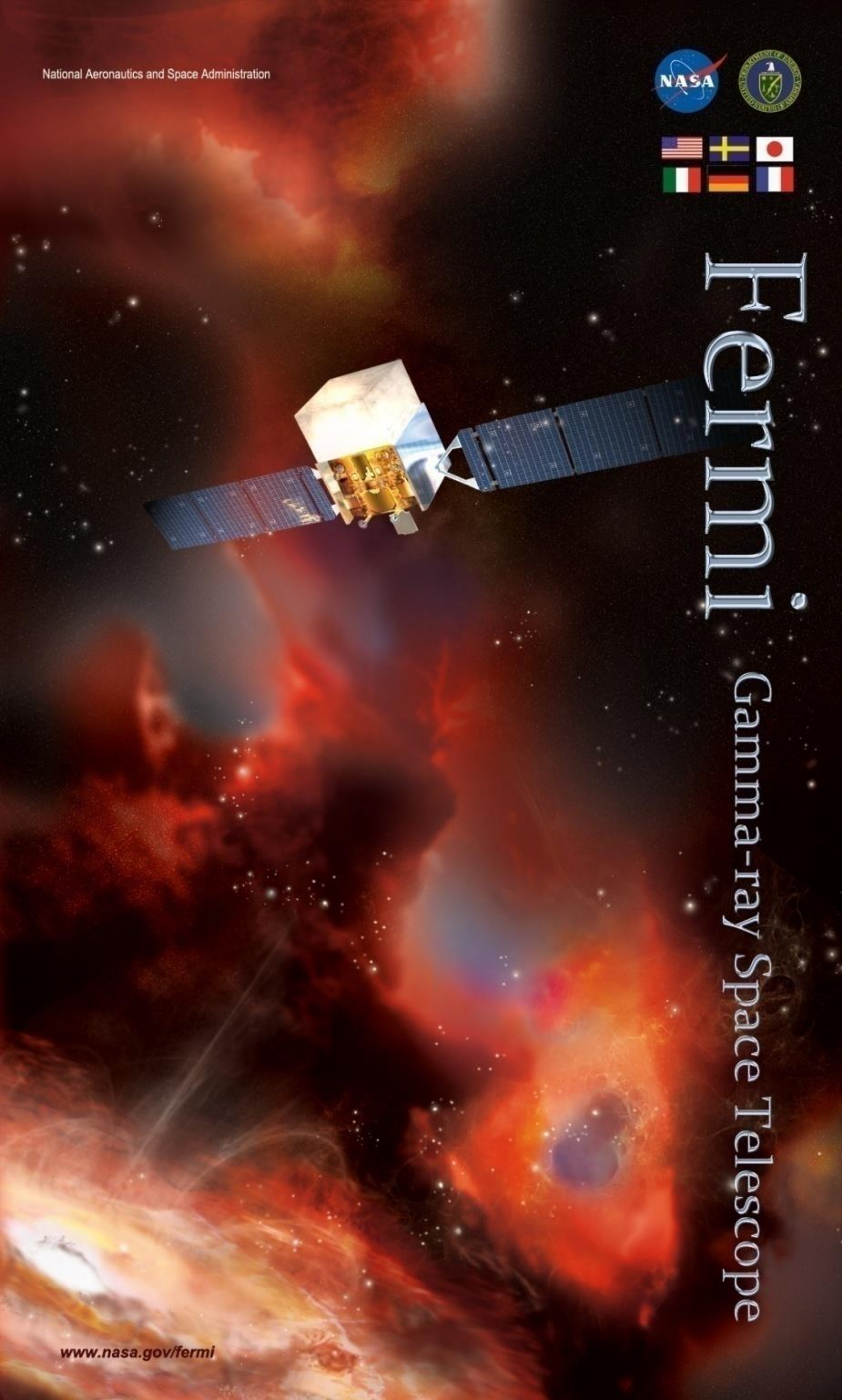
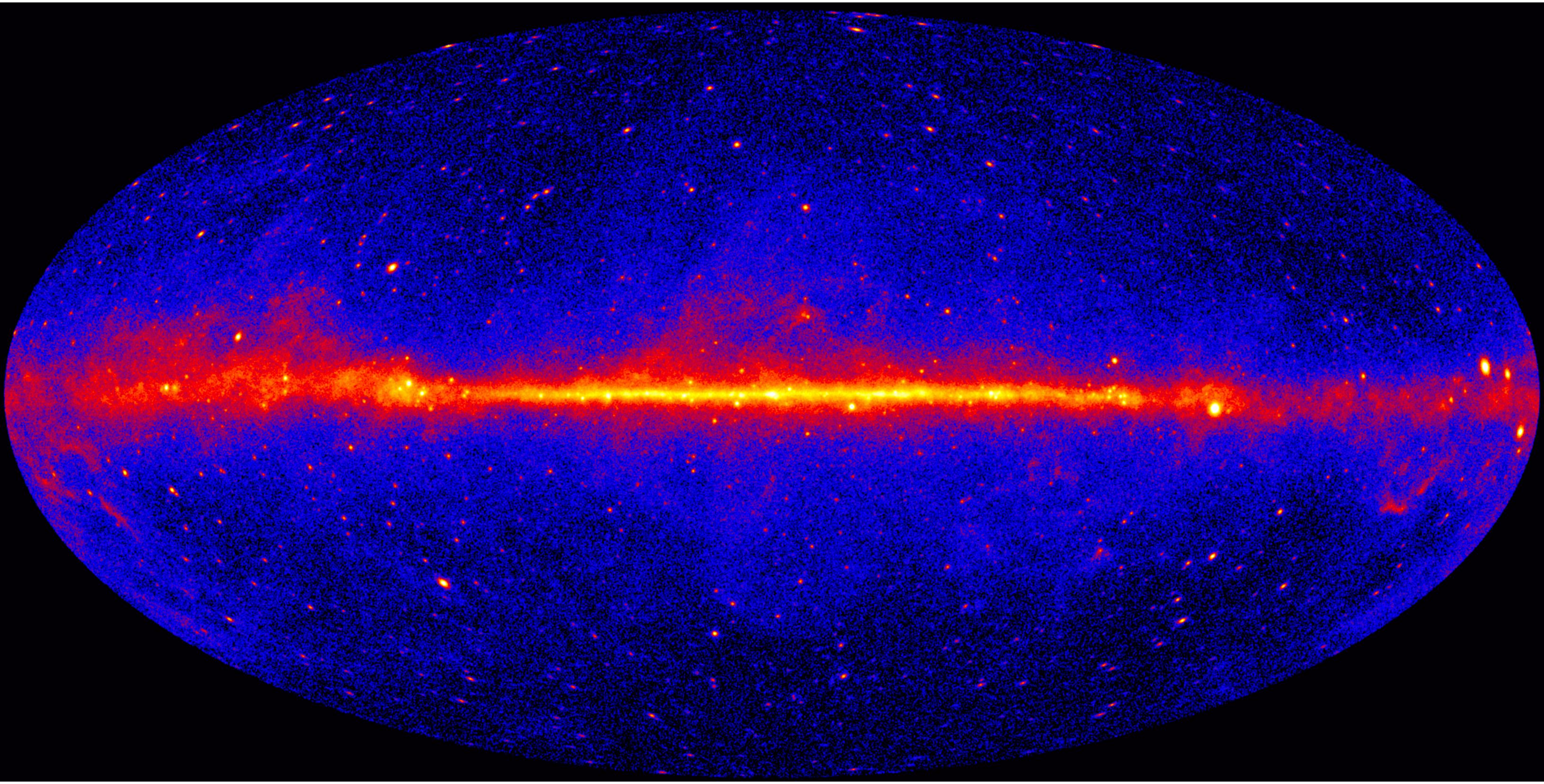


The γ-ray sky above 10 GeV seen by the *Fermi* satellite

Jean Ballet
AIM, CEA Saclay, France
LAT collaboration

APC Paris, May 26, 2014

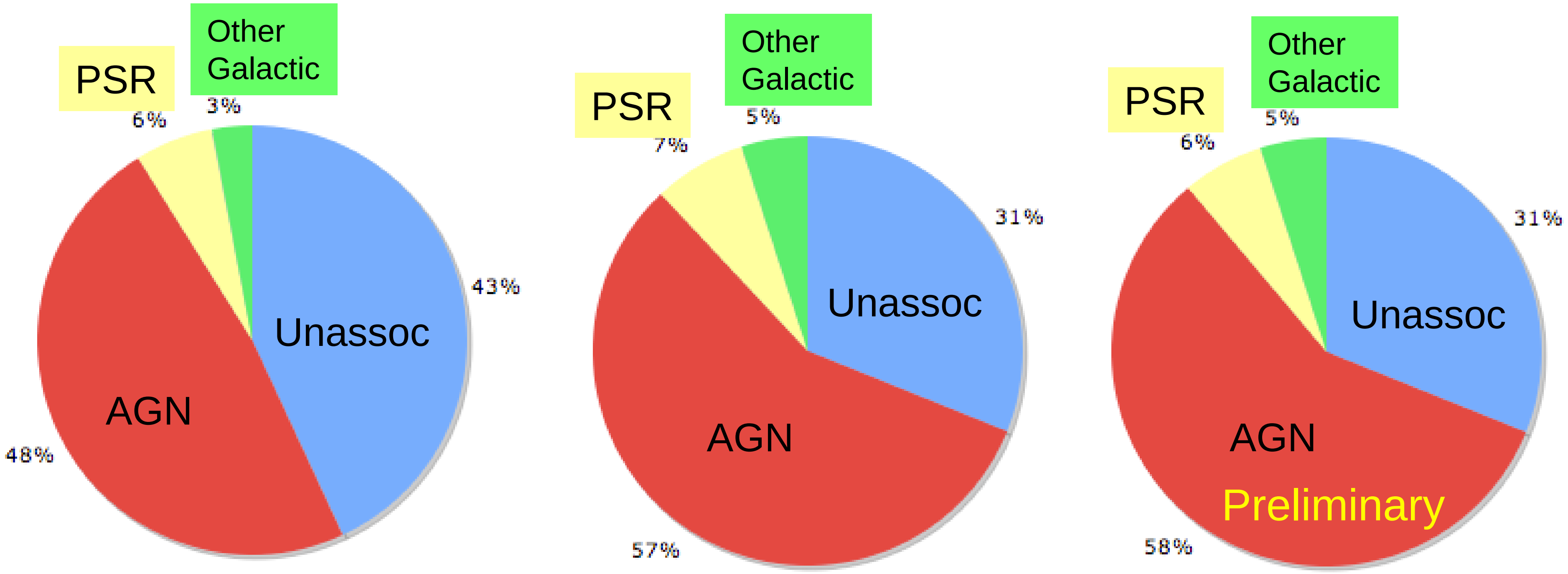
Above 1 GeV



2FGL (2 years): 1873 sources (Nolan et al 2012, ApJS **199**, 31)

Upcoming 3FGL (4 years): ≈3000 sources

Source association



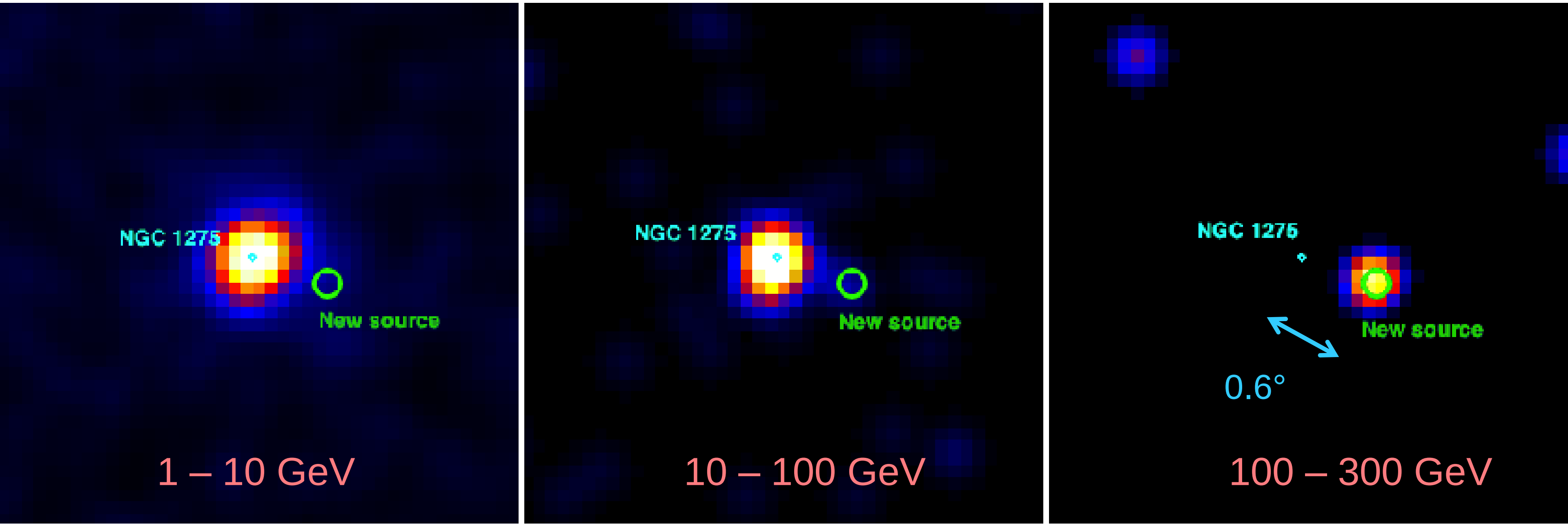
1FGL
(1451 sources)

2FGL
(1873 sources)

3FGL
(≈3000 sources)

Similar fraction of associated sources as in 2FGL, thanks to ongoing effort on deepening counterpart catalogs

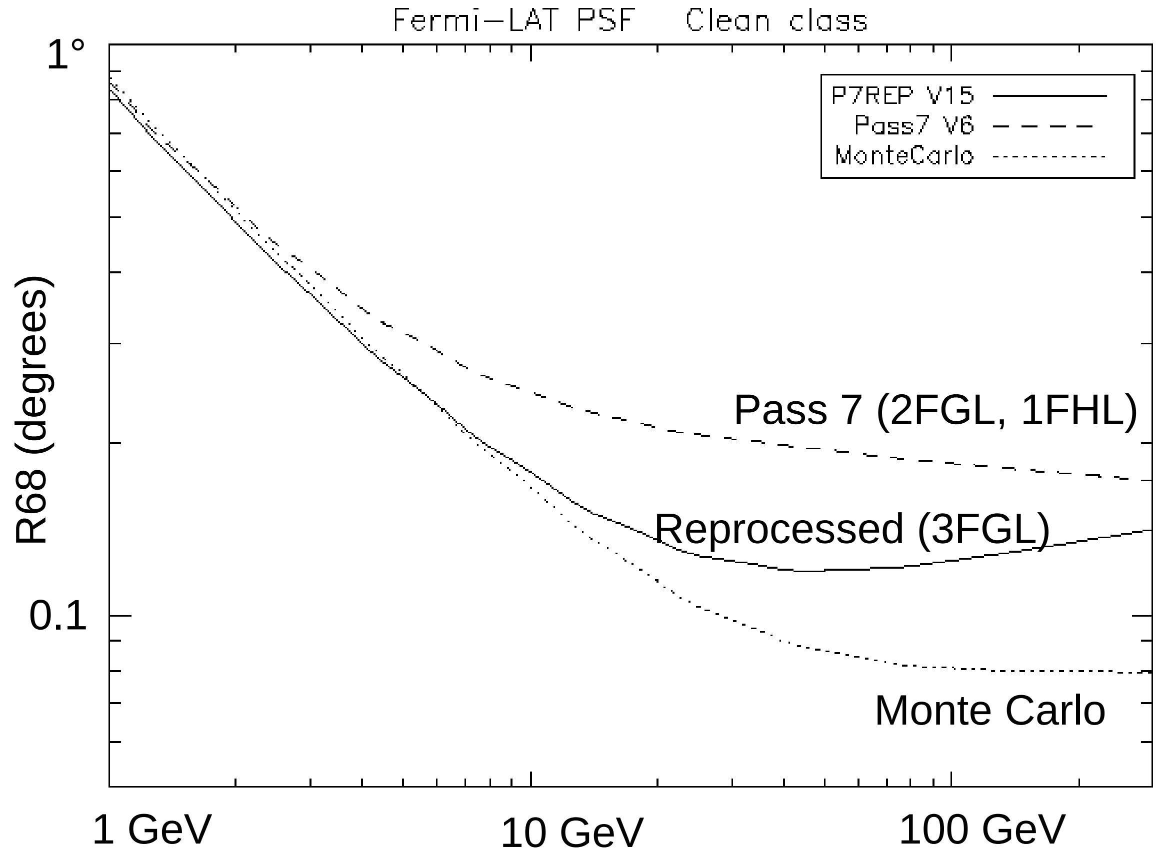
Fermi sources > 100 GeV



Neronov et al 2010 (A&A 519, L6) have found 8 Fermi sources above 100 GeV, among which one was not a previously known TeV source

IC 310 in Perseus cluster: 3 events within 0.1° over 18 months

Spatial resolution



PSF improves considerably with energy up to 10 GeV

Improved calibration of the CAL crystals results in **better high-energy PSF** (J. Bregeon, Fermi Symp 2012)

Expected performance now recovered up to 10 GeV

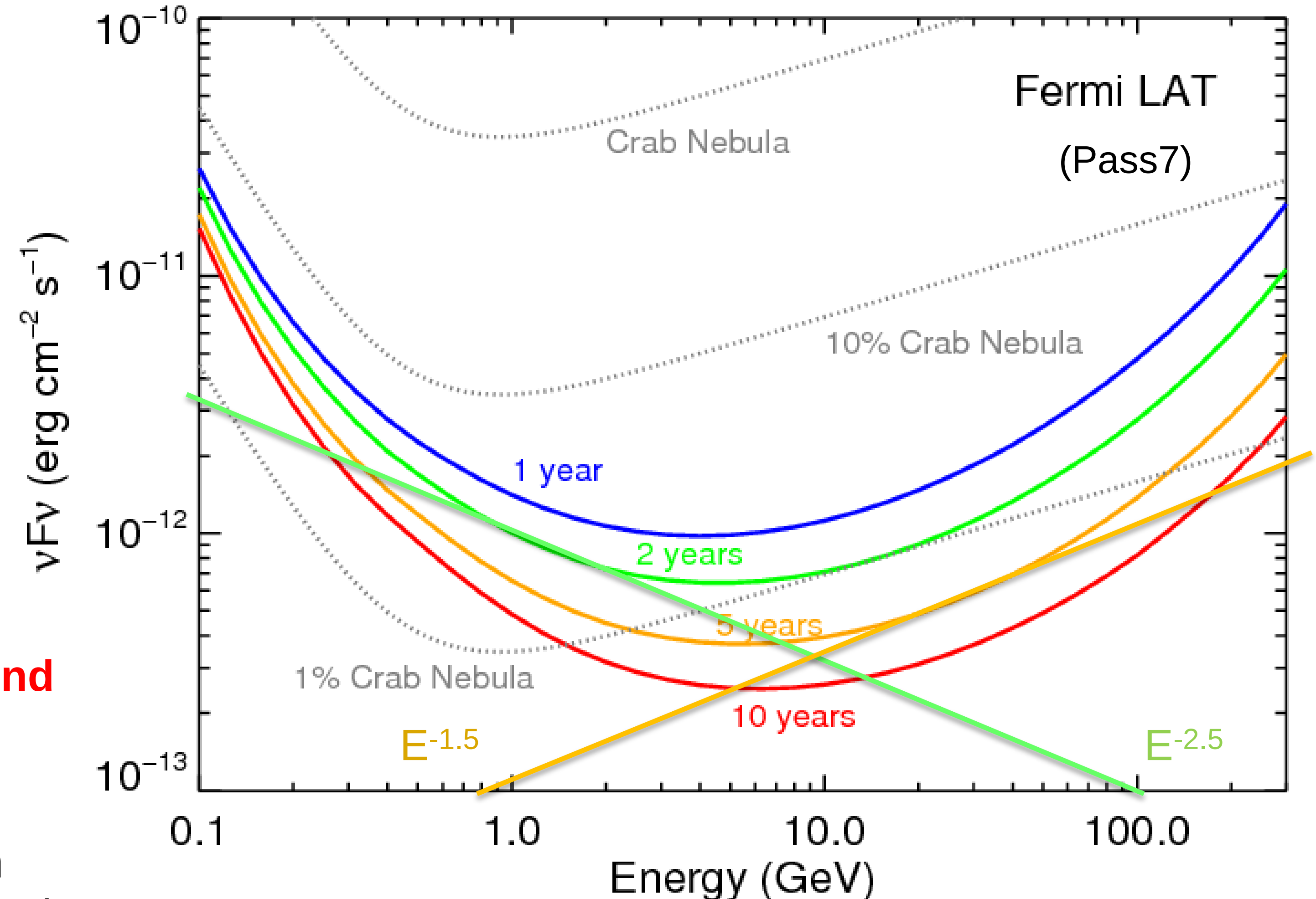
Directly impacts source localization (detection as well)

Power-law detection threshold

P7Source_V6

Rocking angle 50°

|Latitude| > 10°



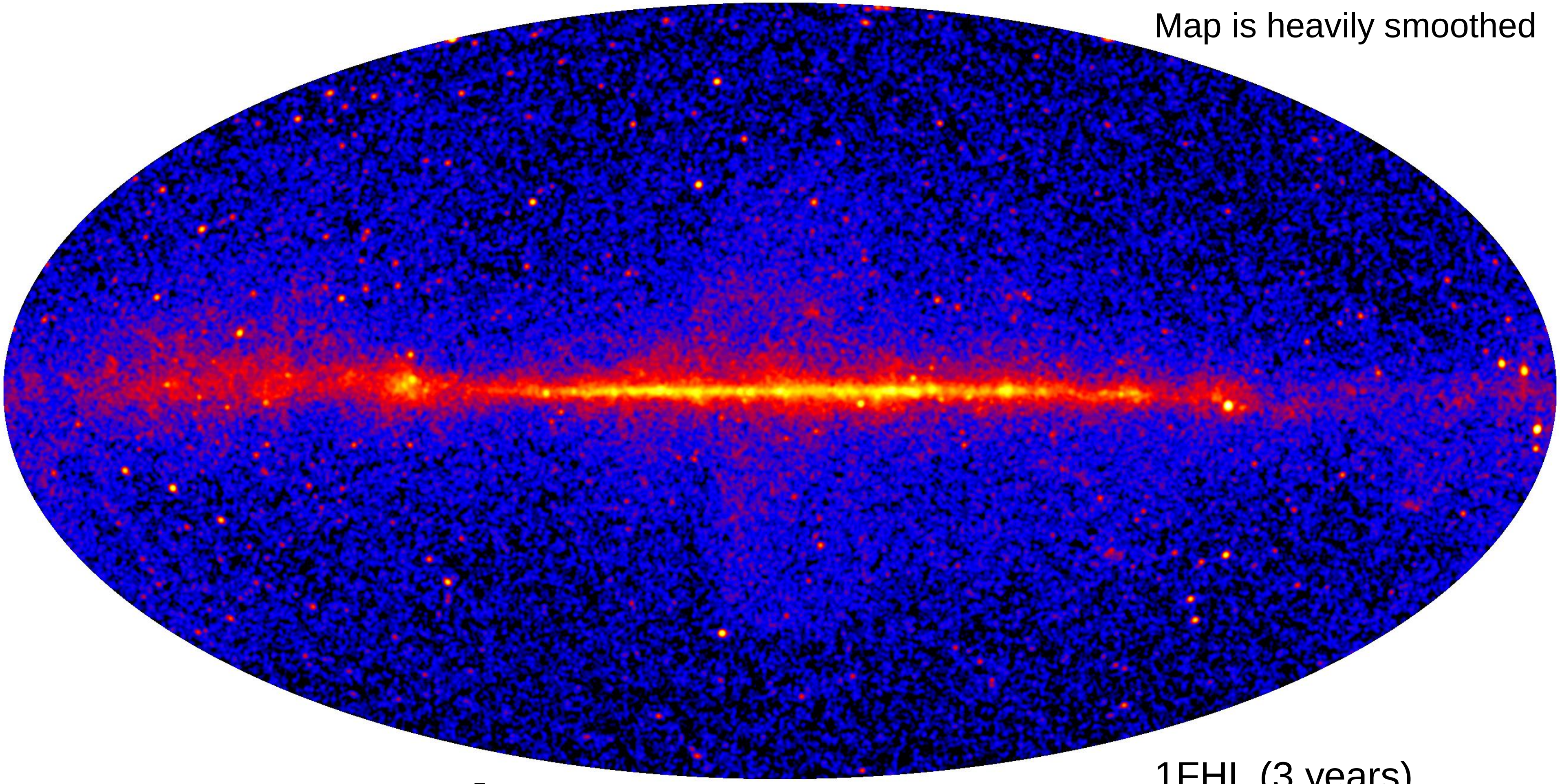
Soft sources limited by:

- Knowledge of **diffuse background** (5% precision)
- **Source density** (extrapolated from measured logN logS)

Hard sources limited by source **count rate**

Detection threshold improves faster than 1 / √t

Above 10 GeV



Map is heavily smoothed

Many fewer events (1.5 10^5 over 3 years)

Galactic diffuse emission not as dominant, except in Ridge

Fermi bubbles

1FHL (3 years)

514 sources

Ackermann et al 2013, ApJS **209**, 34

Fermi sources > 10 GeV

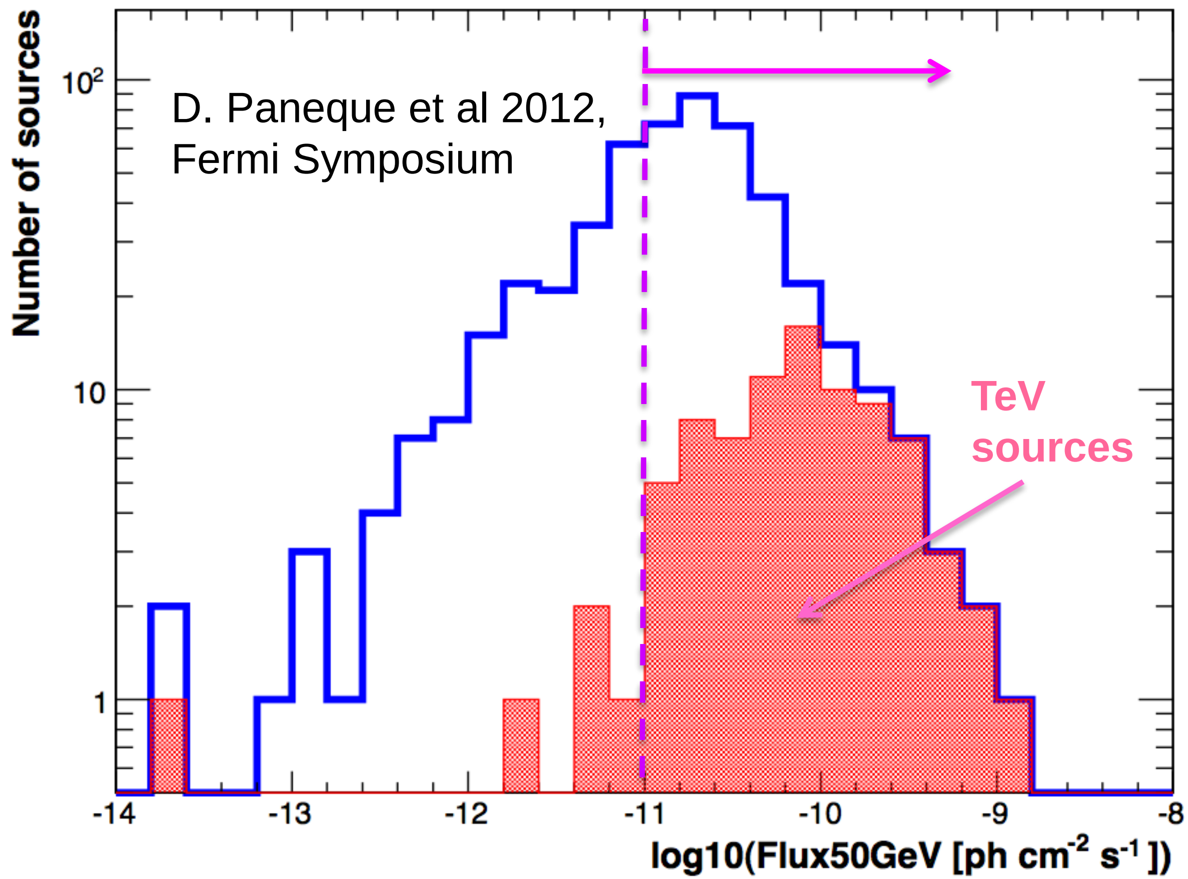
514 sources over 3 years

Integral flux above 50 GeV estimated from power-law fit above 10 GeV

Even though AGN are variable, flux above 50 GeV is a good indicator of TeV detectability

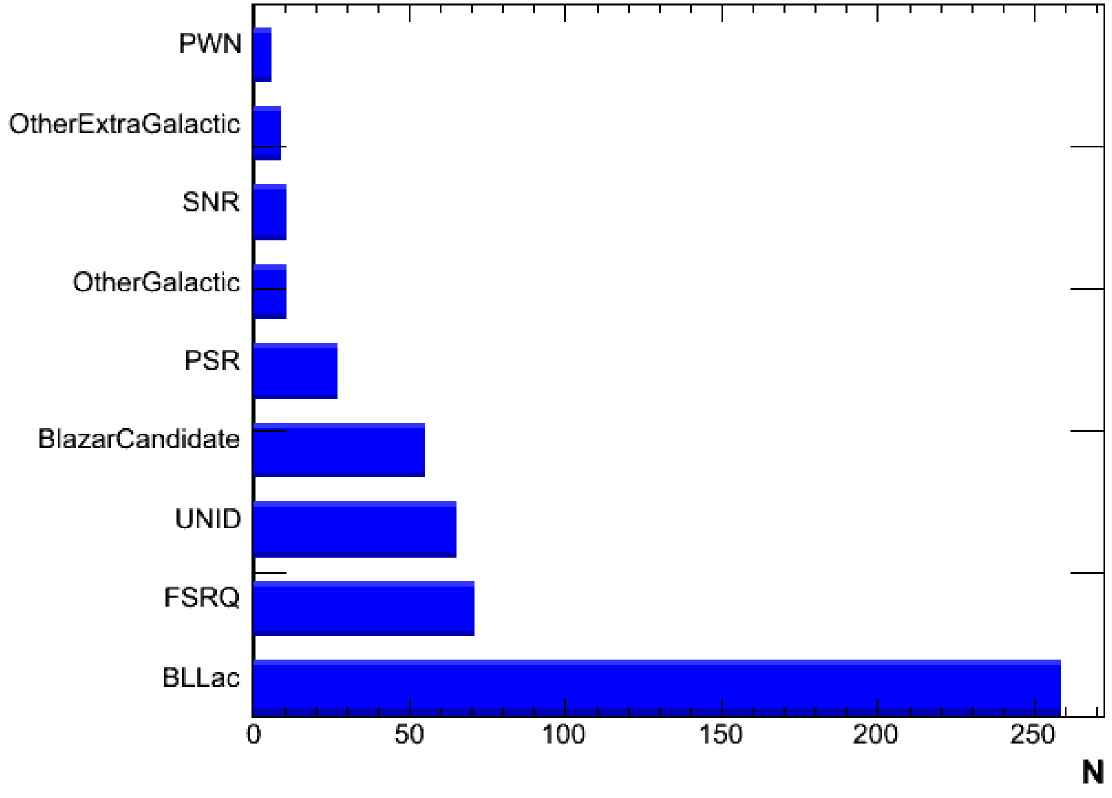
Only 3 point-like TeV sources not in 1FHL

Several Fermi-based TeV detections already



213 objects flagged as good TeV candidates

Fermi sources > 10 GeV



6 (1%)

9 (2%)

11 (2%)

11 (2%)

27 (5%)

55 (11%)

65 (13%)

71 (14%)

259 (50%)

Mostly AGN

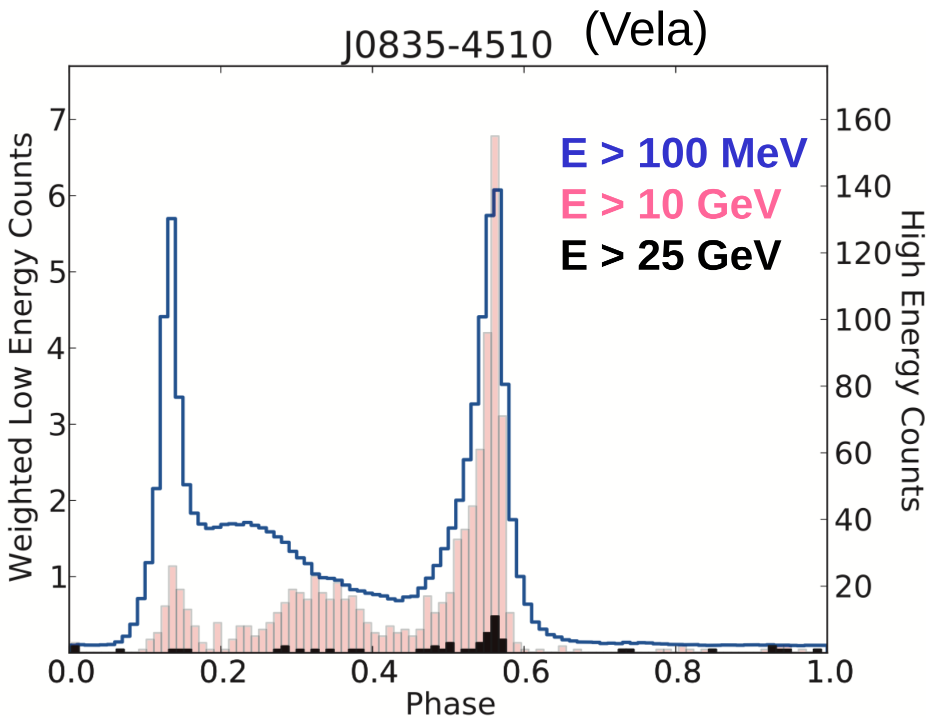
Tail of bright pulsars

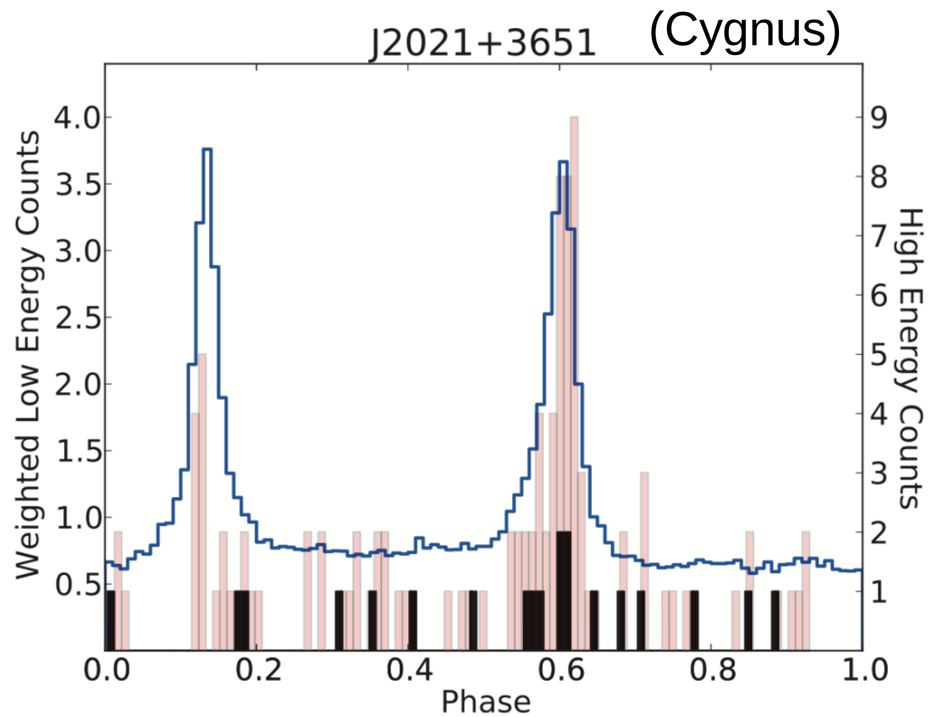
Hard Galactic sources (SNR, PWN)

13% of the sources remain unassociated

D. Paneque et al 2012,
Fermi Symposium

Pulsars > 10 GeV



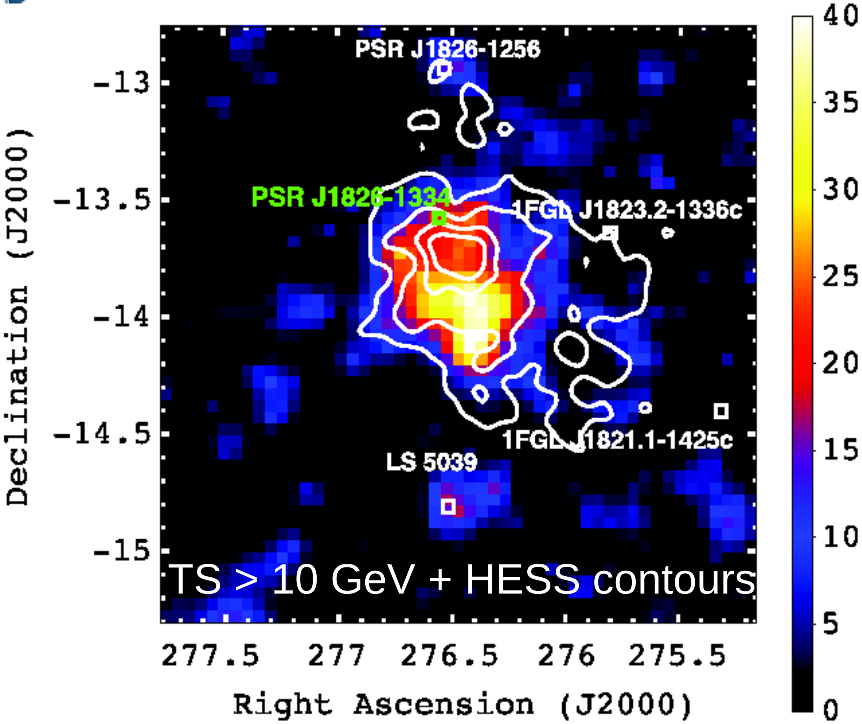


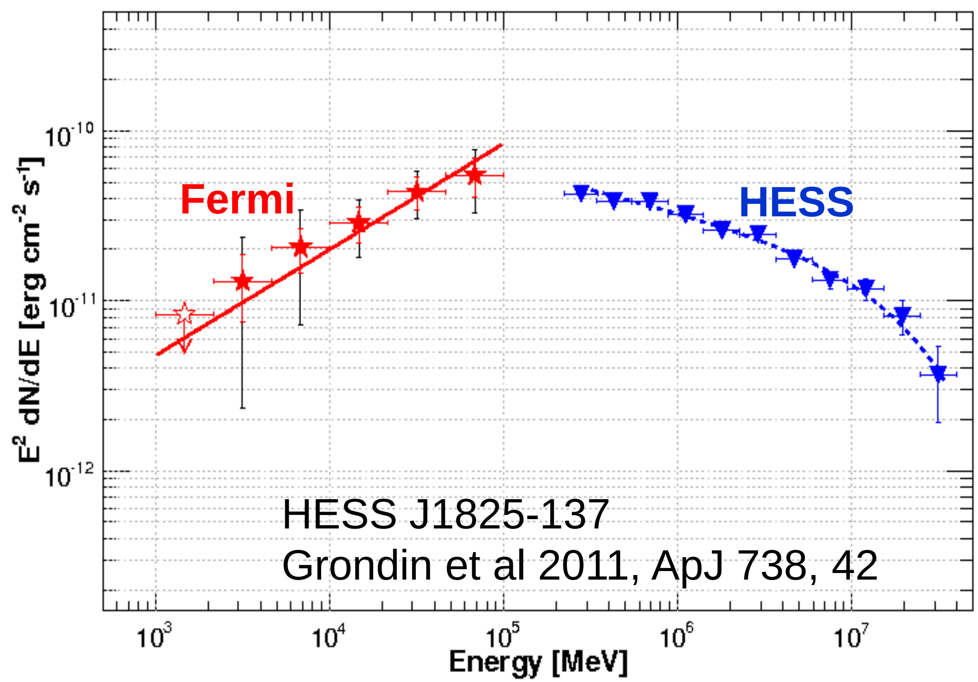
Crab pulsar has been detected by MAGIC then VERITAS over 100 GeV

Pulsations detected above 25 GeV for 11 LAT pulsars; Crab is not alone

Obviously energy-dependent light curve

Pulsar Wind Nebulae





Special case when the pulsar itself was not detected by Fermi

PWN normally harder to detect on top of bright pulsar, but possible with phase selection or spatial information

30 TeV PWN detected at 10 GeV (Acero et al 2013, ApJ **773**, 77)

PWN remain much easier to detect at TeV than GeV energies

Main help from Fermi in pulsar itself for interpretation (power input)

Supernova remnants RX J1713.7-3946

Abdo et al 2011, ApJ 734, 28

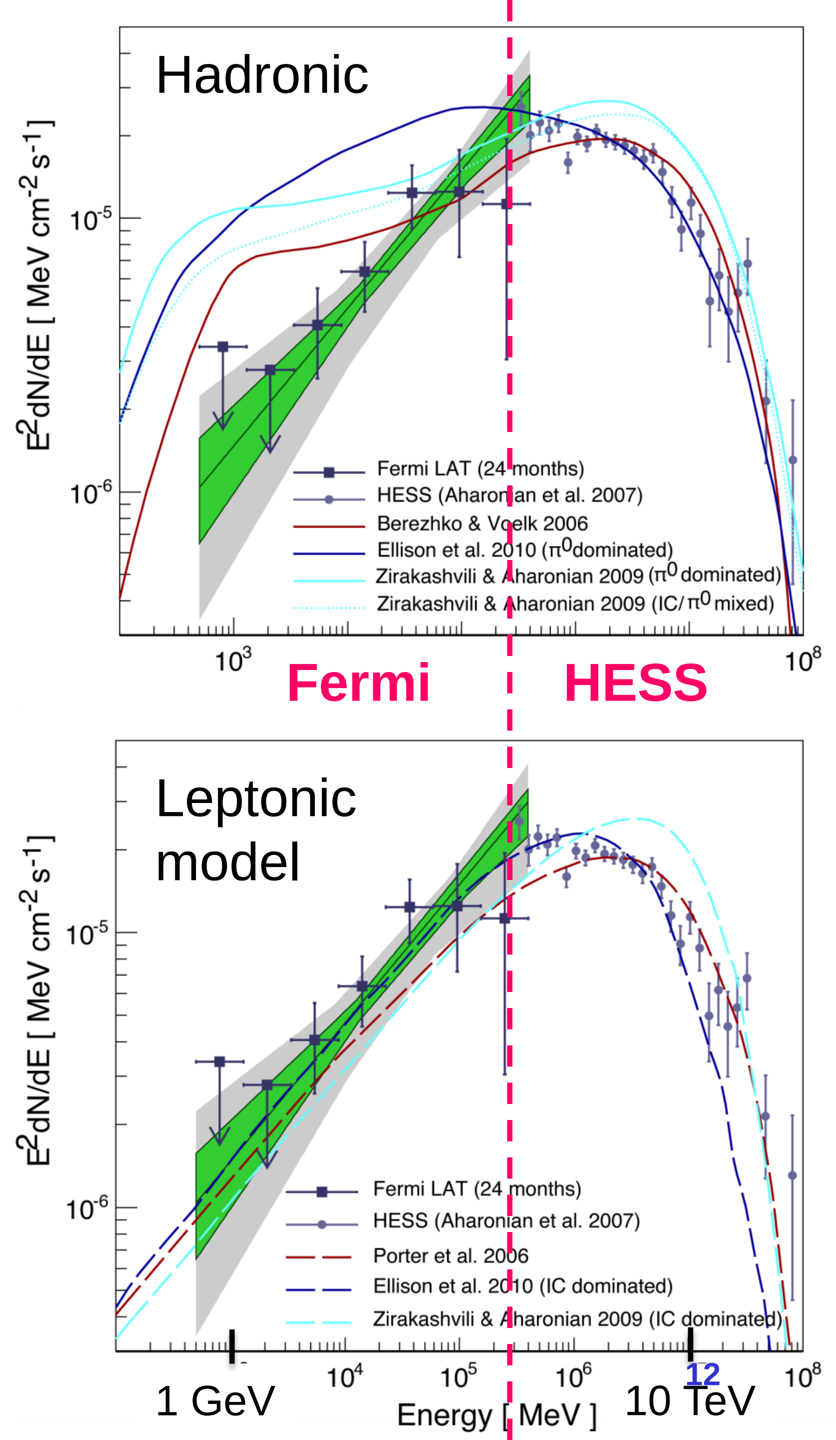
Brightest TeV SNR

Very faint, hard Fermi source in a complicated region of the Galactic plane, not detected below 5 GeV

Extended, compatible with HESS image

Clearly below the extrapolation of hadronic models, in line with **leptonic** models

Does not mean that protons are absent, but that **density is low** (as indicated by absence of thermal X-rays).



Old SNRs: IC 443

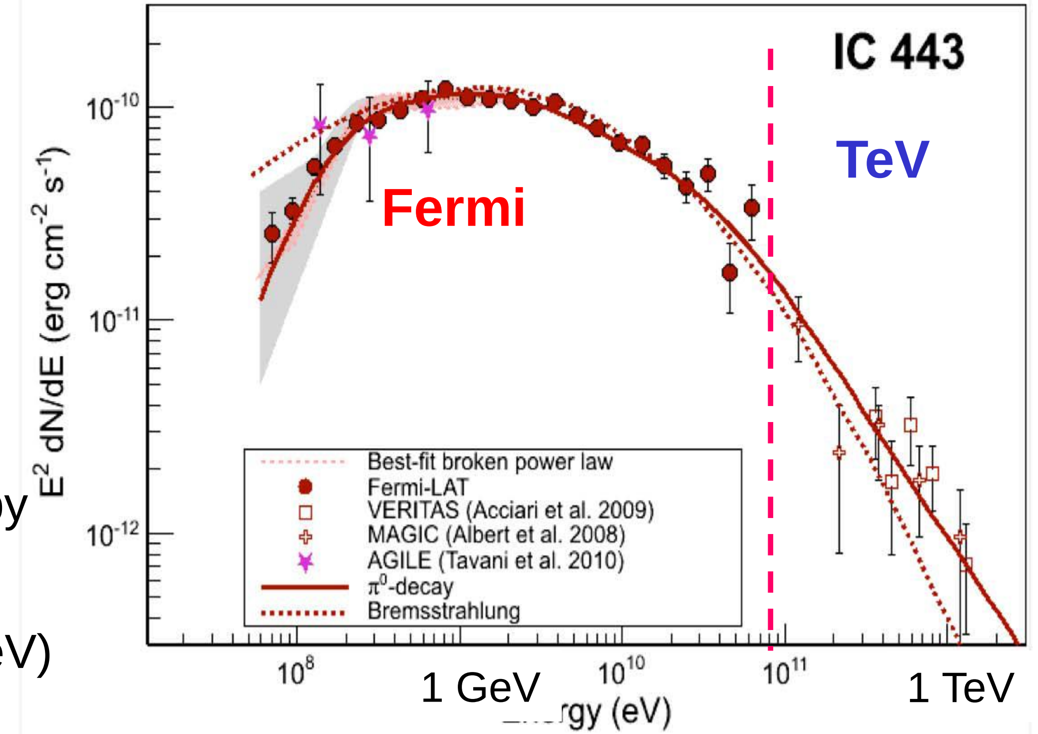
*Ackermann et al 2013, Sci **339**, 807*

Older SNR, between 3 and 30 kyr

Extended, emission where **molecular clouds** interact with the SNR, does not follow radio contours

Break at ~ 3 GeV, corresponding to proton energy of **20 GeV**. Probably reflects the maximum energy reached by freshly accelerated particles

Clearly **hadronic**, but soft (Γ = 2.9 at TeV)

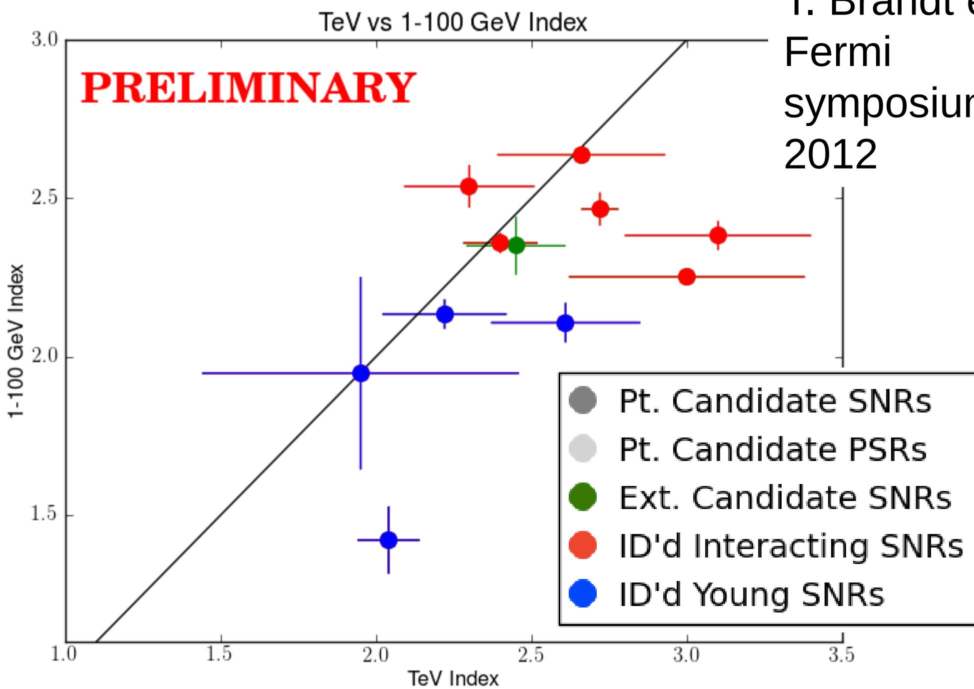


Very large diversity in SNR spectra, depending on age (shock speed) and surroundings (density)

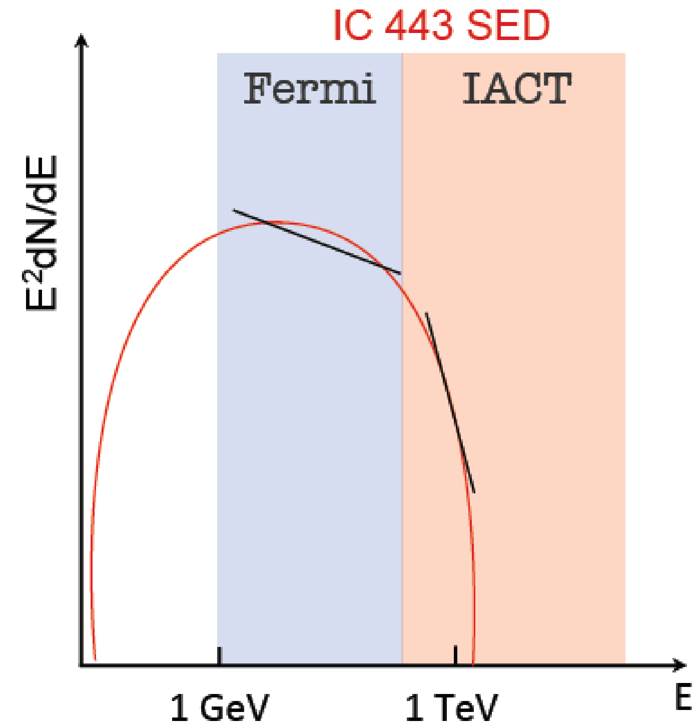
Global emission very slowly variable: no need for coincidence

GeV and TeV observations are very complementary

SNR catalog



T. Brandt et al., Fermi symposium 2012



Many TeV spectra are steeper (break between GeV and TeV range)

Some do not even appear on this plot because undetected at TeV

No TeV spectrum is significantly harder

Young SNRs are harder (and less luminous) than old ones

Cygnus X cocoon

Ackermann et al. 2011, Sci **334**, 1103

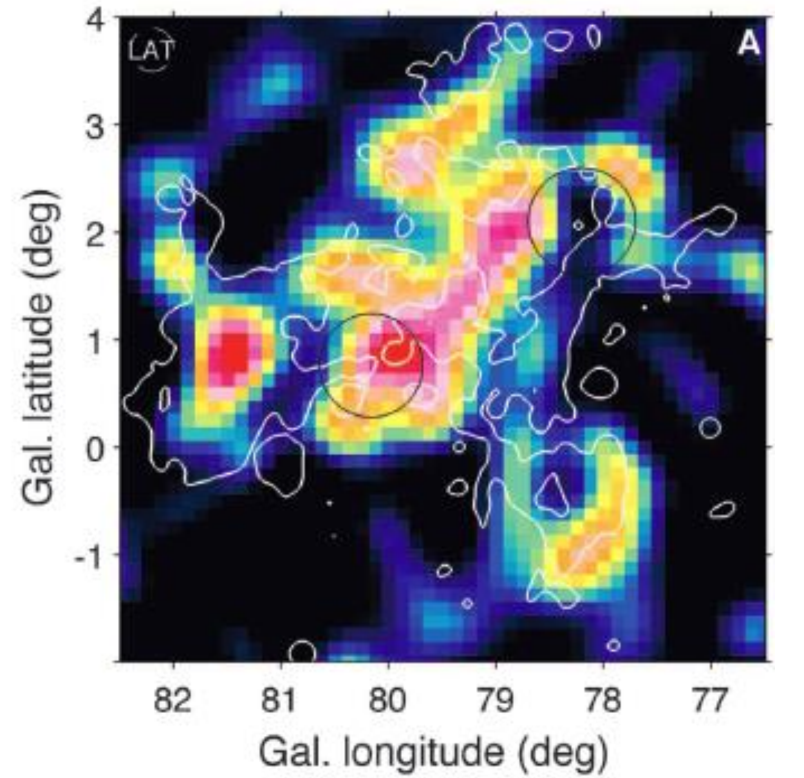
Large nearby **star-formation** region

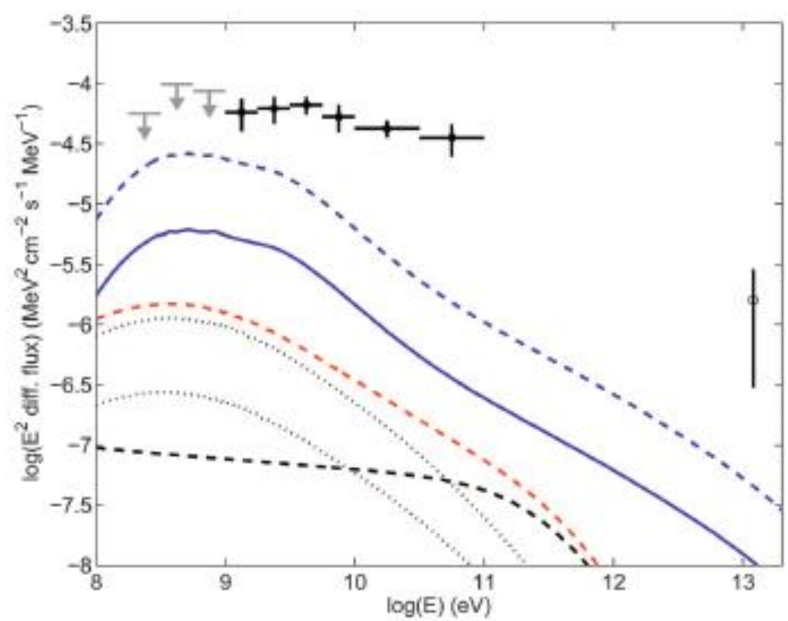
Broad **γ–ray excess** (50 pc wide) on top of expected diffuse emission (delicate subtraction exercise)

Circled by molecular clouds

Hard spectrum possibly related to MGRO J2031+41

Could be accumulation of CRs accelerated by many SNe in the region, half-way between SNRs and Galactic CRs





Fermi bubbles

D. Malyshev et al., AAS 2014, Washington

Attention to **systematic uncertainties** due to underlying diffuse emission

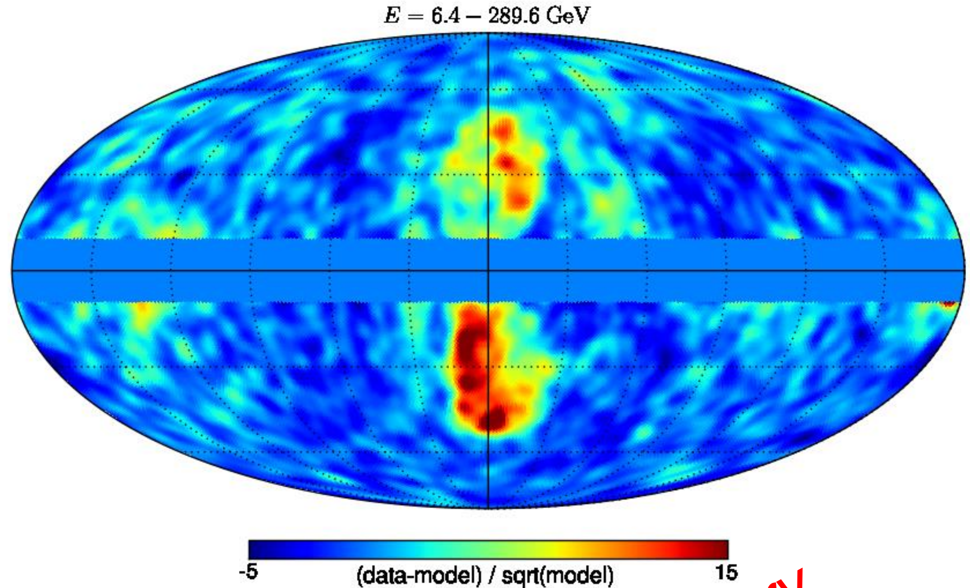
Large uncertainties at low energies (Loop I on top of North bubble)

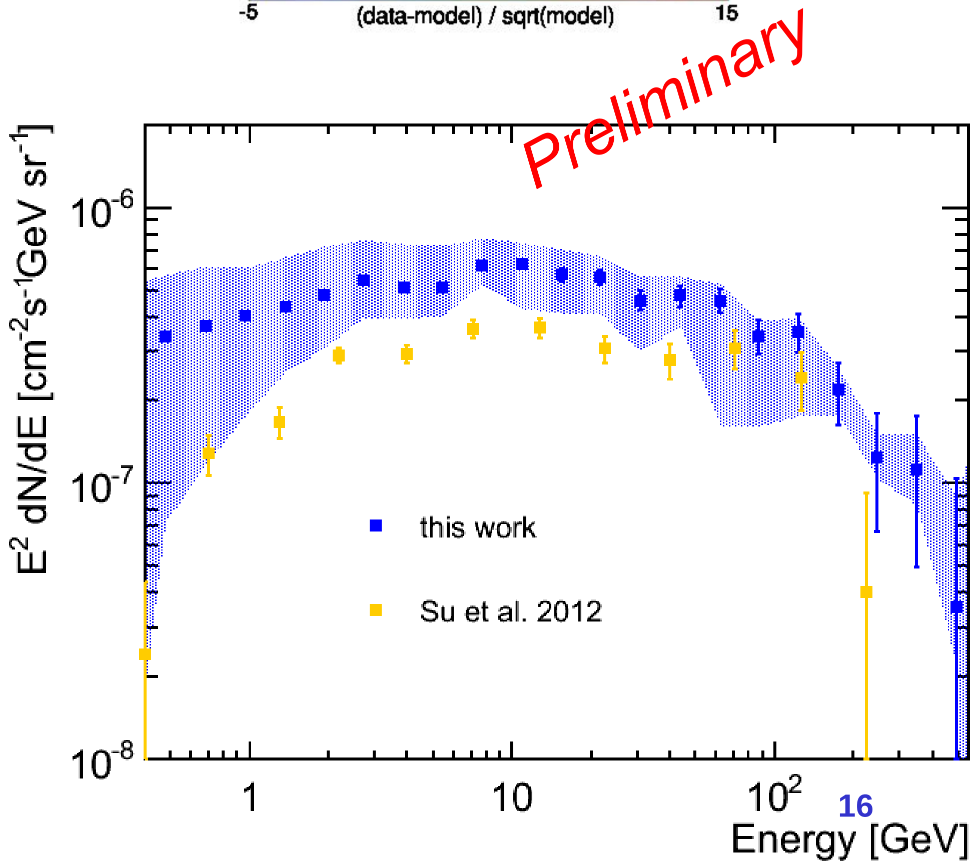
Confirms analysis by Su et al 2012, brightness a little different

Spectrum definitely **falling down above 100 GeV**

Many open questions on interpretation.

Good targets for wide-field high-energy instruments (HAWC)



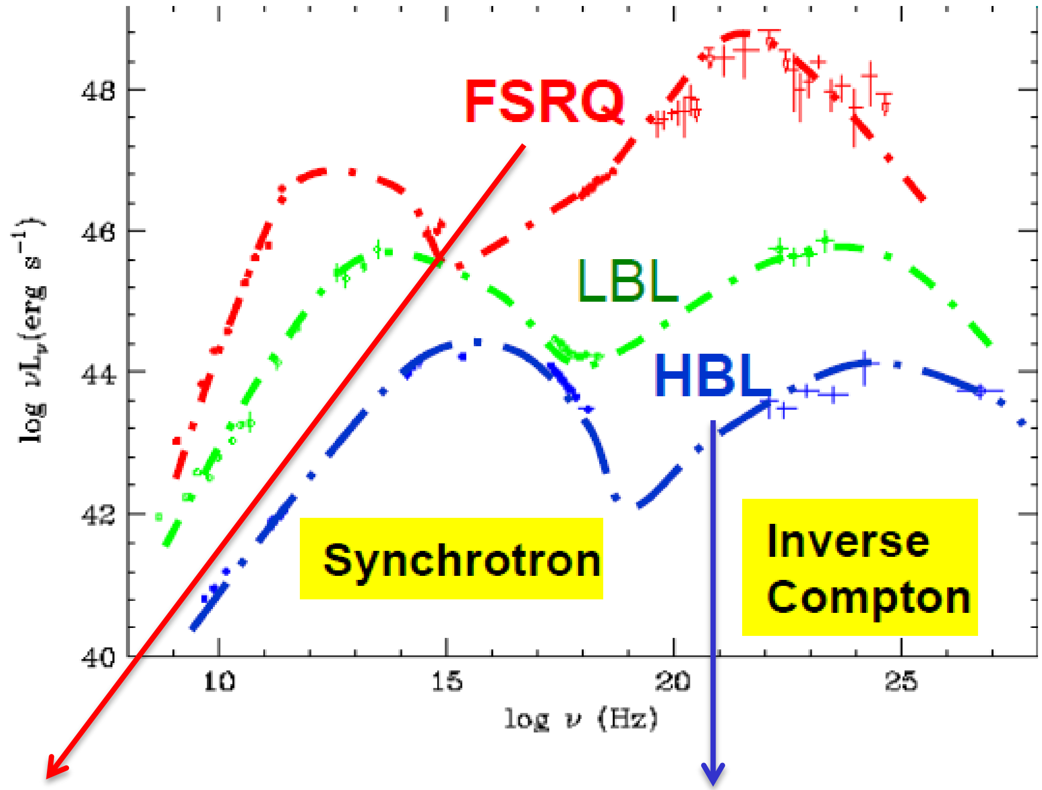


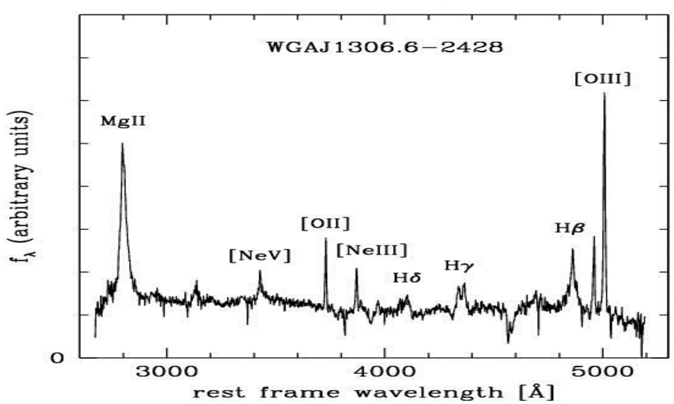
AGN classes

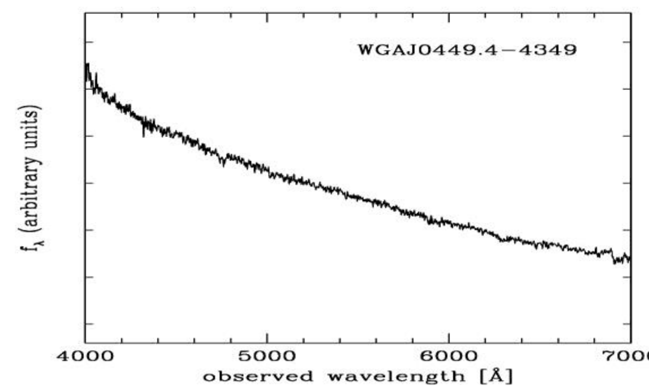
Blazar sequence

FSRQs to BL Lacs

Low synchrotron peak (LBL or LSP) to high synchrotron peak (HBL or HSP) BL Lacs

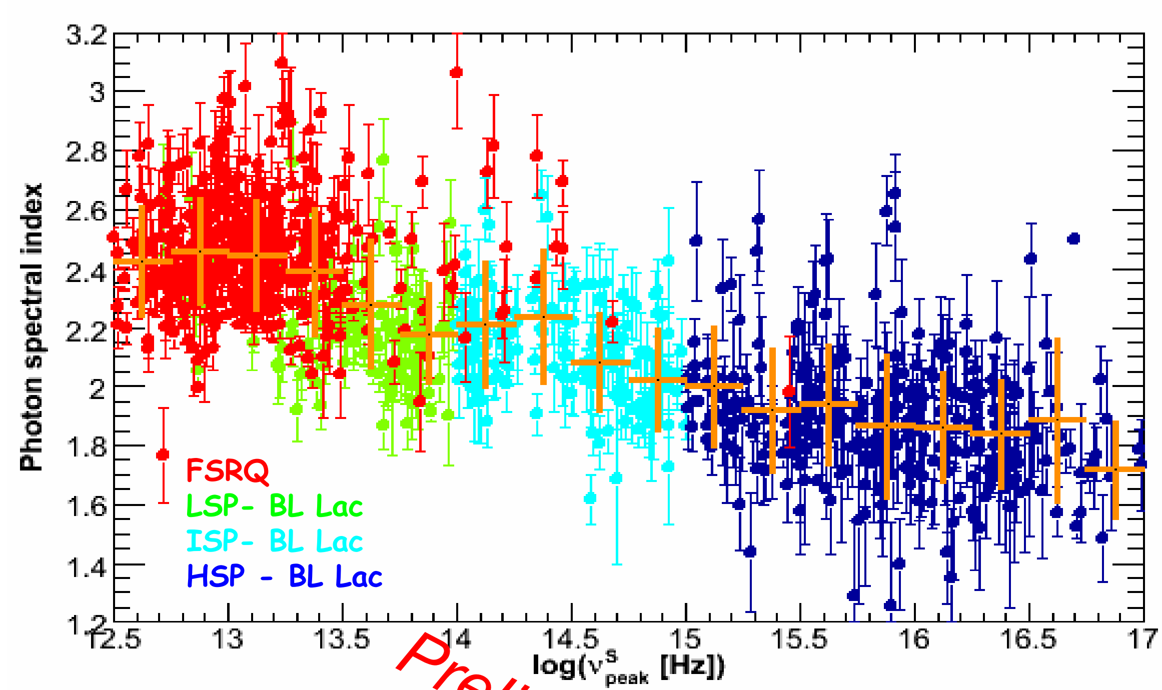




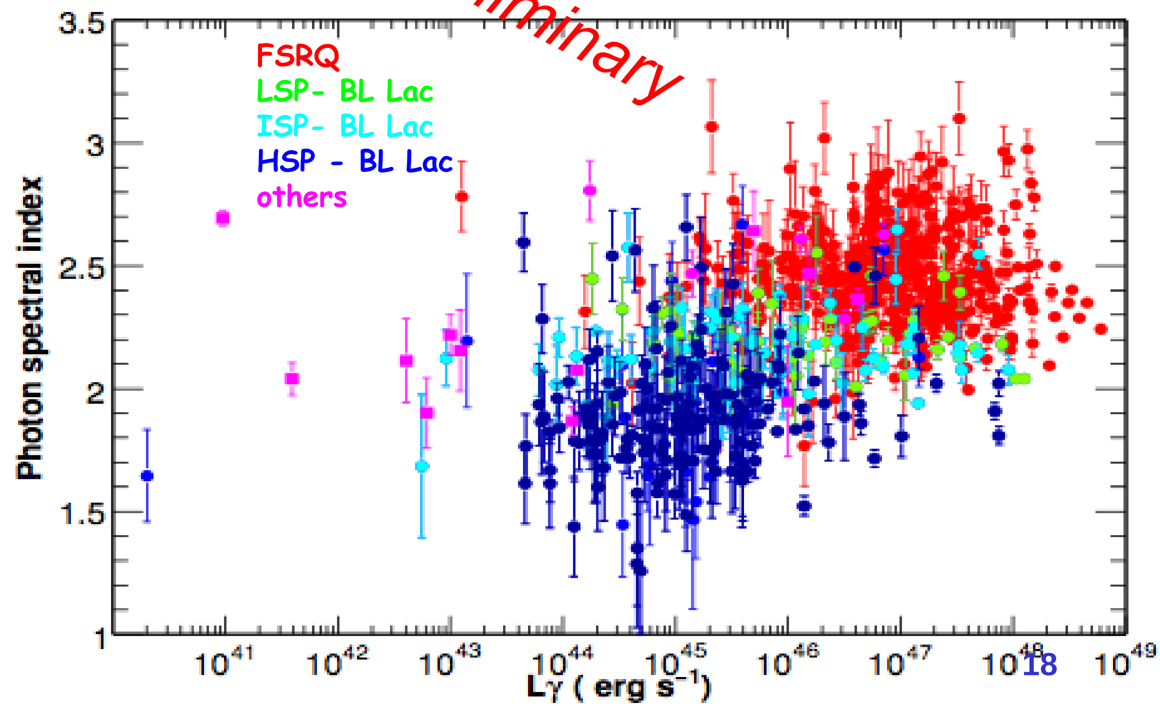


Fermi Gamma-ray Space Telescope

AGN – 3LAC



Preliminary



Same sources as 3FGL

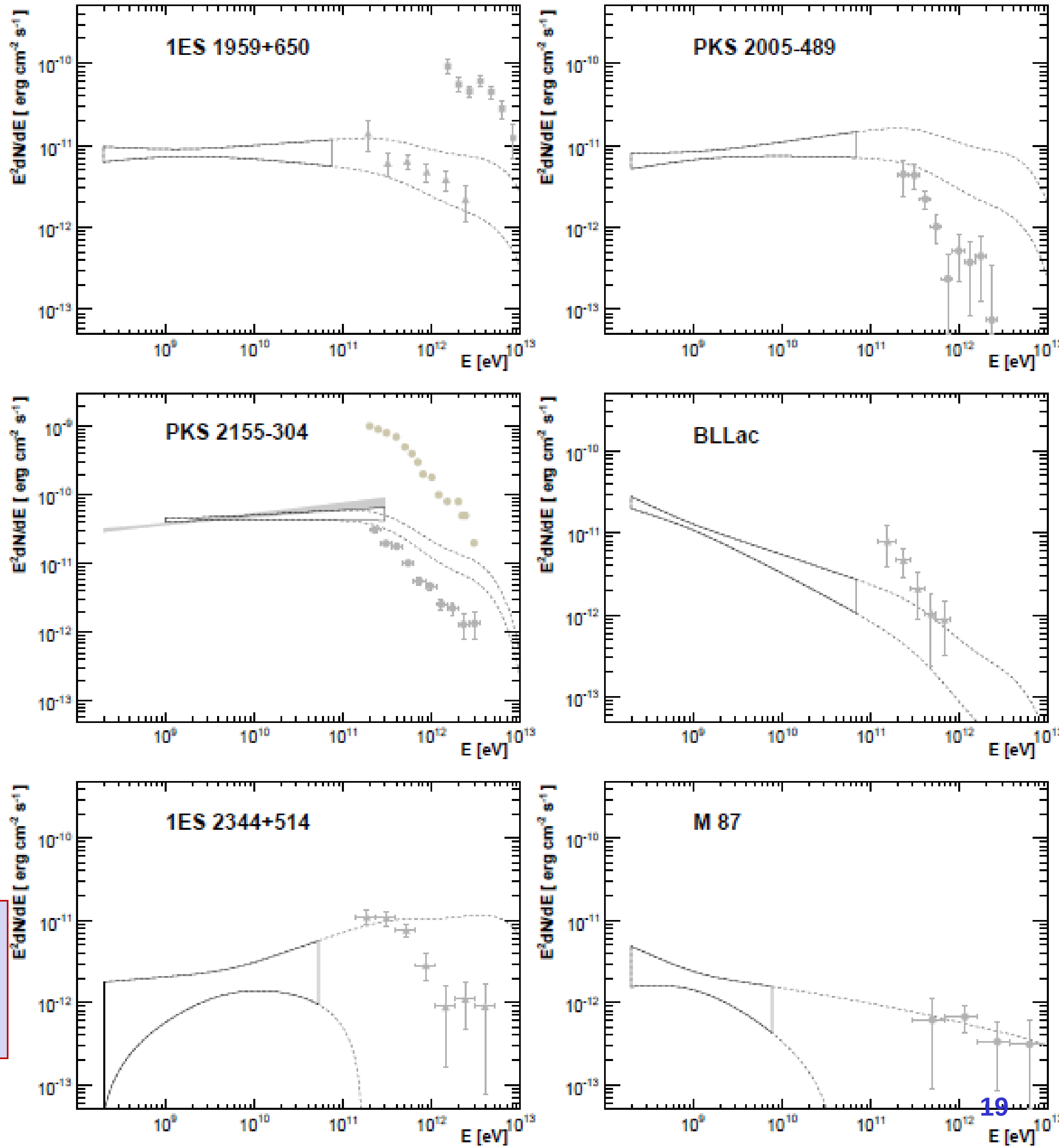
Nearly flux-limited sample in terms of **energy flux** over full band

Follows nicely blazar sequence, from luminous faraway FSRQs to less luminous nearby HSP BL Lacs

S. Cutini et al.,
BOHEME meeting 2014

AGN: GeV - TeV connection

Abdo et al. 2009, ApJ 707, 1310



Fermi spectra of known **TeV AGN**

Fermi: average flux

Comparison difficult due to intrinsic variability

Fermi is not well suited to MW studies of correlated variability

AGN > 10 GeV: redshift effects

194 1FHL blazars have a known redshift

71 FSRQs, **73 HSP BL Lacs**, 50 other BL Lacs

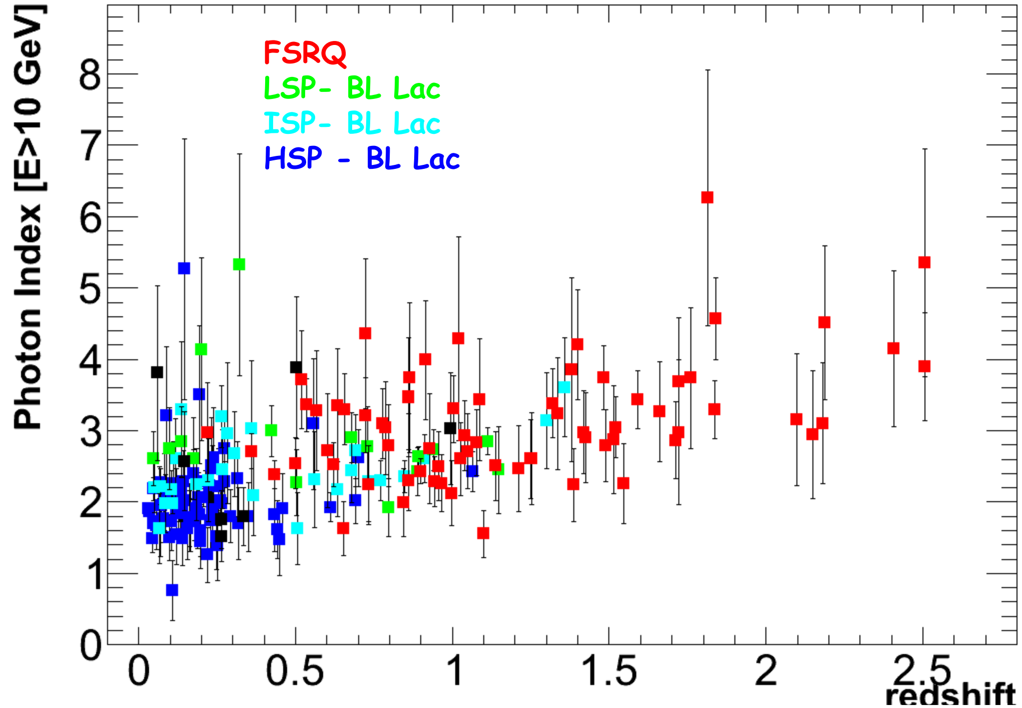
Photon index above 10 GeV softer than above 100 MeV (curved)

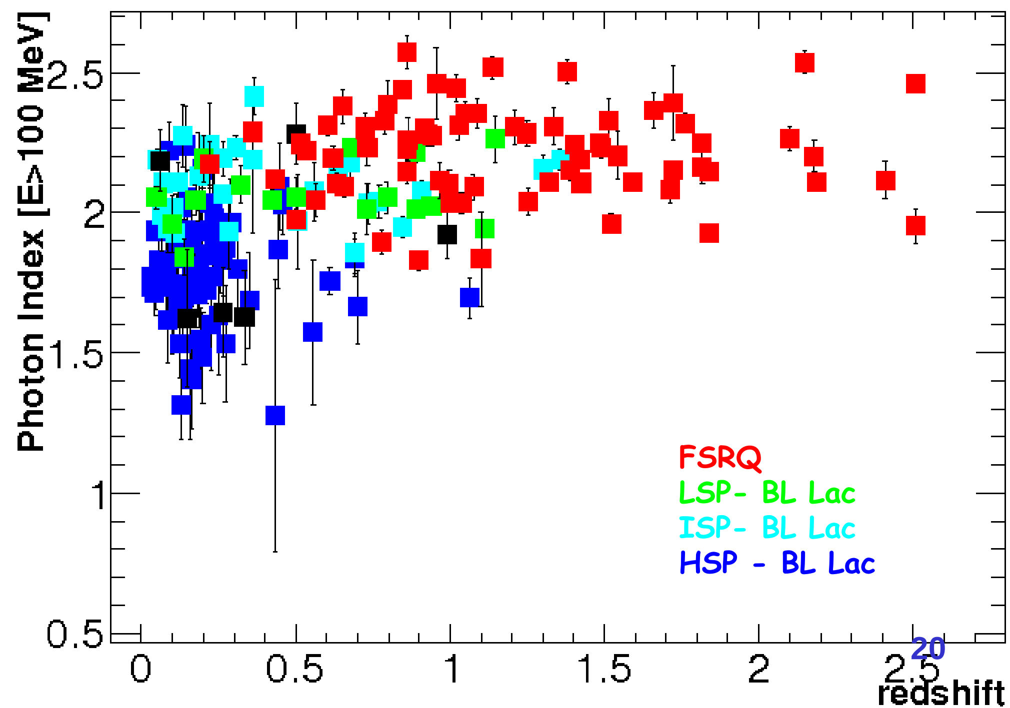
High-z FSRQs tend to be softer

Not observed when considering photon index above 100 MeV

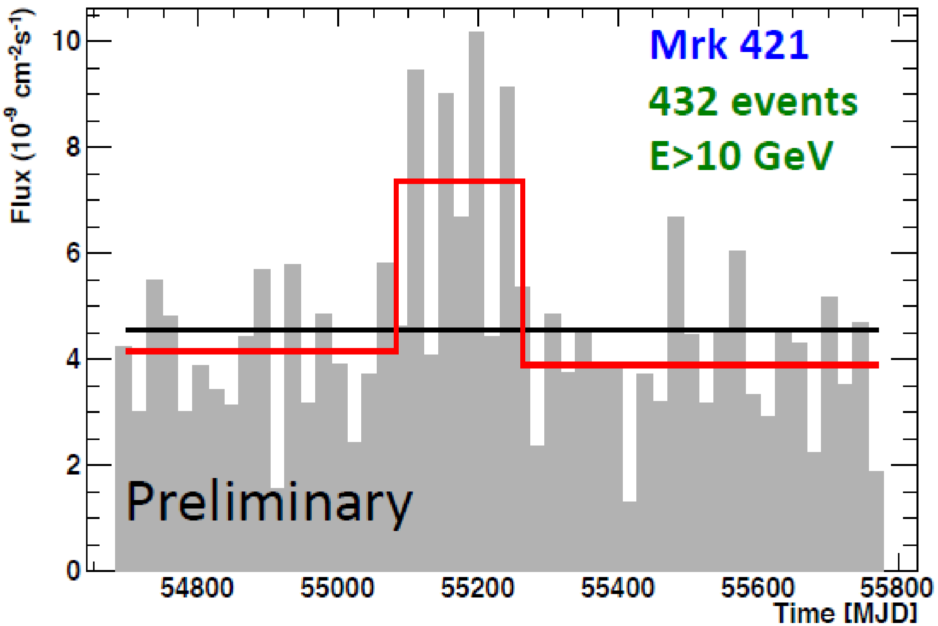
Possibly due to **attenuation by EBL**

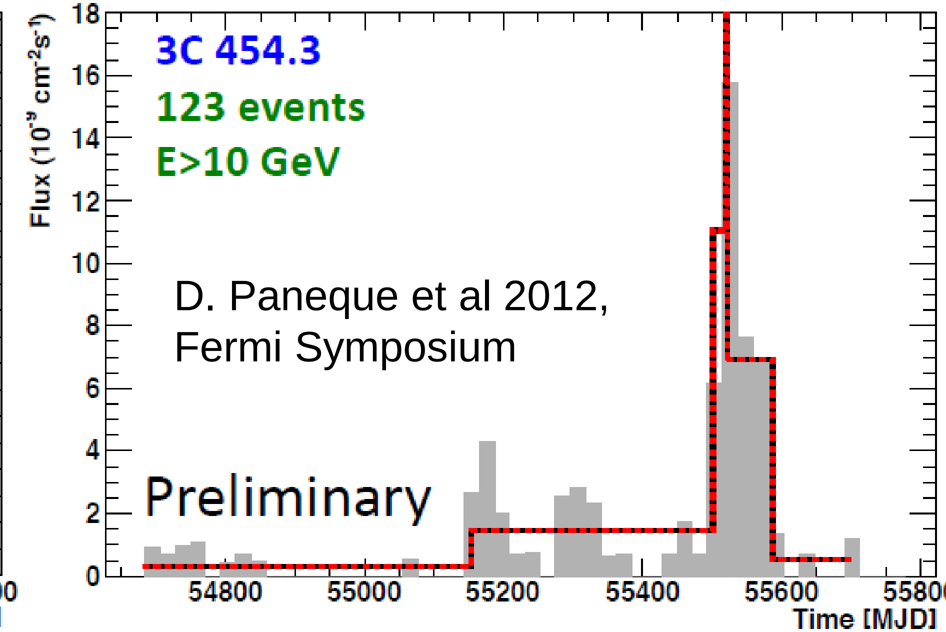
Ackermann et al 2013, ApJS **209**, 34





AGN > 10 GeV: variability





Variability not detected in Mrk 421 with 1% false positive threshold (Bayesian blocks)

Very strong variability of falling edge of Compton bump of FSRQs

Fermi sees **long time scales**, but short time scales not reachable for most sources

TeV instruments can characterize short term (but not long term) variability

GeV and TeV observations are very complementary for statistical studies

AGN: variability

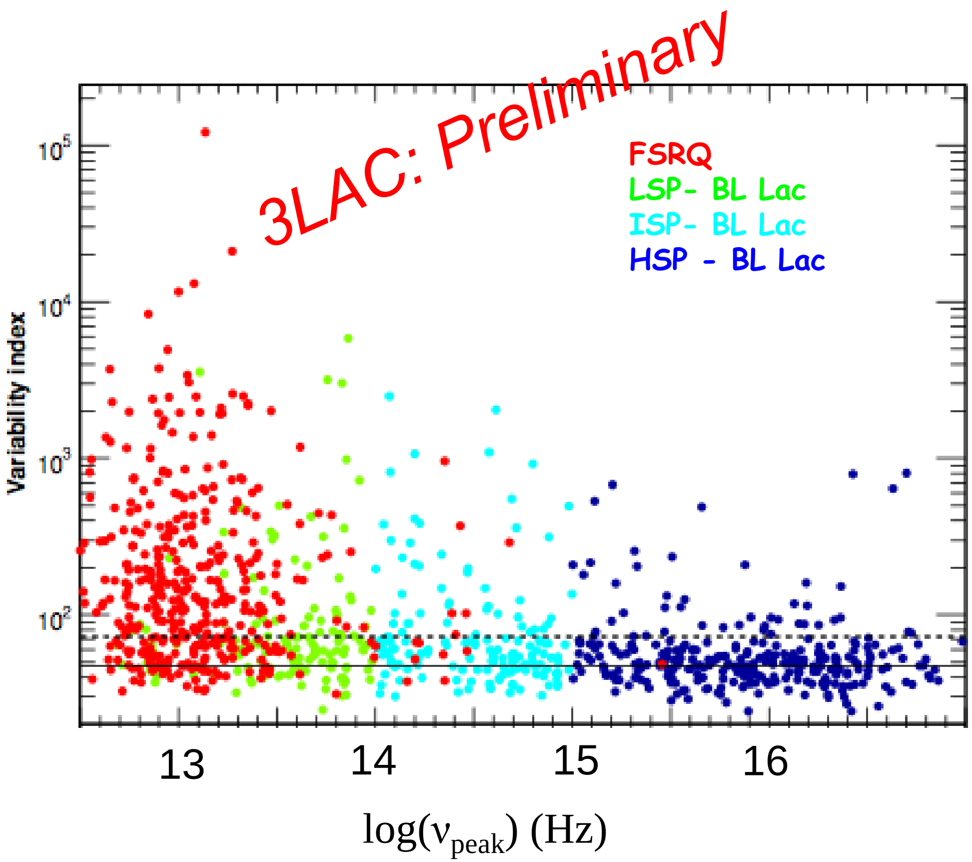
Automated search for **flaring sources** on 6 hour, 1 day and 1 week timescales

200 Astronomers Telegrams

Detects flaring sources at low energy, TeV behavior can be guessed from average spectrum

FSRQs more variable than BL Lacs

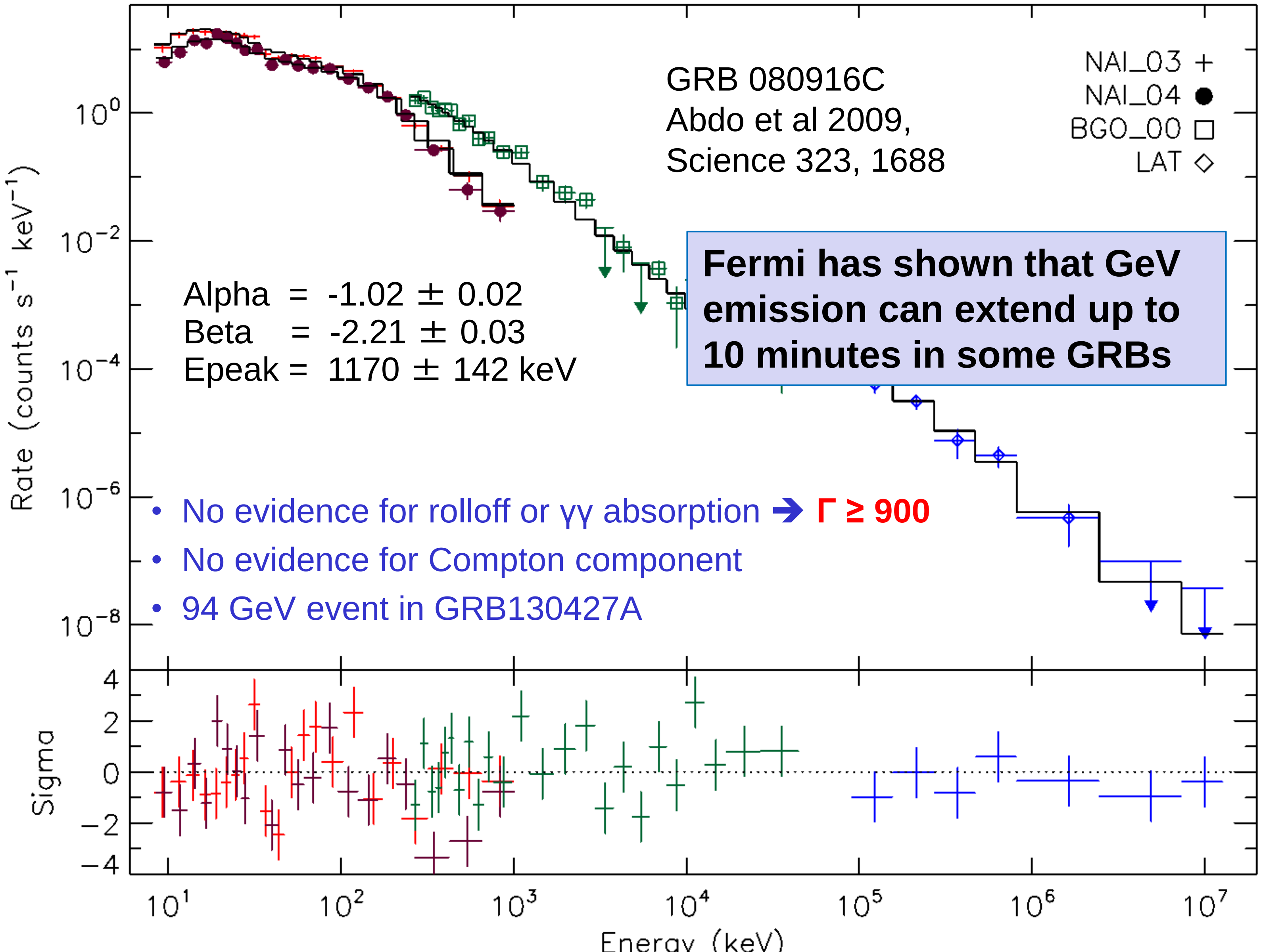
The most variable part of the spectrum corresponds to the highest energy electrons



Fermi is an excellent all-sky monitor, but not that good for TeV variability

Monthly time scale
S. Cutini et al.,
BOHEME meeting 2014

Gamma-ray Bursts



Fermi has shown that GeV emission can extend up to 10 minutes in some GRBs

- No evidence for rolloff or γγ absorption ➔ **Γ ≥ 900**
- No evidence for Compton component
- 94 GeV event in GRB130427A

Fermi at high energy

- Spatial resolution 0.2° limiting in Galactic plane
- Detects > 500 sources above 10 GeV
- All-sky survey: reservoir of TeV targets
- Good prospects for hard sources with increasing exposure
- Excellent GeV – TeV complementarity for SNRs
- PWN: can detect pulsar inside and measure power
- AGN: blazar sequence, variability over long time scales
- GRBs await detection at TeV energies. Need to be fast.

NASA senior review advised extension up to end 2018

But not indefinitely; no other GeV instrument in sight, but most studies do not require observations at the same time

Backup slides

AGN: GeV - TeV connection

Compare **spectral index** rather than flux

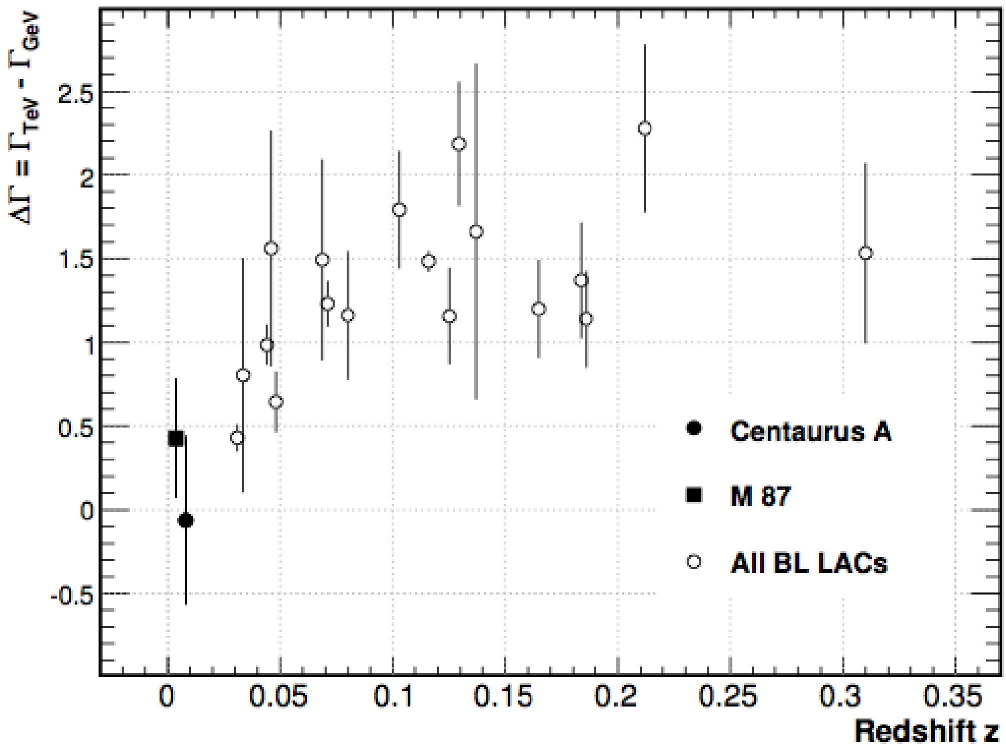
39/45 TeV AGNs are in the 2LAC (34 in clean sample)

26 AGN are well fitted with simple power law in the LAT band

17 HSP, 2 ISP, 2LSP, 5 unknown

Deficit of distant sources with small values of ΔΓ

EBL: softening of the VHE spectrum dependent on z



B. Lott at Fermi meets Jansky 2011
Updated from Abdo et al. 2009, ApJ 707, 1310

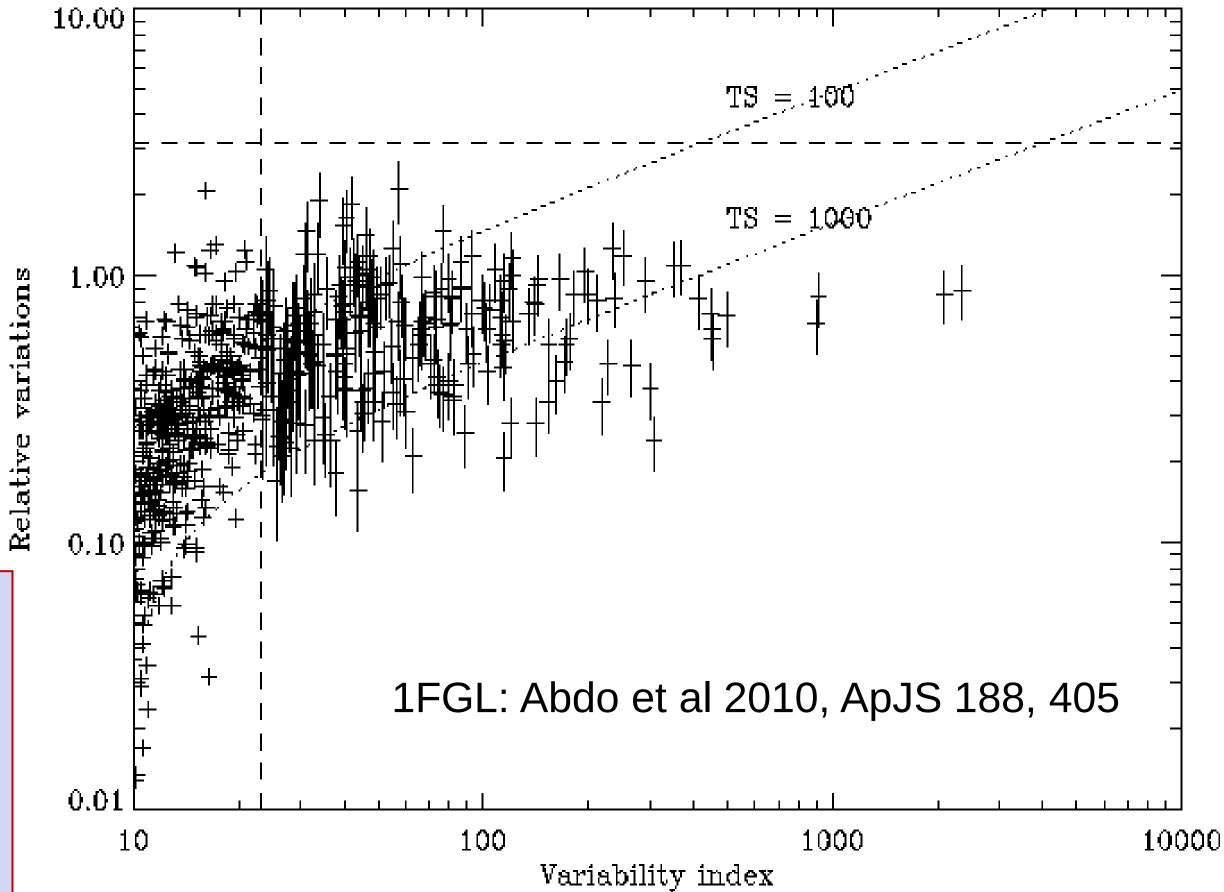
AGN: variability

When variability is detected, **large relative variations**

Fermi can characterize variability on **long time scales** but short time scales not reachable for most sources

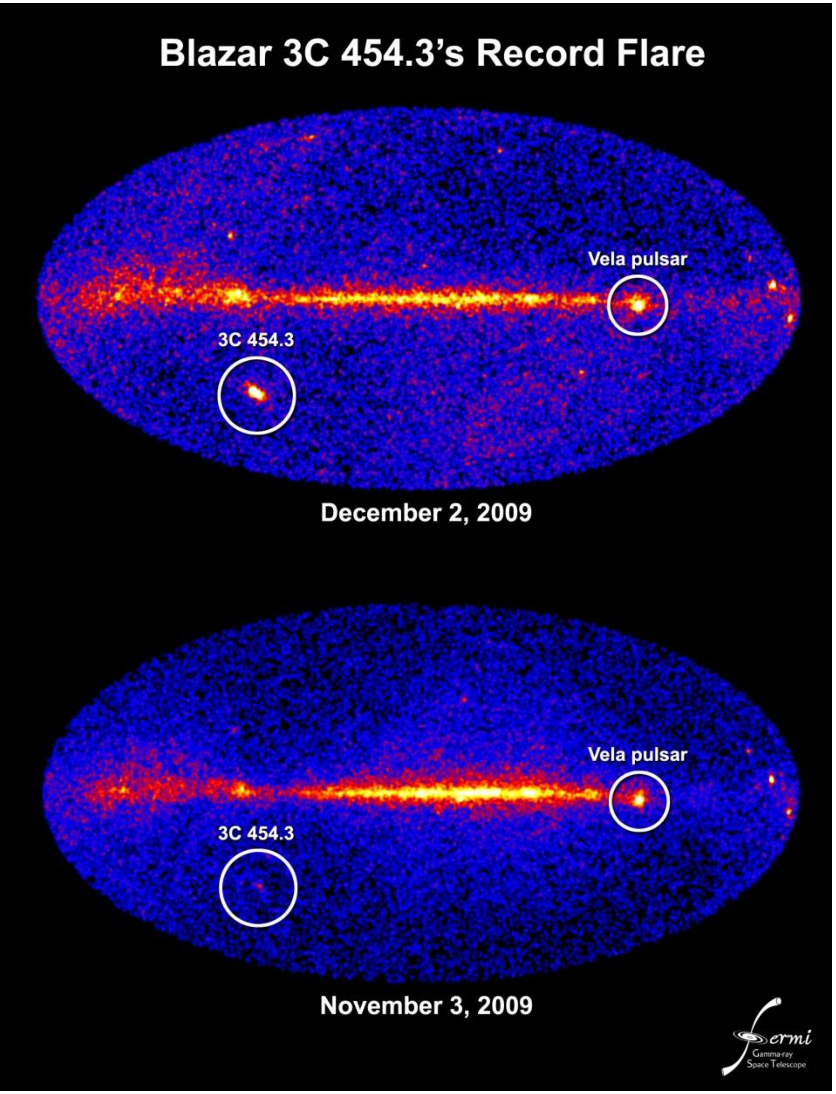
TeV instruments can characterize short term (but not long term) variability

GeV and TeV observations are very complementary for statistical studies



1FGL: Abdo et al 2010, ApJS 188, 405

Flaring sources



- **Automated search for flaring sources on 6 hour, 1 day and 1 week timescales.**
  - **LAT scientists perform follow-up analyses, produce ATels, and propose ToOs**
- **>200 Astronomers telegrams**
  - **Discovery of new gamma-ray blazars**
  - **Flares from known gamma-ray blazars**

Fermi is an excellent all-sky monitor

Detects flaring sources at low energy

TeV behavior can be guessed from average spectrum

Most (like this one) are soft