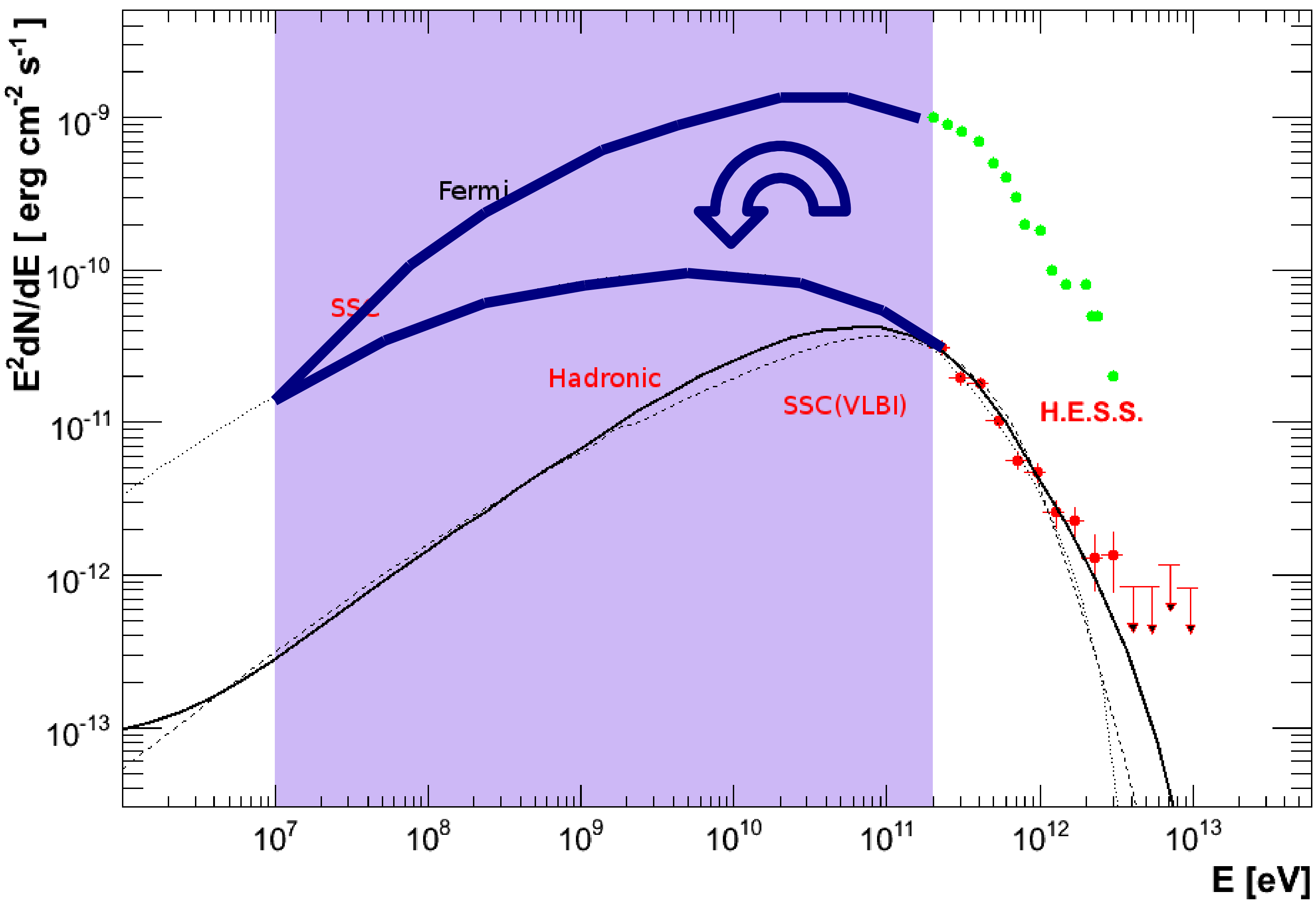

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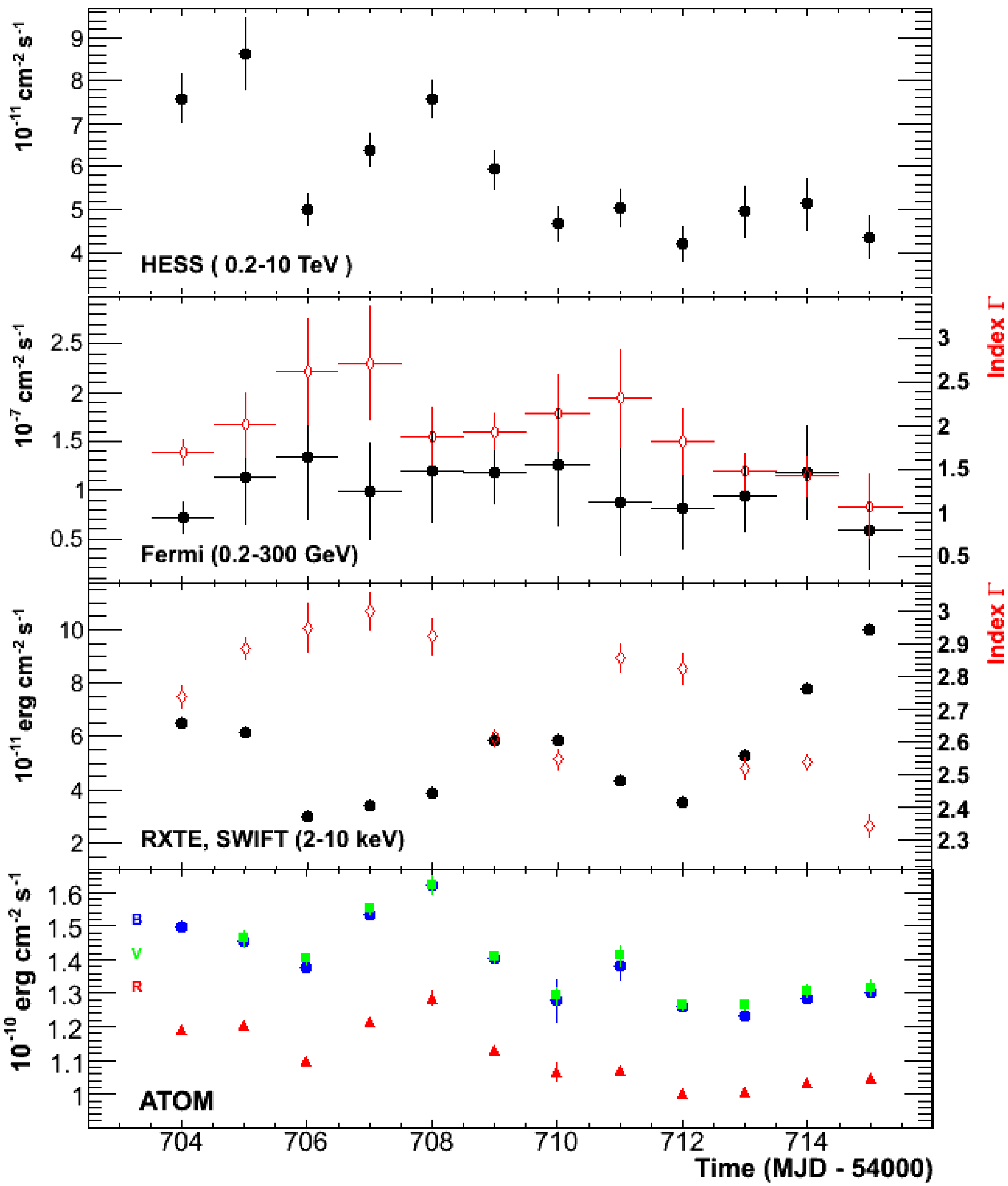
Peak in emission is likely in the *Fermi* energy range

Simultaneous observations can measure full I.C. emission peak regardless of flux state

(From: D. Sanchez)

Mutli-wavelength lightcurves



Flux variability:

VHE:	23%
HE:	<20% (UL)
X:	35%
O:	8%

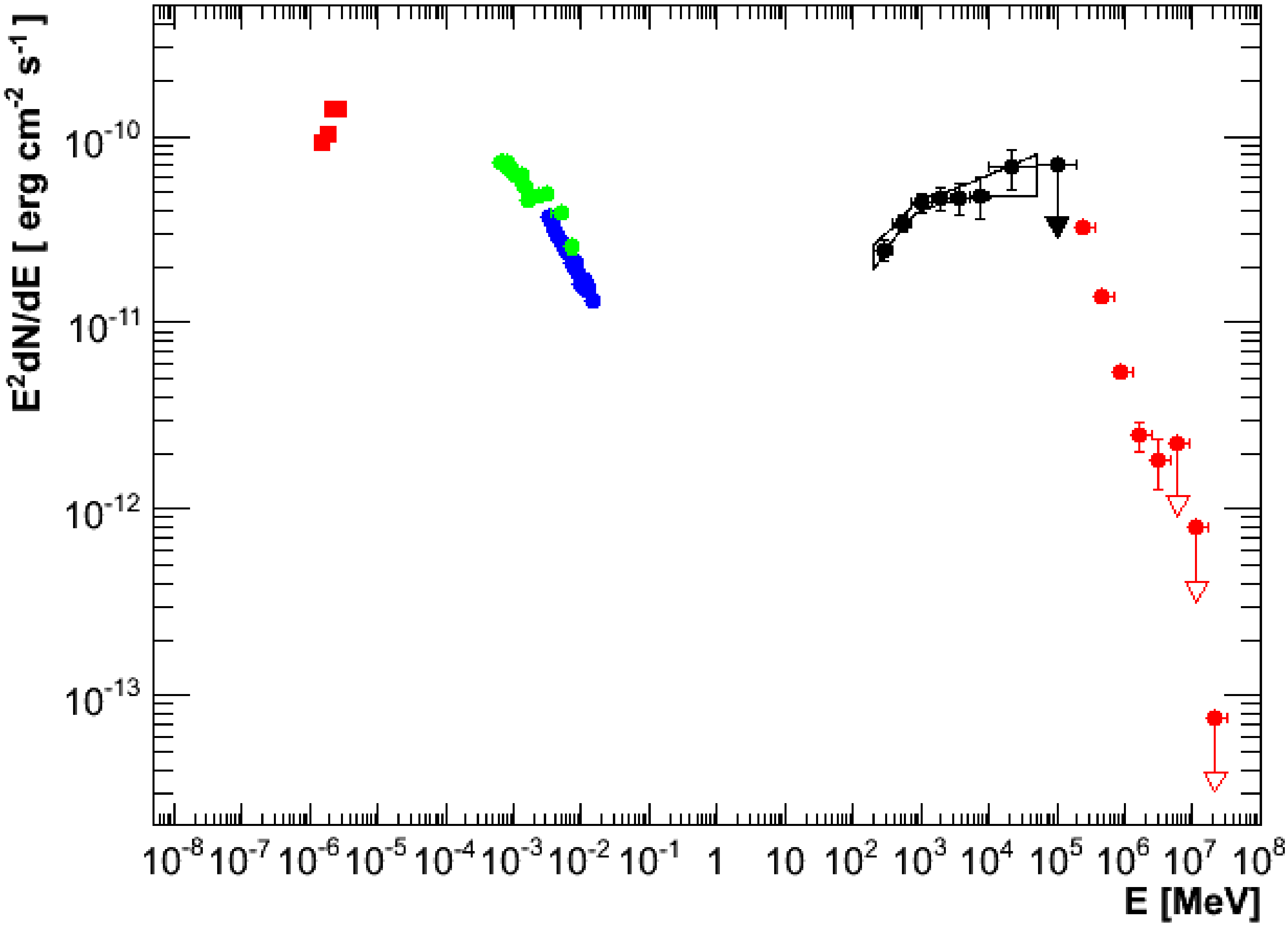
Fermi flux shows no evidence for variability, but *Fermi* spectral index does

Correlations:

O-VHE:	0.77-0.86
X-HE Index:	-0.80
X-VHE:	0.12

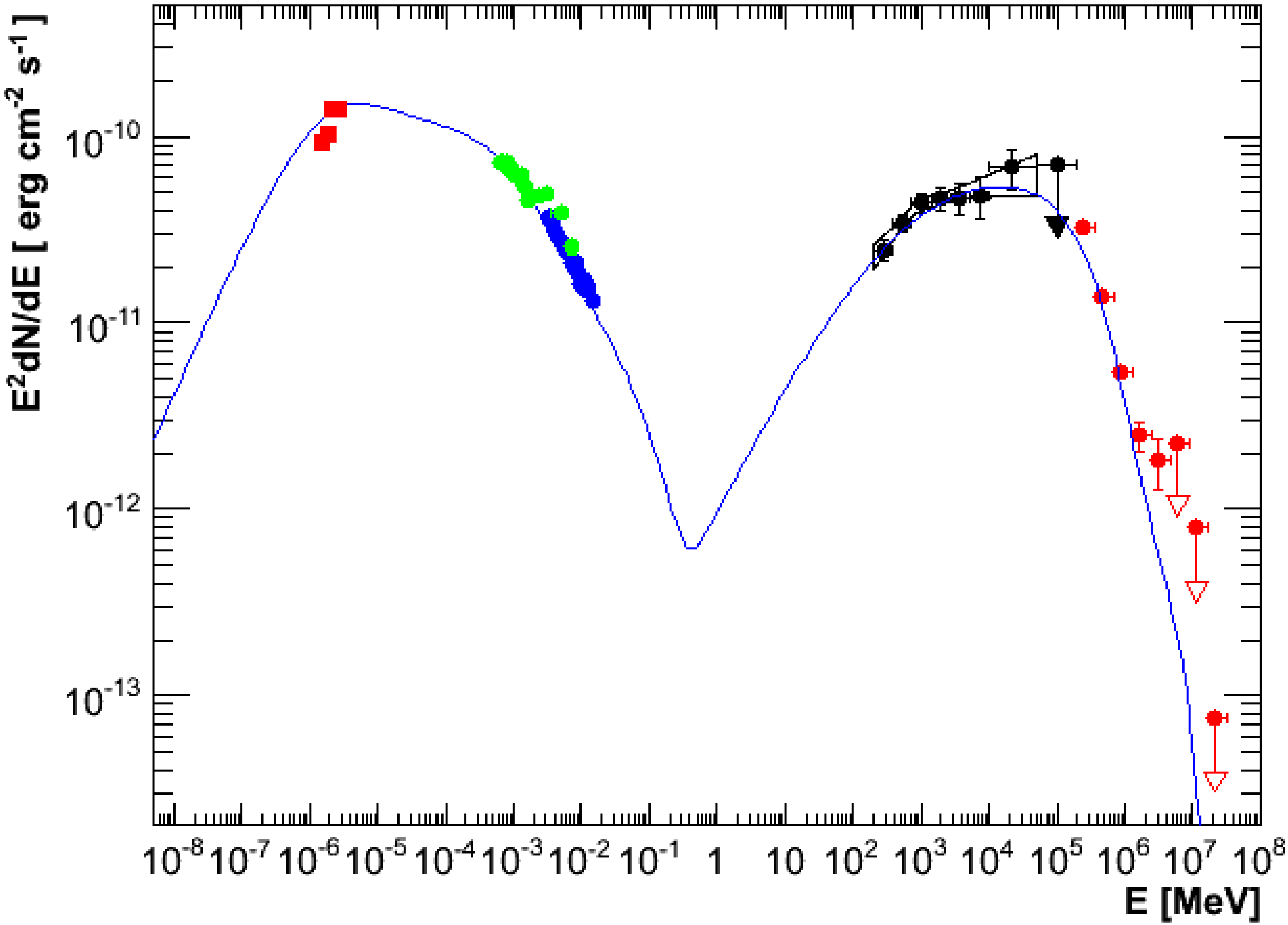
Abdo et al., ApJ, 700, 597 (2009)
From: D. Sanchez

Combined SED



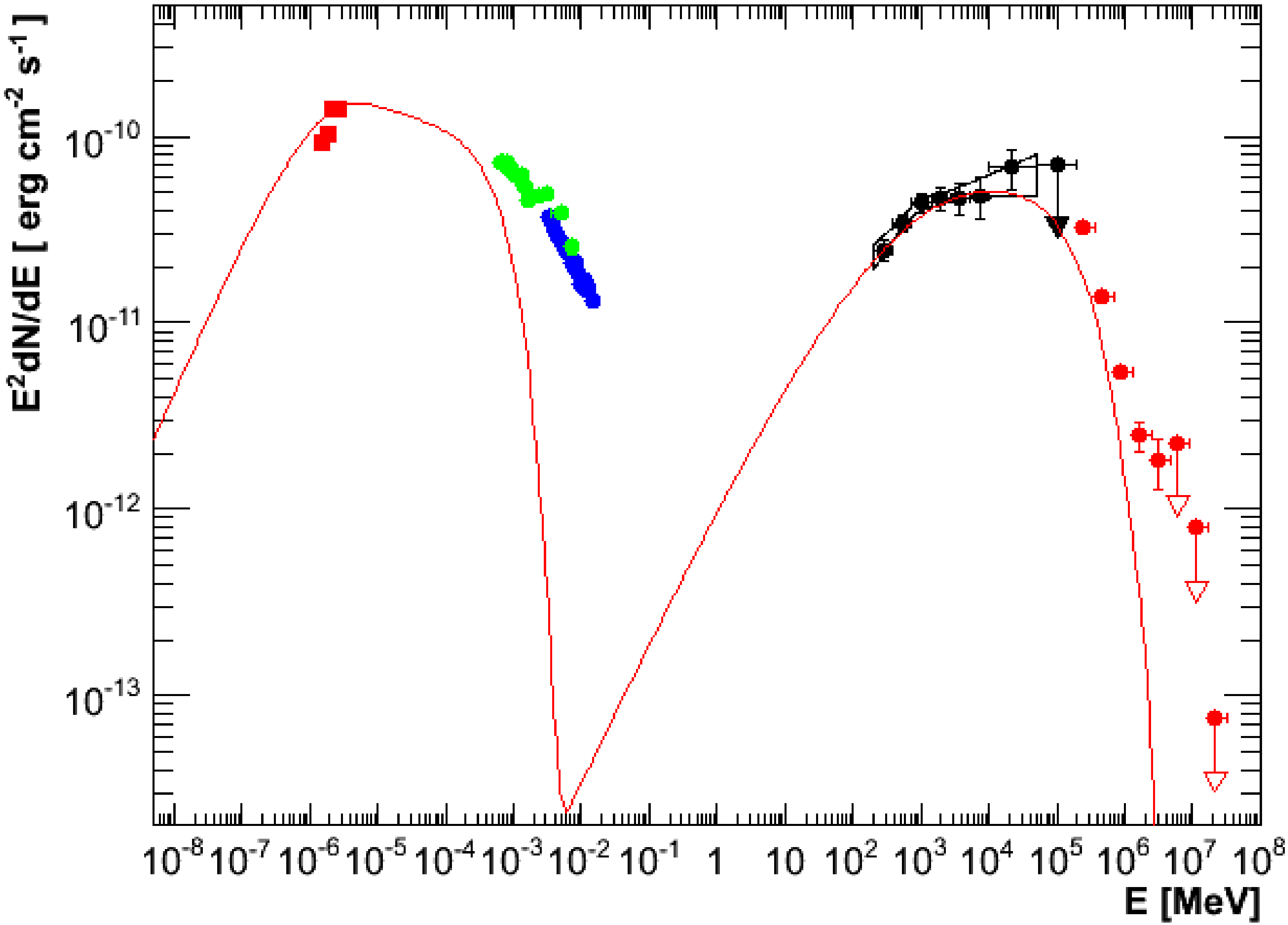
(From: D. Sanchez)

Combined SED



(From: D. Sanchez)

Combined SED



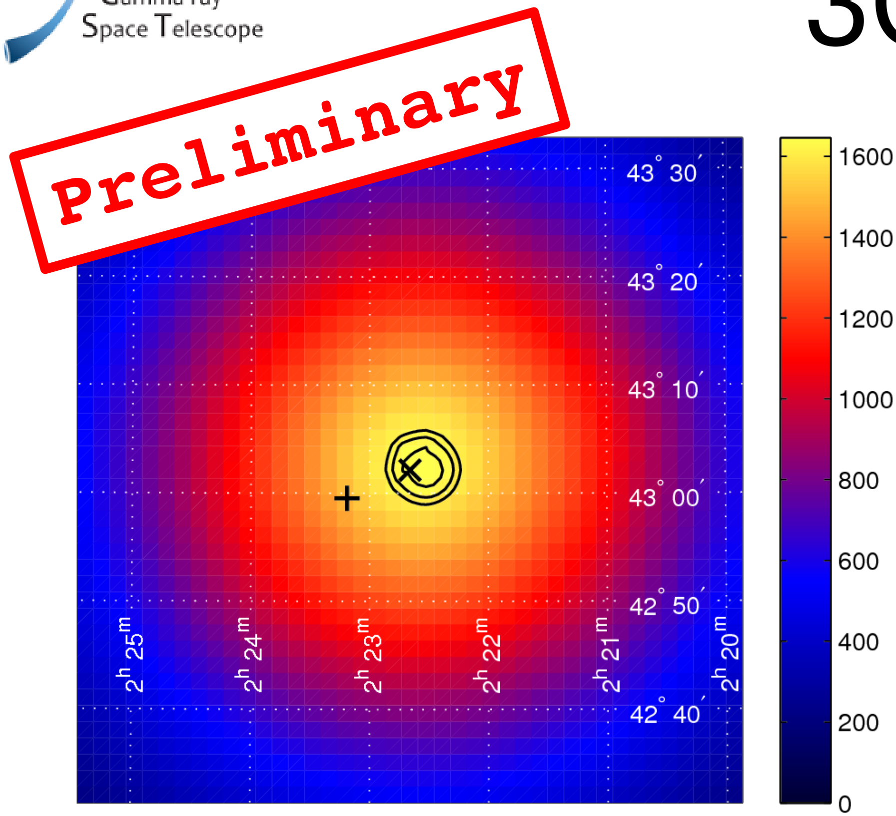
(From: D. Sanchez)

Fermi view of TeV AGN

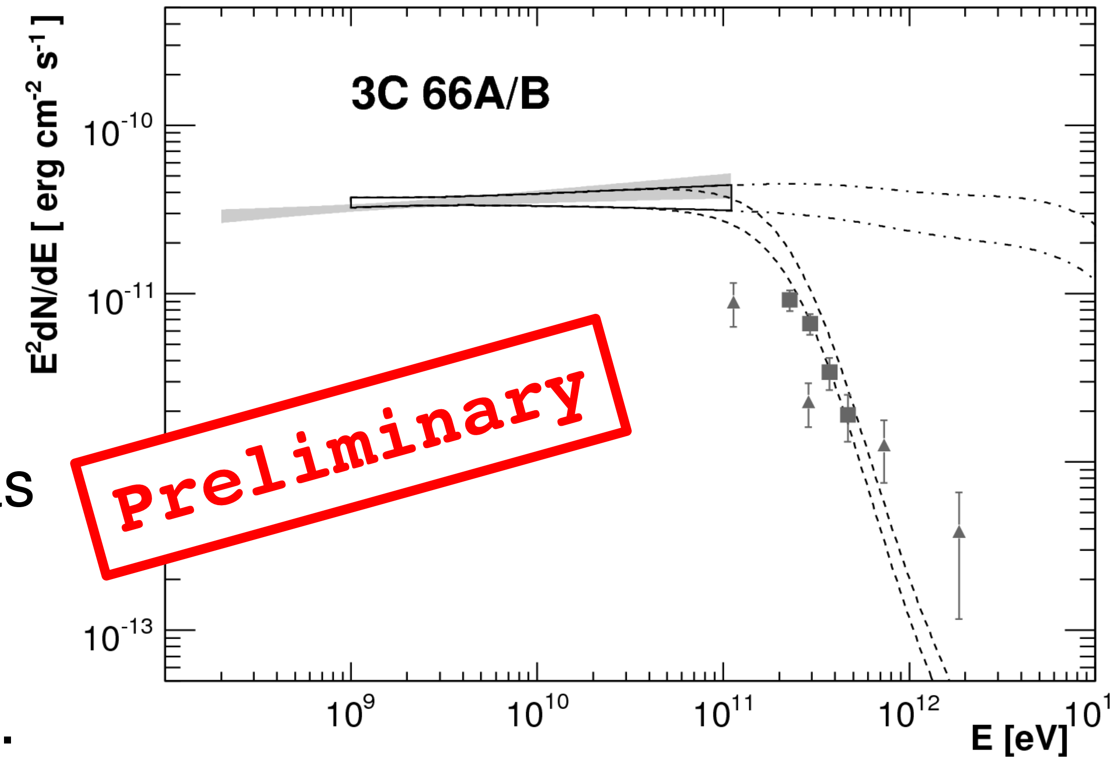
Preliminary

- 21 TeV AGN are detected at >5σ in ~6 months of Fermi data (out of a total of 28)
- The majority have Γ<2 at GeV energies (the median index is 1.9)
- The majority do not show evidence of variability on month timescales during this period
- The gamma-ray spectra for many of them can be explained by a power-law modified by absorption through interactions with the EBL!

3C 66A/B

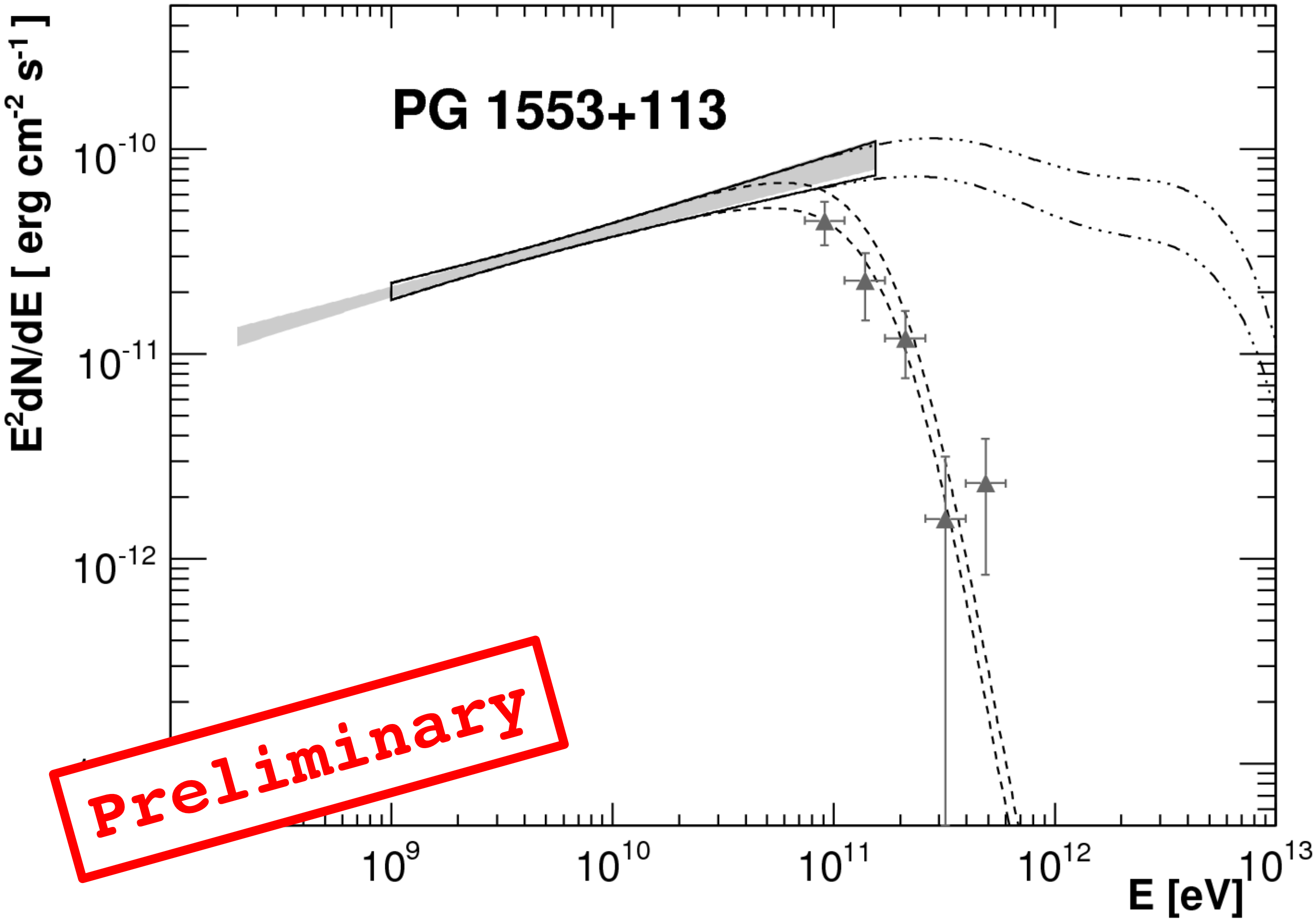


VHE gamma-rays:
VERITAS and MAGIC detected VHE emission from this region.
V: 3C 66A (HBL z=0.444?)
M: 3C 66B (RG z=0.0211)



HE gamma-rays:
Fermi detects significant emission, and prefers 3C66A as the source of the bulk.
Extrapolation of PL spectrum "more consistent" with z=0.444.

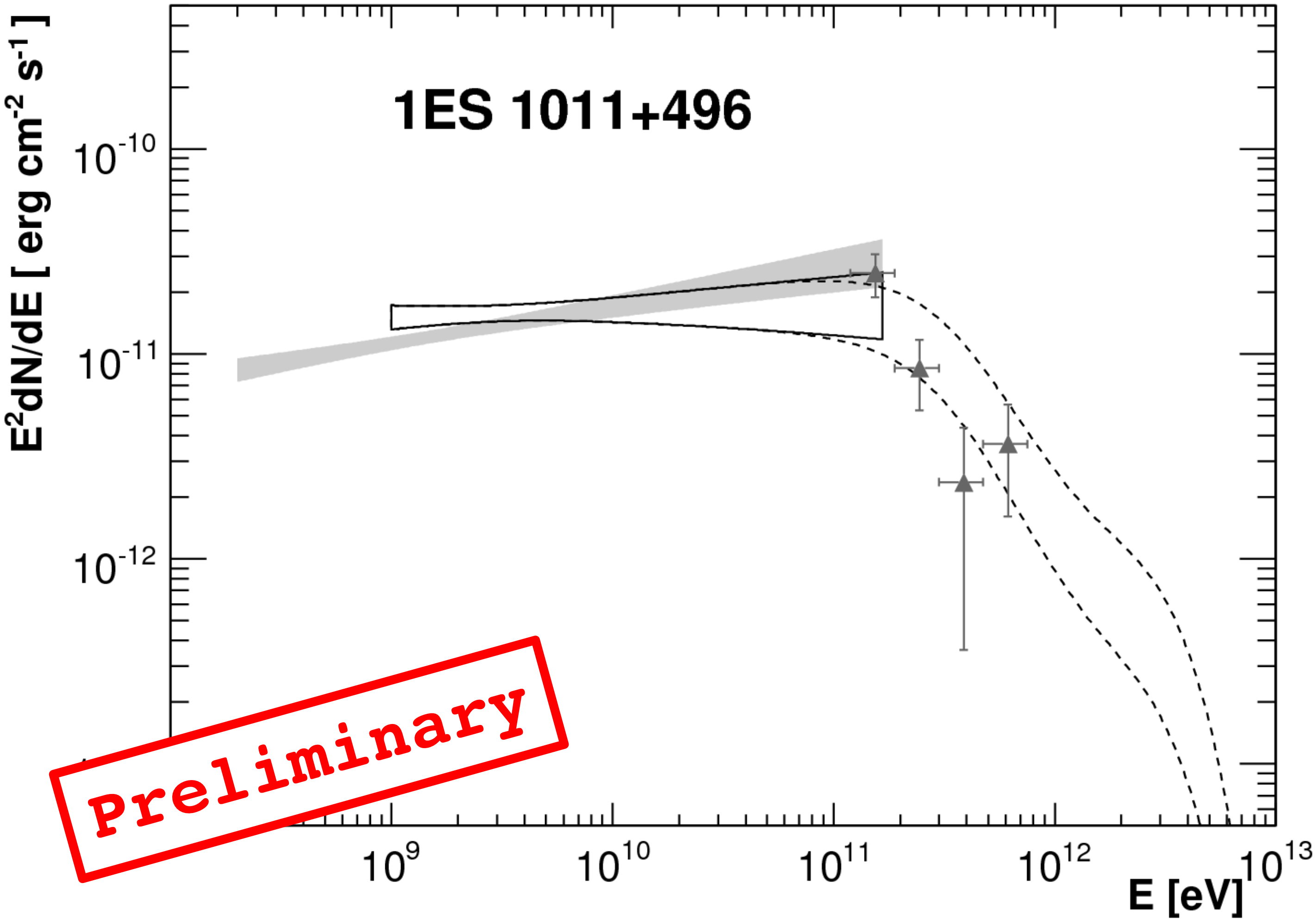
PG 1553+113



VHE gamma-rays: Detected by HESS. One of the hardest of the TeV sources with Γ=4.0±0.6. Unknown redshift, with 0.09<z<0.78.

HE gamma-rays: Bright hard source with Γ=1.69. Extrapolation of a PL spectrum is more consistent with z=0.78 than 0.09

1ES 1101+496

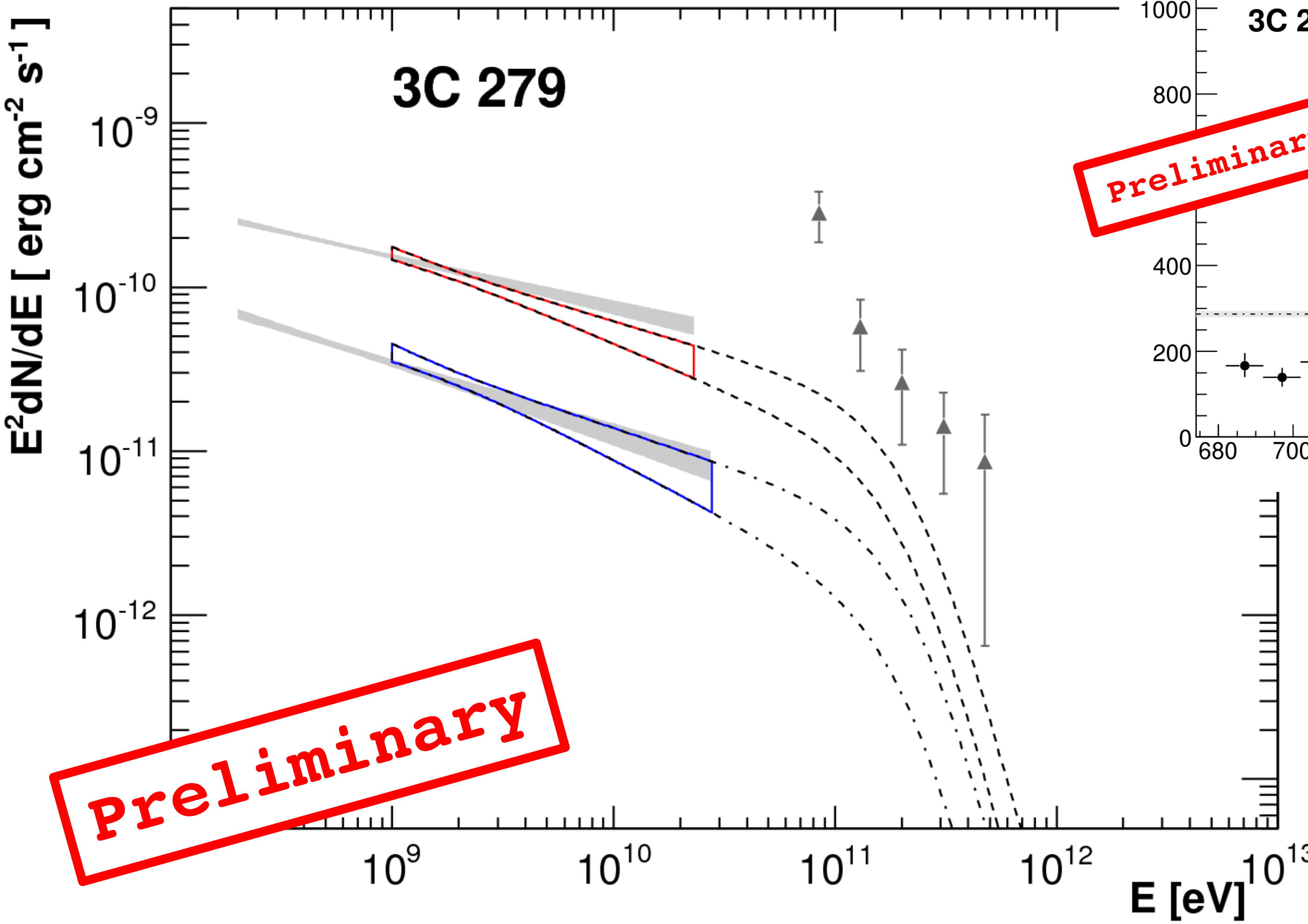


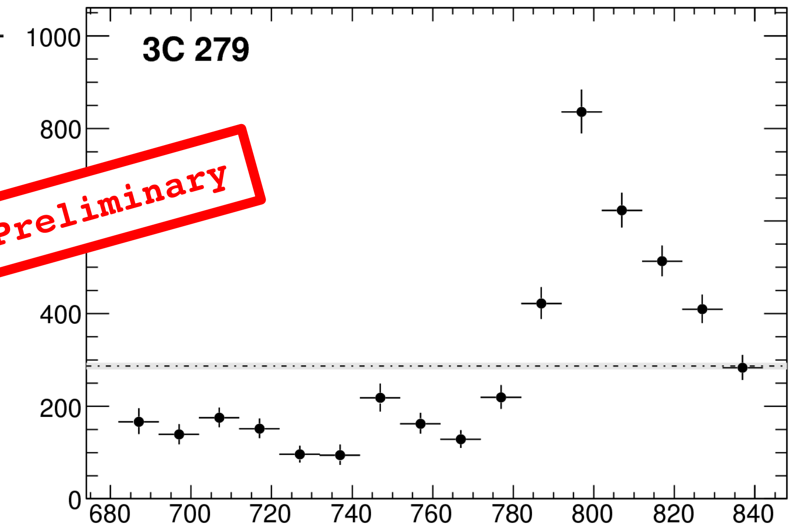
VHE gamma-rays: MAGIC spectrum starts at 150GeV.

HE gamma-rays: Hard spectrum with some evidence of curvature.

Extrapolated GeV spectrum agrees quite well with VHE measurements.

3C 279



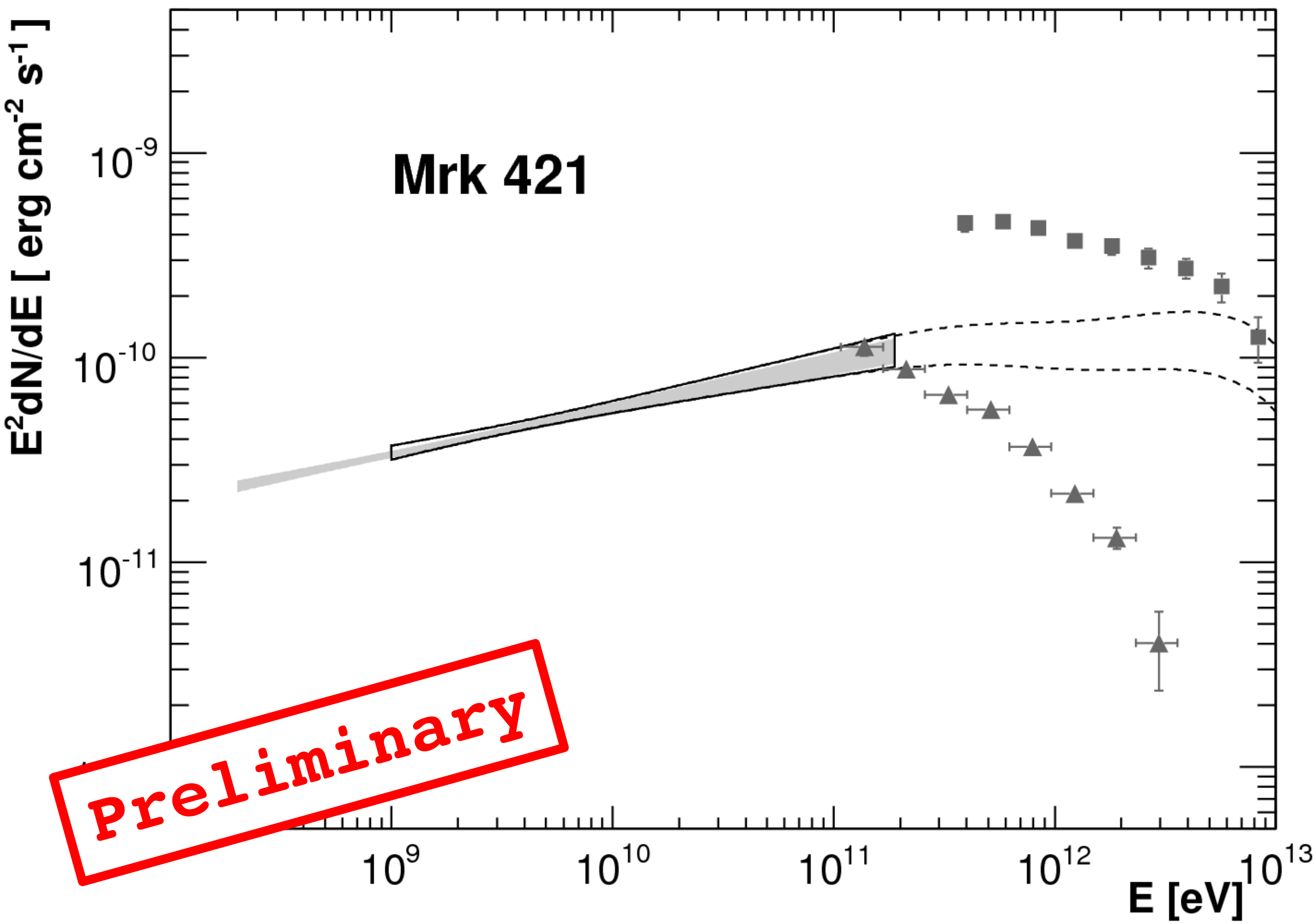


VHE gamma-rays:
MAGIC detection of first TeV FSRQ

HE gamma-rays:
Clear curvature.
Bright flare during lasting ~40 days.

Extrapolation of both low & high GeV states under-predict TeV flux.

Markarian 421



VHE gamma-rays: Long history at TeV energies. Shows extreme variability, hard spectrum, and is relatively close. One of the few TeV AGN showing non-PL spectrum.

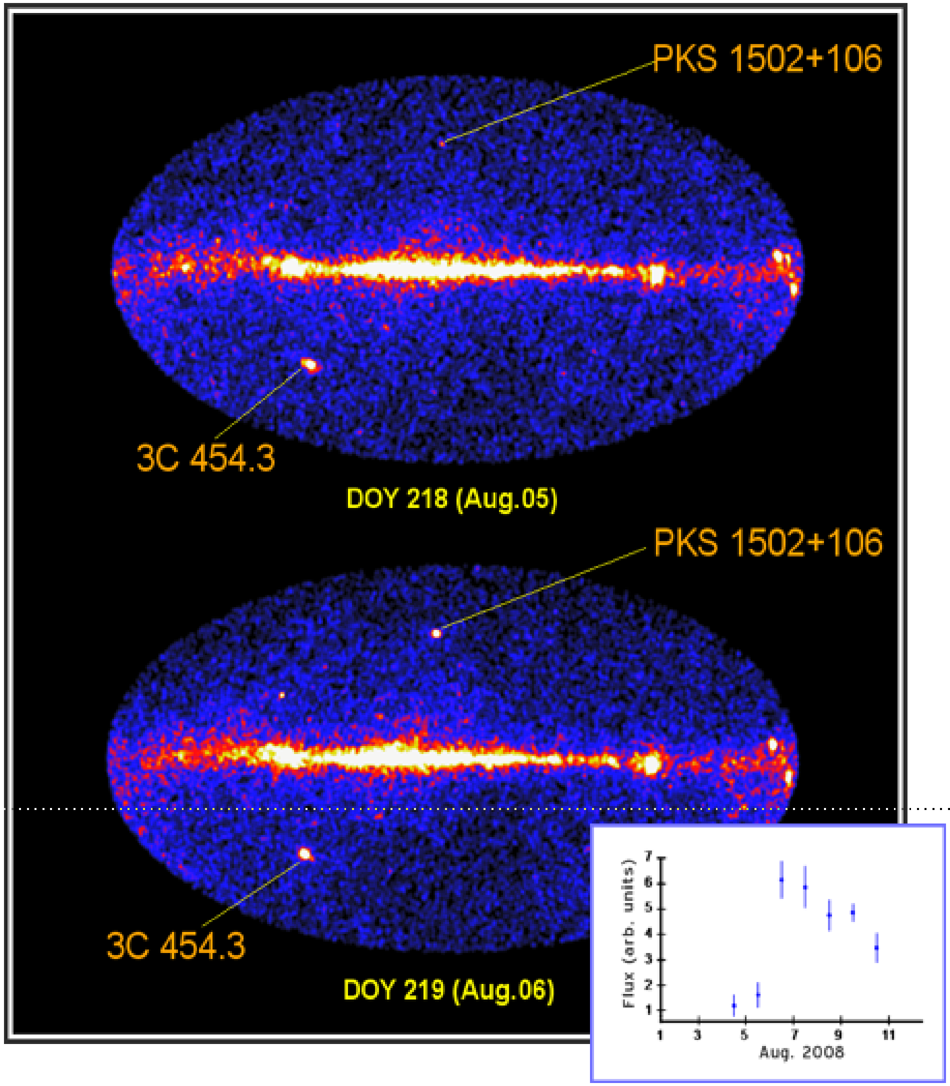
HE gamma-rays: Hard spectrum with no evidence for curvature.

Extrapolation of GeV spectrum yields spectral index in TeV regime that is harder than ever observed. Curvature at 50-100GeV?

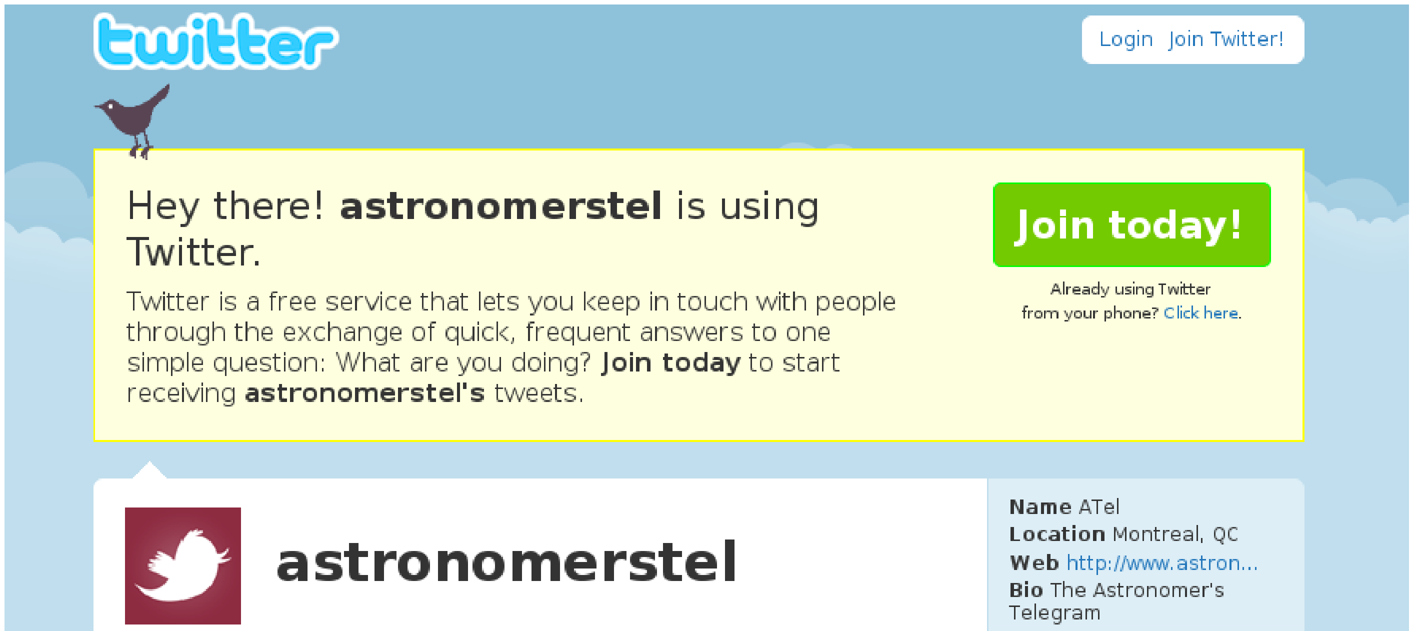
Joint fitting of GeV/TeV spectra

- Overlap between GeV and TeV increasing
  - Number of HE photons detected by Fermi increasing (Mrk 421: 5 ph > 150GeV in 6 months)
  - Threshold of TeV instruments set to decrease with HESS-2 and MAGIC-2
- Is there interest in having ability to fit spectra across both instruments simultaneously?
  - Based on Xspec or merger of existing code sets
  - Cross calibration tools

LAT as a flare detection tool



ATels (just check Twitter)



ATel 2175: Fermi LAT detection of GeV flare from blazar PKS 2023-07 http://bit.ly/A43x2
6:10 AM Aug 27th from twitterfeed

ATel 2168: Fermi LAT detection of a GeV flare from 3C 273 http://bit.ly/RF8AF
1:05 PM Aug 20th from twitterfeed

ATel 2160: Fermi LAT detection of increasing gamma-ray activity of blazar PKS 2052-474 http://bit.ly/Ou5UR
4:35 PM Aug 14th from twitterfeed

ATel 2154: Fermi LAT and INTEGRAL detection of increasing high-energy activity of blazar 3C279 http://bit.ly/3gzDA1
3:04 PM Aug 7th from twitterfeed

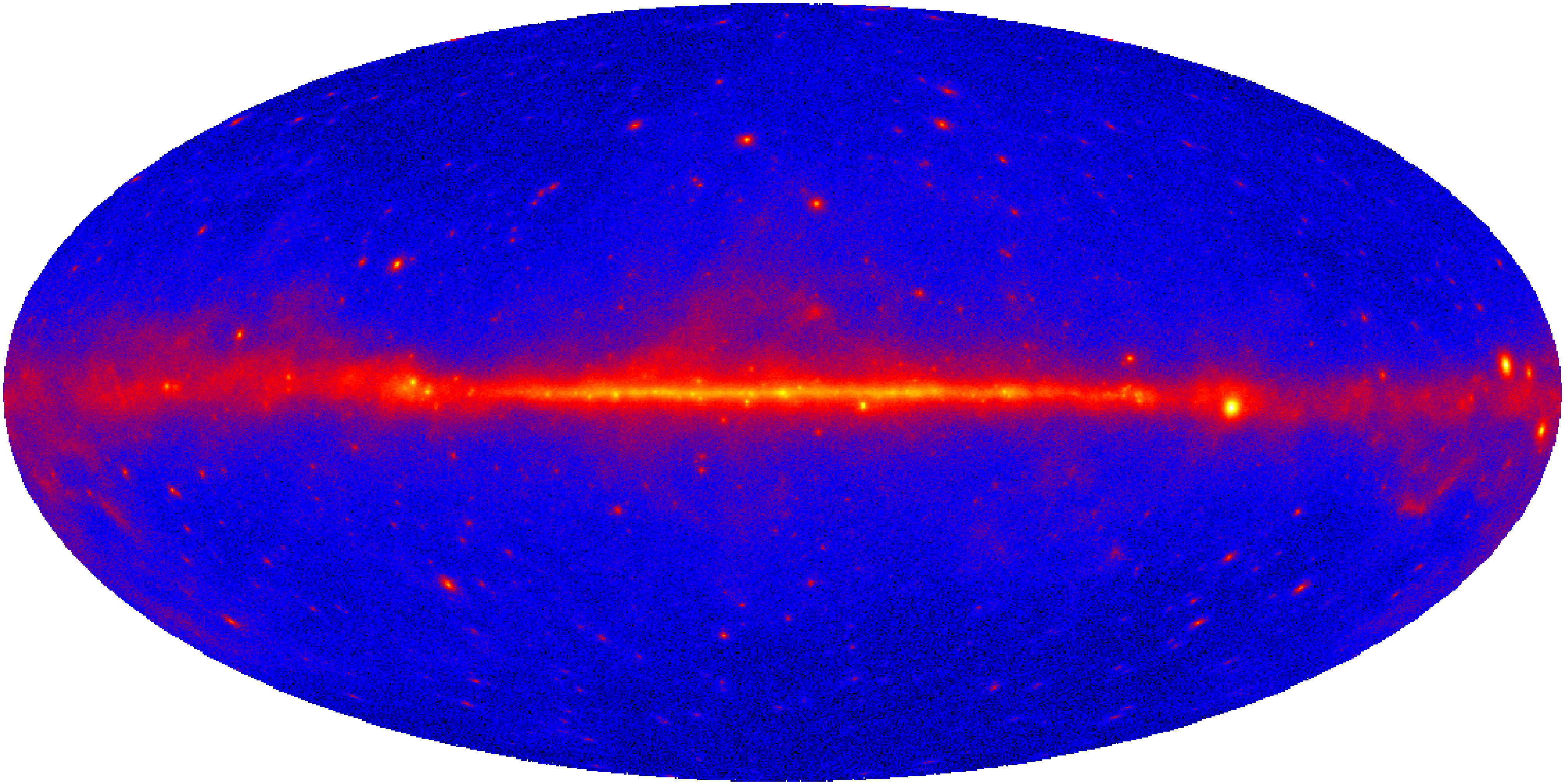
ATel 2136: Fermi LAT detection of GeV flares in high redshift blazars 4C 38.41 (B2 1633+38) and PKS 0805-07 http://bit.ly/ssm72
7:35 AM Jul 23rd from twitterfeed

ATel 2124: Fermi LAT detection of a GeV flare from BL Lac PKS 0537-441 http://tinyurl.com/l4zp94
3:49 PM Jul 10th from twitterfeed

Where are the TeV flares?

- Current flaring criteria (based on integral flux going above $10^{-6}cm^{-2}s^{-1}$) have not resulted in triggers on TeV AGN
  - They detect flares from FSRQ and LBL
- Development of a TeV trigger of considerable interest to LAT and VHE collaborations
  - Initial investigations show that a trigger based on detections of multiple HE photons (>10-50GeV) in the LAT from same region of sky is promising
- Hope to have something in place for coming year

New AGN targets for TeV instruments



Conclusions

- Learned a lot about GeV blazars from LBAS
- TeV observations of LBAS sources underway, the 1FGL AGN and unidentified sources will provide further interesting TeV targets
- Fermi flaring source trigger not a useful tool for TeV instruments during 1st year. A specific HE trigger may be more fruitful in upcoming years
- To really understand GeV-TeV AGN there is much work to be done by TeV observatories and Fermi. This first year was a great start!

Conclusions

- Learned a lot about GeV blazars from LBAS
- Dedicated MW campaigns including Fermi and TeV instruments promise to reveal more secrets of particle acceleration and emission
- GeV-TeV AGN are amongst the hardest detected by Fermi. Many are consistent with simple intrinsic power-law spectrum
- 1st Fermi catalog will help guide TeV observations
- Dedicated TeV flare trigger
- Joint-analysis tools may be useful for HESS2 etc.

To do

- New catalog
  - Predictions for new TeV sources
  - Unidentified hard-spectra targets
- Precision measurements of gamma-ray spectra
  - Understand Fermi systematics – on orbit simulation and calbration (Pass 7 IRFs and beyond)
  - Cross calibration with TeV instruments as number of >100GeV photons increases
- New TeV instruments
  - H.E.S.S. 2 and MAGIC 2 extend to <100GeV
- Improved modeling

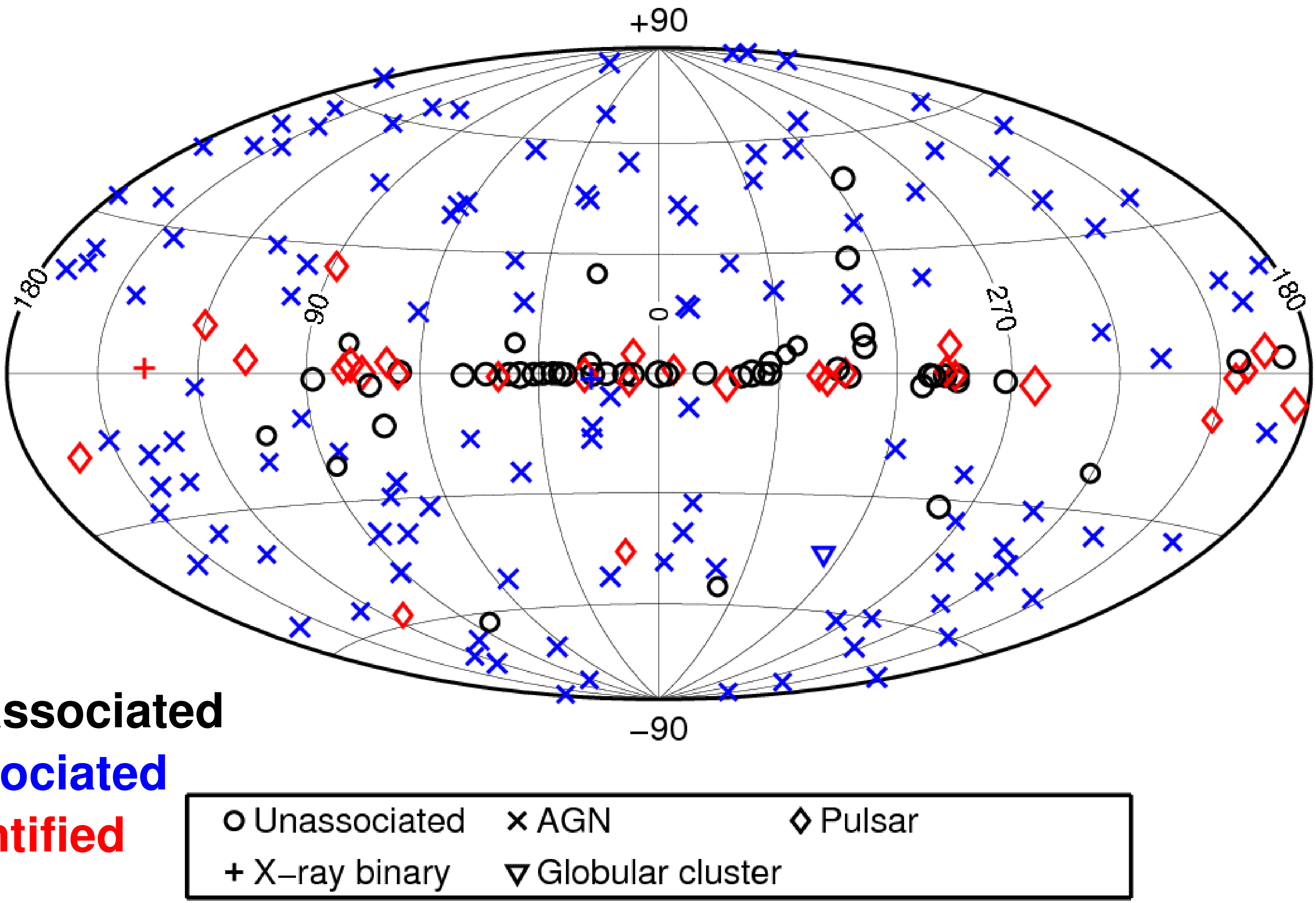
AGN: GeV-TeV connection

- Simultaneous observations with *Fermi* and TeV instruments will be crucial to understand the physics behind emission from extreme objects
  - VHE spectra are often simple power-laws
  - Parameters of astronomical objects required for modeling the emission are usually not well known
  - Therefore in many cases models for different emission mechanisms can be made to fit VHE data
  - The 3 orders of magnitude between 100MeV and 100GeV will help measure features in the spectra and make it more difficult to fit different models

AGN: GeV-TeV connection

- At LLR we are working on a comprehensive paper on *Fermi* observations of VHE blazars which will cover nearly 6 months of *Fermi* data and have a cutoff at the 5σ level.
- *Fermi's* all-sky capability is a natural trigger for VHE instruments. A specific "high energy photon" trigger would be useful to initiate MW campaigns.
- Cross calibration of *Fermi* with VHE instruments can be addressed as *Fermi* collects more data

Bright source associations



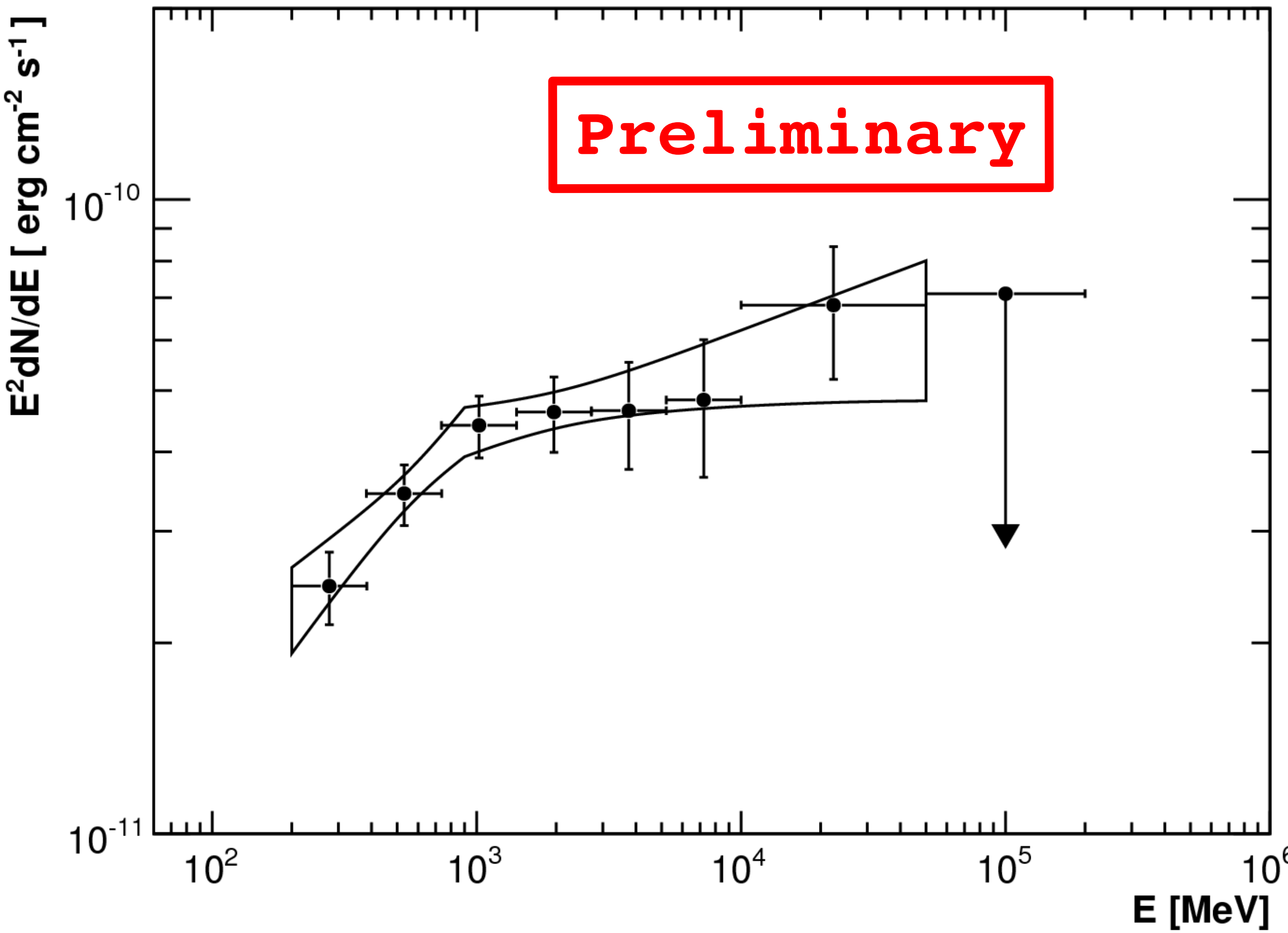
Unassociated
Associated
Identified

Source associations summary

Class	Number
Radio/X-ray pulsar	15
LAT gamma-ray pulsar	14
HMXB	2
BL LAC	46
FSRQ	62
Other blazar (Uncertain type)	11
Radio galaxy	2
Globular Cluster	1
LMC	1
† Special cases	14
Unassociated	37

(205)

Fermi spectrum



Fermi spectrum from the 2 month period around the campaign (to enhance statistics)

Broken power-law preferred over simple:
$\Gamma_L = 1.61 \pm 0.16$
$\Gamma_H = 1.96 \pm 0.08$

(From: D. Sanchez)