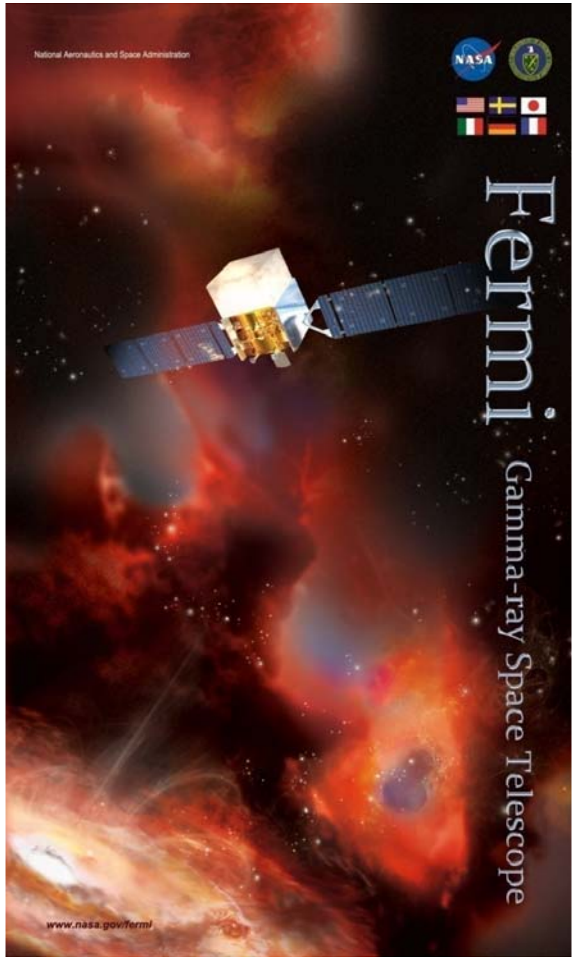
2015.3.22 日米物理学会

Gamma-Ray Observations with Fermi Gamma-ray Space Telescope and CTA

fermi
Gamma-ray Space Telescope



Yasushi Fukazawa

Hiroshima University

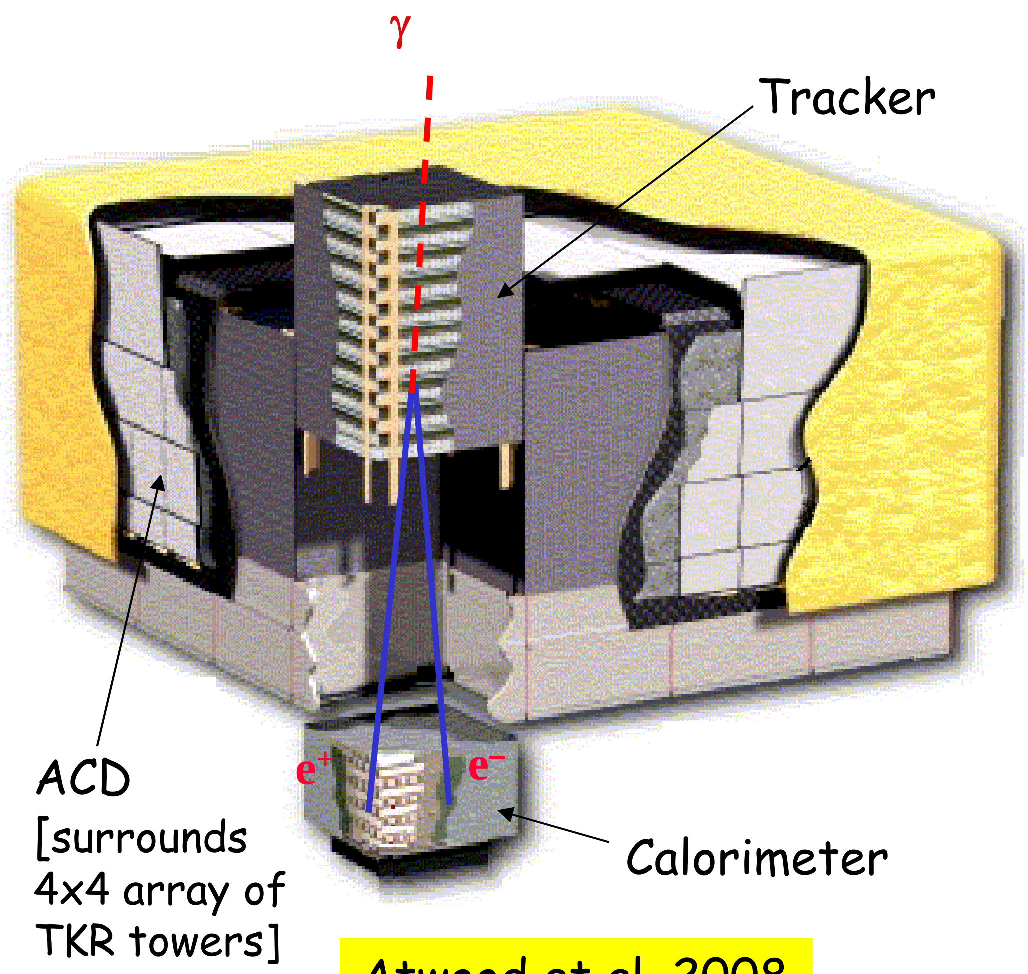
Contents

- Introduction to Fermi-LAT
- Recent highlights and Catalogs
- Supernova Remnants
- Blazars and Other AGNs

Most of unpublished results are referred to the slides at the 5th Fermi Symposium web site:
http://fermi.gsfc.nasa.gov/science/mtgs/symposia/2014/program/

Overview of LAT: How it works

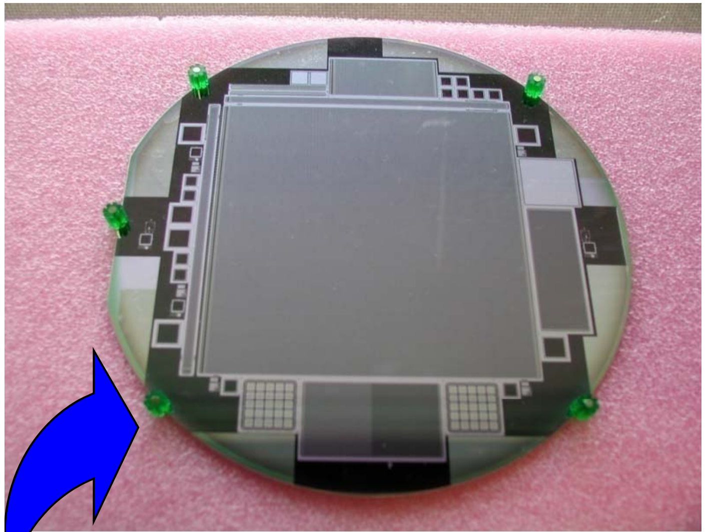
- Precision Si-strip Tracker (TKR) Measure the photon direction; gamma ID.
- Hodoscopic CsI Calorimeter (CAL) Measure the photon energy; image the shower.
- Segmented Anticoincidence Detector (ACD) Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.
- Electronics System Includes flexible, robust hardware trigger and software filters.



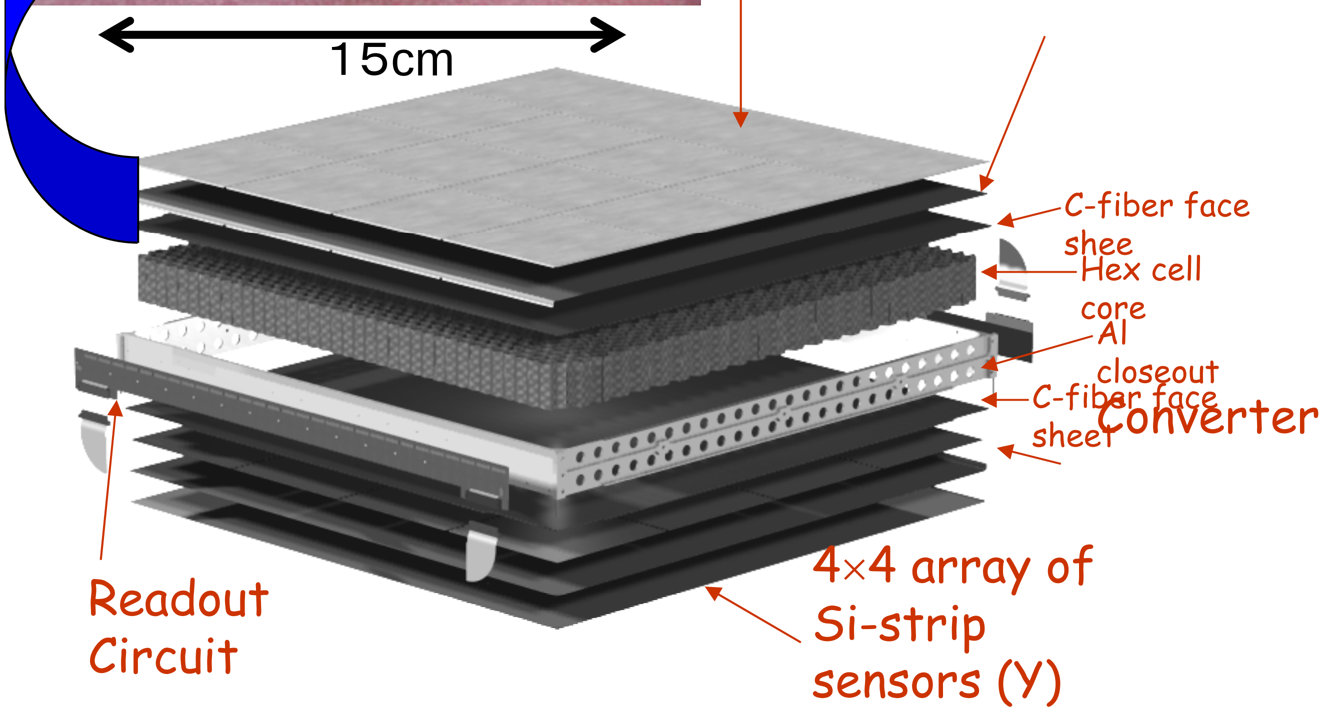
Atwood et al, 2008

Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.

Tracker Module Mechanical Design



Developed
by Hiroshima Univ.



16 identical towers

36 layers

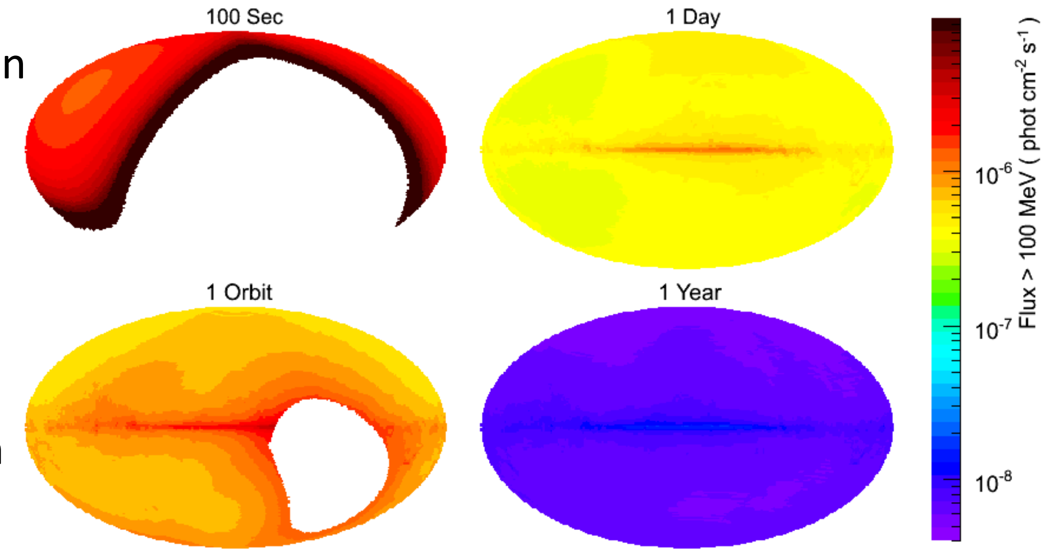
6.7 years have passed since launch!

All-sky survey is continuing without any significant problems of satellite and instrument.

- Launch from Cape Canaveral Air Station 11 June 2008 at 12:05PM EDT
- Circular orbit, 565 km altitude (96 min period), 25.6 deg inclination.

Operating modes

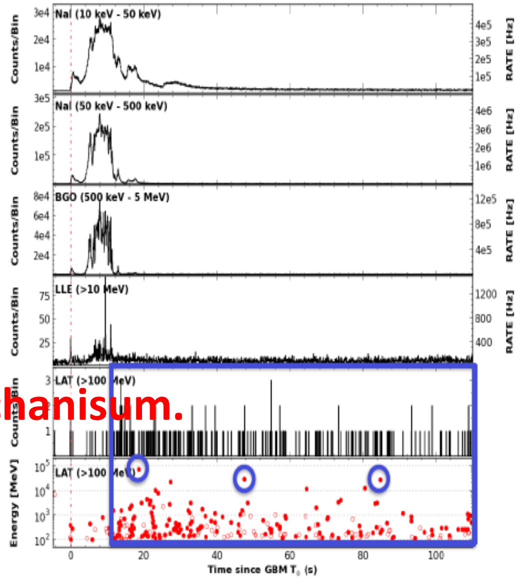
- Primary observing mode is Sky Survey
  - Full sky every 2 orbits (3 hours)
  - Uniform exposure, with each region viewed for ~30 minutes every 2 orbits
  - Best serves majority of science, facilitates multiwavelength observation planning
  - Exposure intervals commensurate with typical instrument integration times for sources
  - EGRET sensitivity reached in days



- **Pointed observations when appropriate (selected by peer review in later years) with automatic earth avoidance selectable. Target of Opportunity pointing.**
- **Autonomous repoints for onboard GRB detections in any mode.**

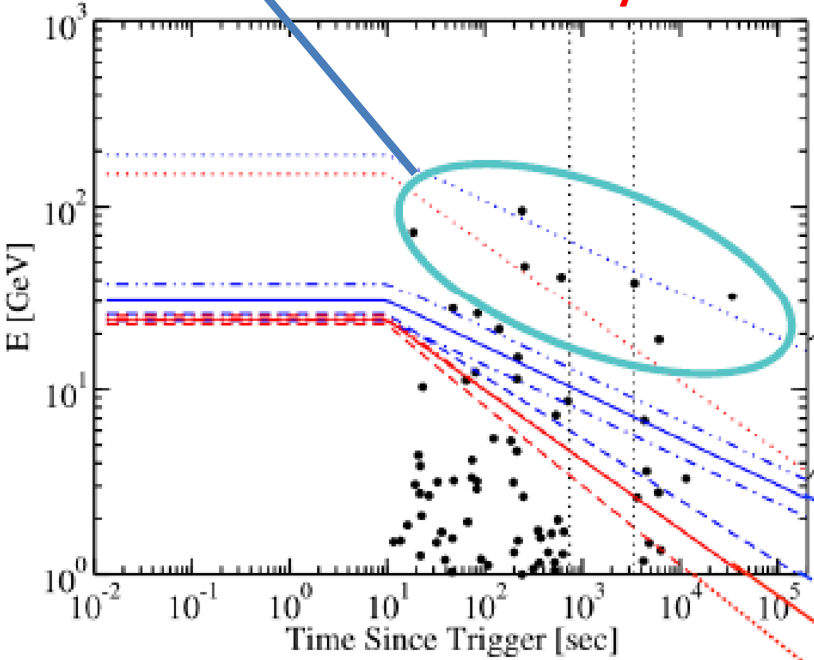
GeV-brightest gamma-ray burst GRB130427A (Science Magazine)

Ackermann+14
Preece+14
Racusin+14



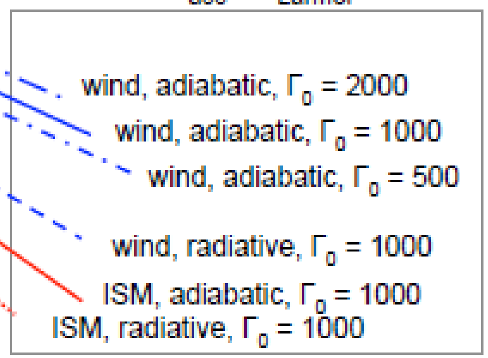
Detection of the highest energy gamma-ray than ever
Detection of 50GeV gamma-rays after several hours

Synchrotron cannot explain.
Need very fact acceleration mechanism.



extremely fast acceleration (less realistic)
$t_{acc} \sim t_{Larmor}/2\pi$

$t_{acc} \sim t_{Larmor}$

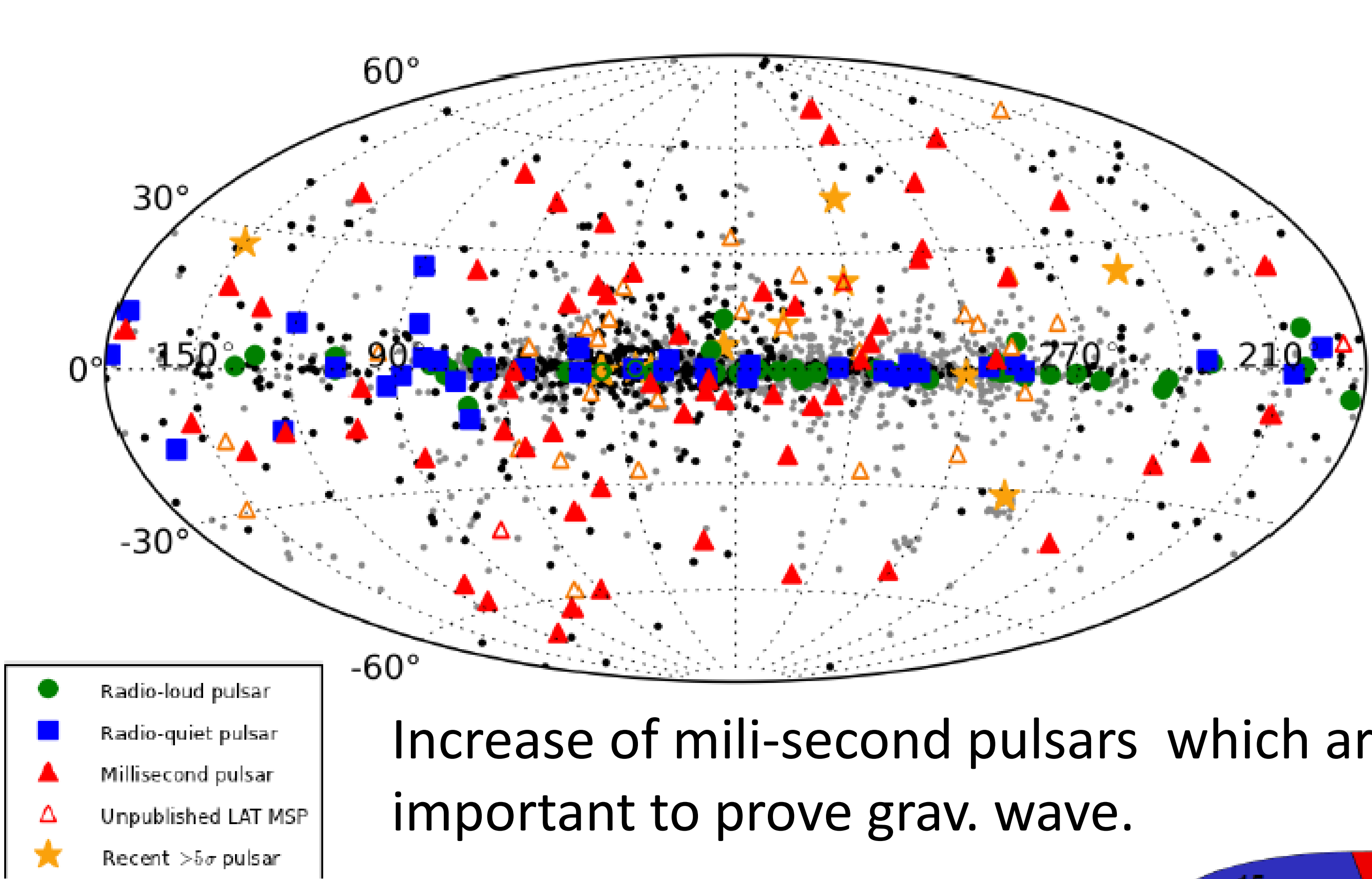


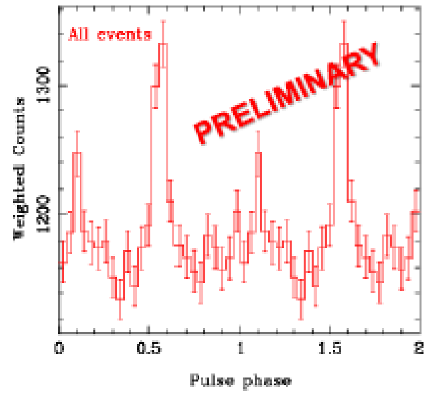
Lorentz Invariance Violation

Abdo+10
Vasileiou+15

- **The high-energy LAT-detected photons violate maximum synchrotron energy for even the most extreme models**
- **Requires modifications to standard Synchrotron shock physics or alternative model (Non-uniform magnetic field, Diffusive shock acceleration, magnetic reconnection, Electromagnetic cascades)**

Up to 160 gamma-ray pulsars have been discovered !

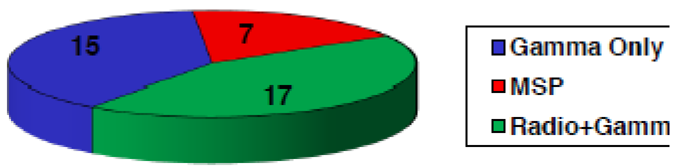




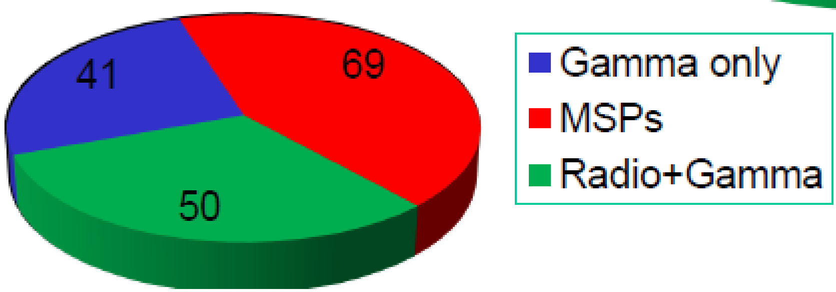
Laffon+14

Increase of mili-second pulsars which are important to prove grav. wave.

2009, R. Romani (AAS conf.)



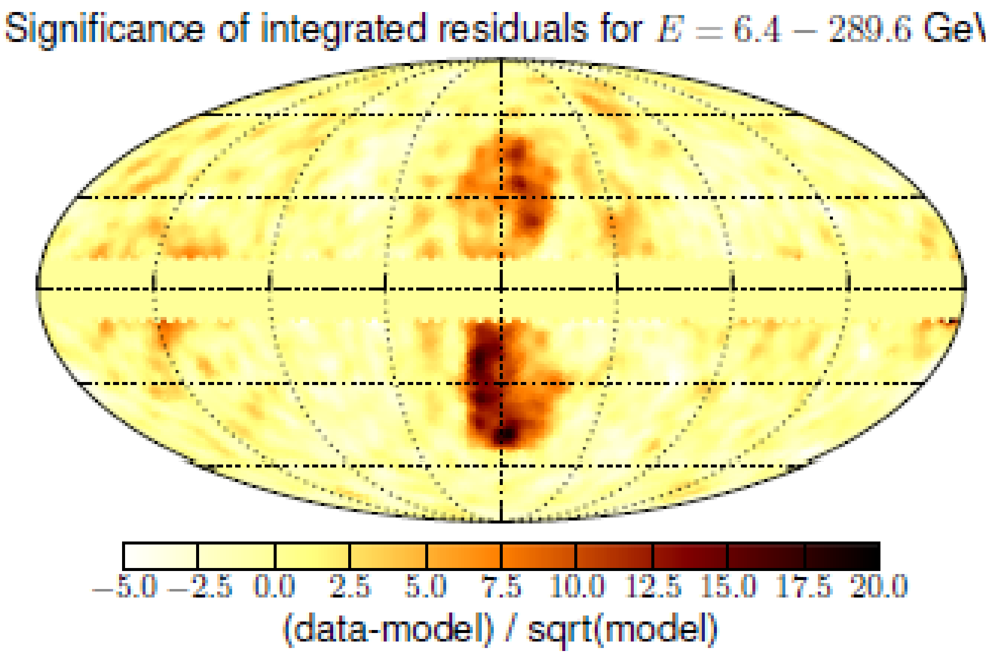
2014



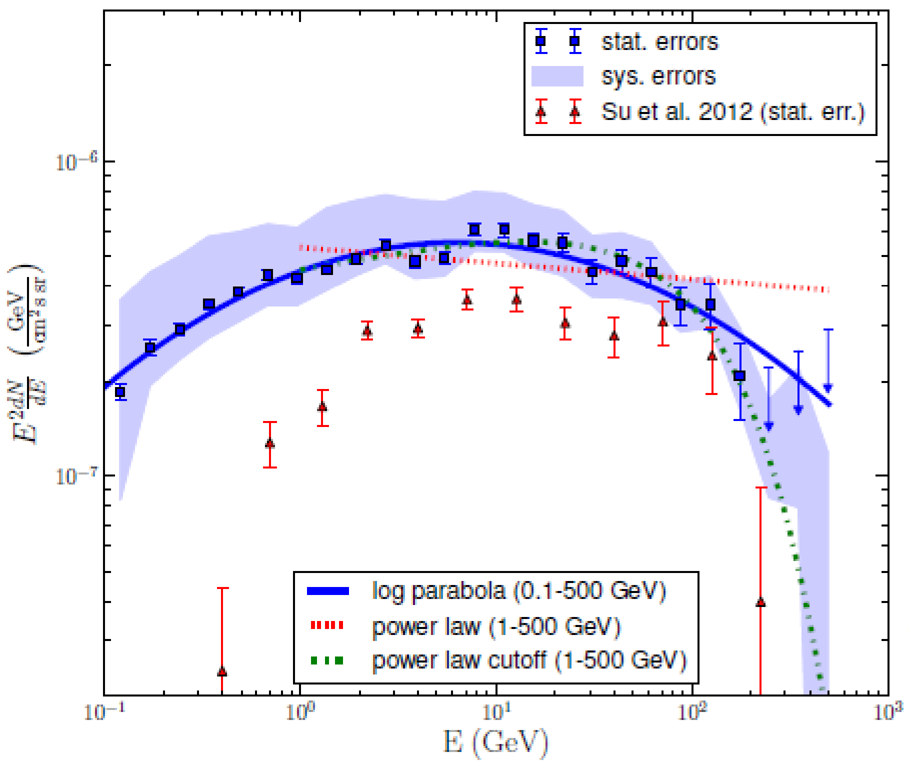
Accurate measurement of Lobe-like structure of our Galaxy
（Fermi Bubble）

Very important phenomena in high-energy astrophysics

New source of cosmic-ray acceleration



Ackermann+14



Origin of Fermi Bubble ?

Franckowiak+14

Leptonic / Hadronic Summary

	Leptonic	Hadronic
• **Gamma-ray spectrum**	☺	☺
• **Microwave haze**	☺	☹
• **No spectral changes**	☹	☺
• **Narrow boundary**	☺	☹
• **Absence of a visible shock front**	☹	☺

Possible leptonic scenario: (Mertsch, Sarkar, Guo, Mathews etc.):

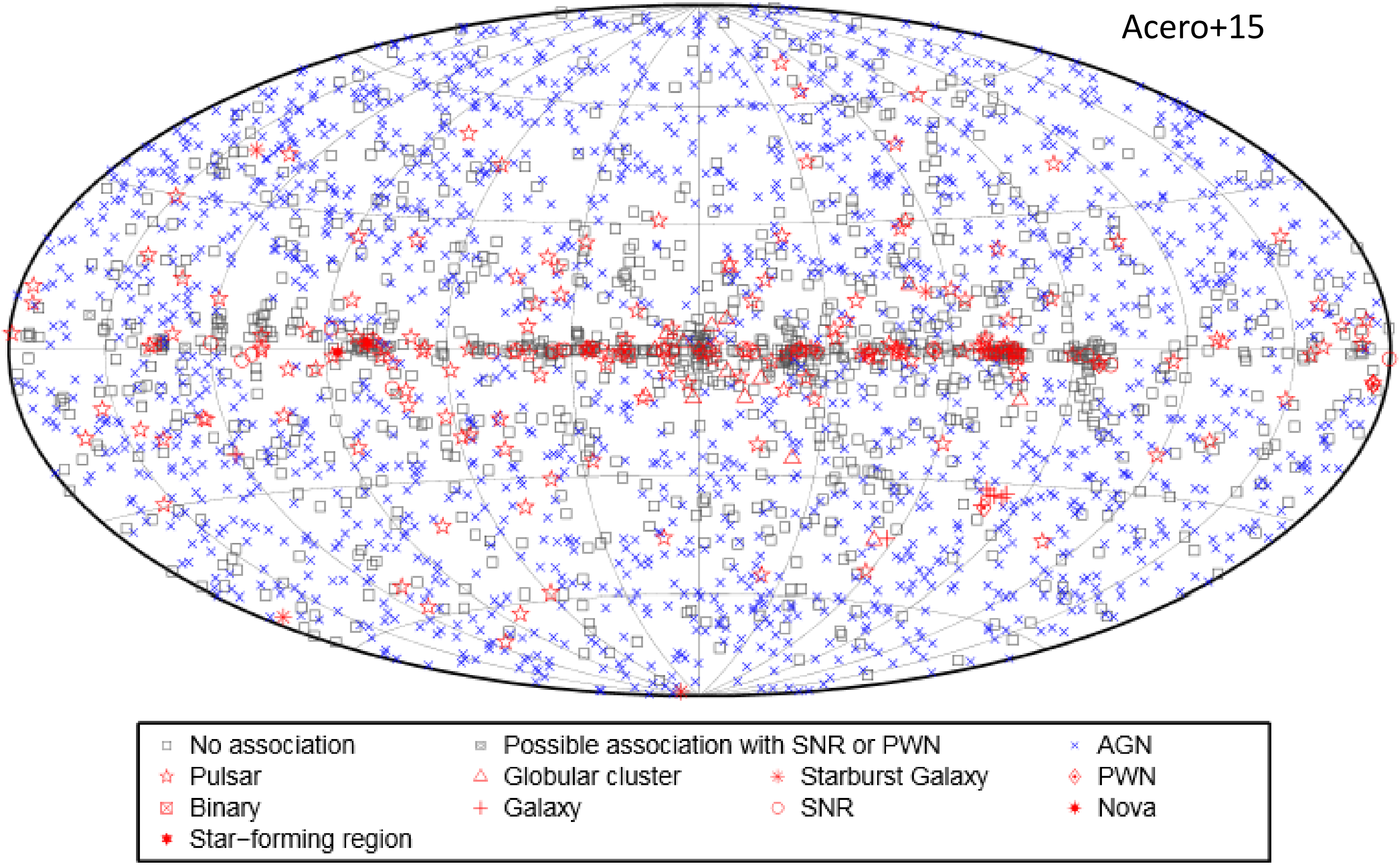
- Jets from the black hole create shock front
- Shock front dissipates, but leaves plasma turbulences behind
- Electrons are accelerated on the turbulences with a characteristic time less than the cooling time

Possible hadronic scenario: (Crocker, Aharonian):

- Wind from SNRs produces CR during several billions of years
- Magnetic fields confine the CR in the bubble volume
- WMAP haze produced by ~ 30 GeV electrons in the SNR wind which have a characteristic cooling time ~ 10 Myr

Fermi-LAT 3rd Catalog in public

Contain >3000 gamma-ray sources detected in 4 year survey



More Fermi-LAT Catalogs

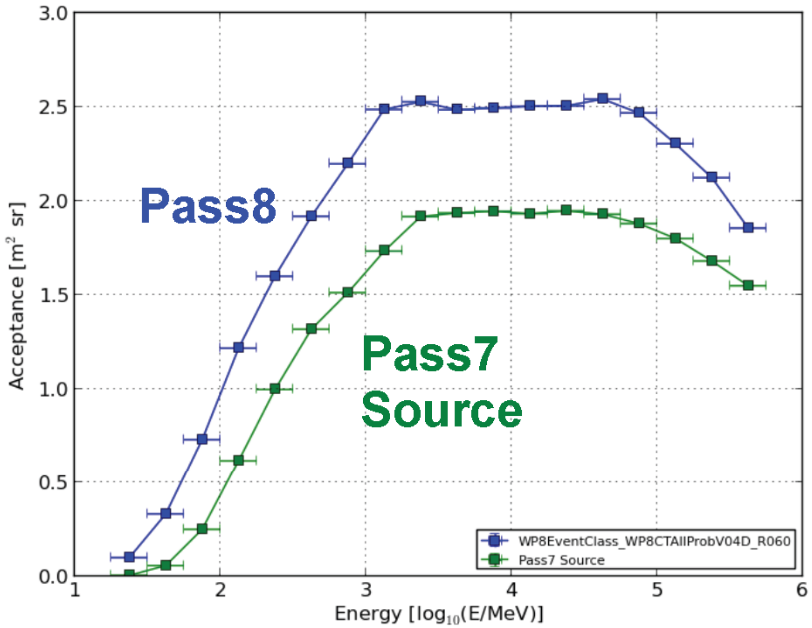
- 3FGL (4 years, P7REP): general catalog (3033 sources)
- 3LAC (based on 3FGL): AGN catalog (1591 sources)
- SNR (3 years, P7): 32 sources (out of the 289 in the Green catalog)

- 2FHL: (will be in public)
  - >6 years of P8 data
  - 50 GeV<E<2 TeV
  - 350 sources (238 in 1FHL, 300 in 3FGL, 84 seen by ACTs)

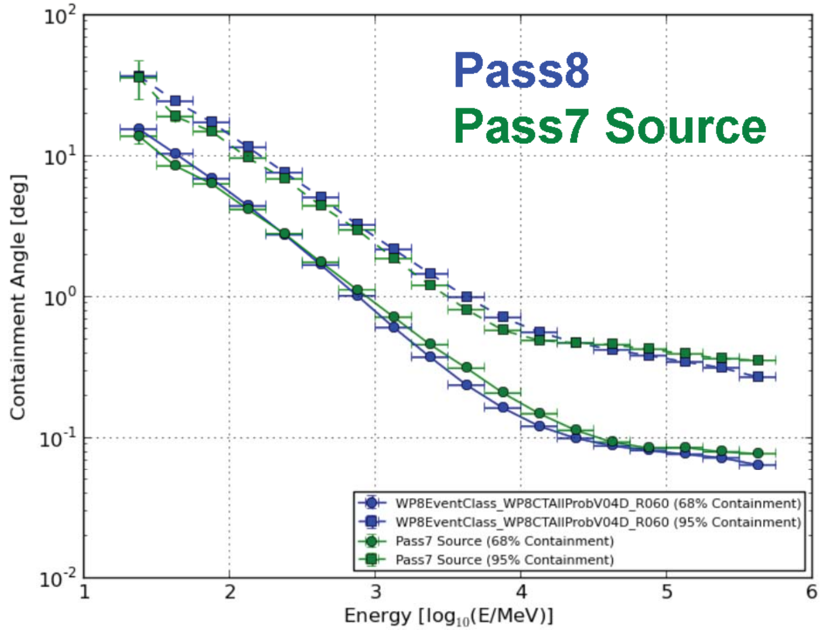
- 1st GRB Catalog (Ackermann+13)
- 2nd Pulsar Catalog (Abdo+13)

Start of data analysis using new reconstruction algorithm(PASS8)
(PASS-8 data will be public soon.)

Acceptance

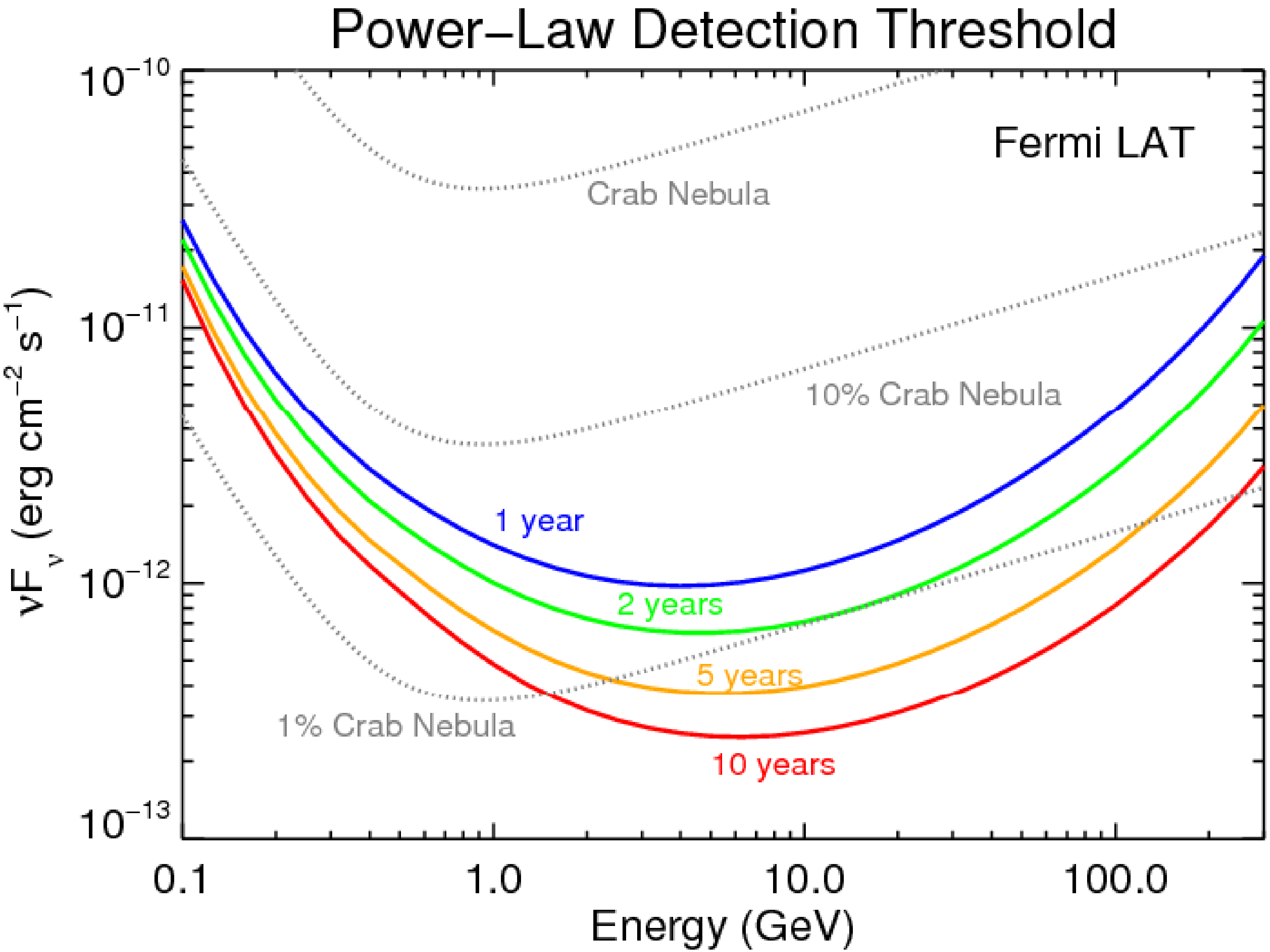


Point Spread Function



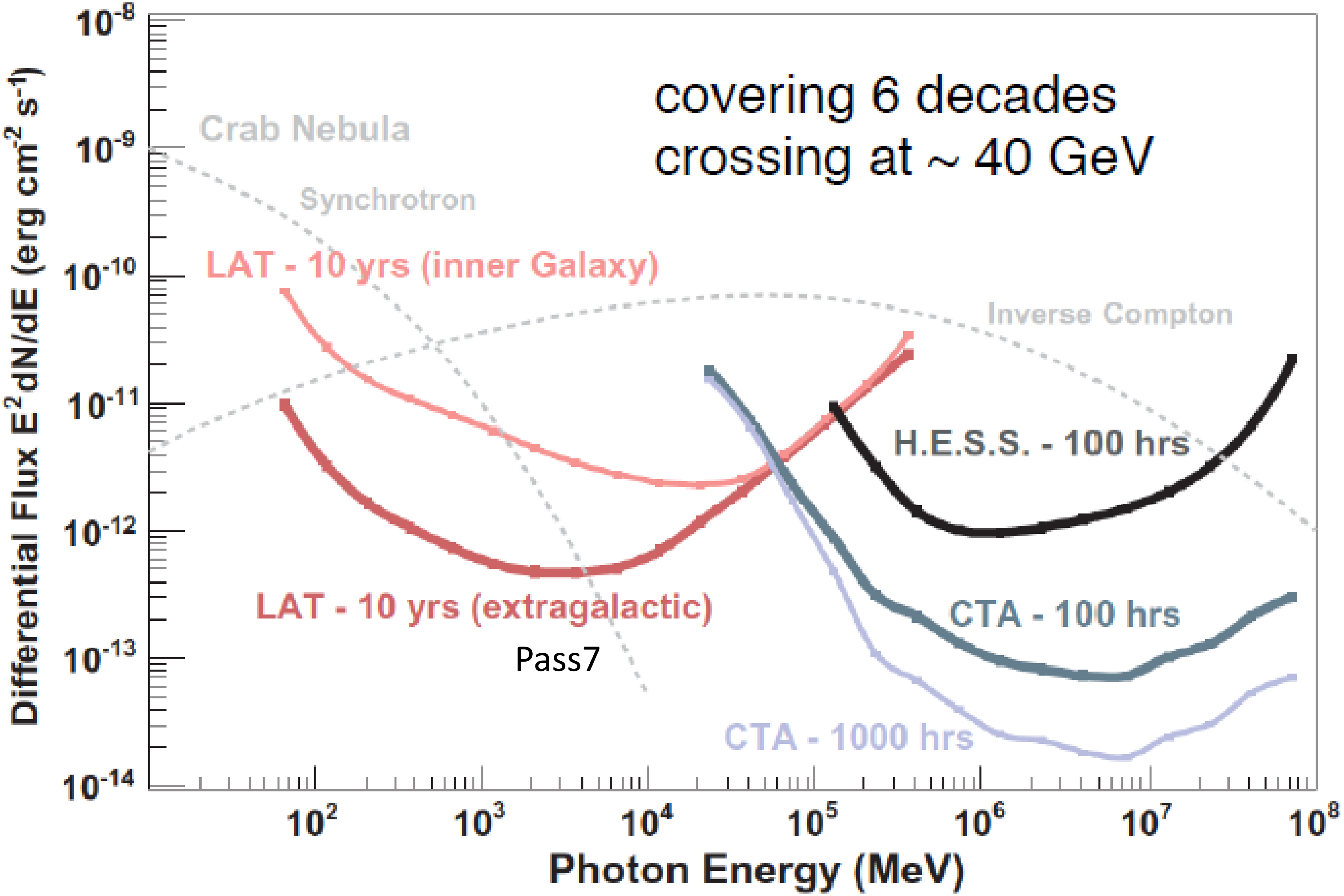
2/26/13 LAT Collabor

Sensitivity Improvement



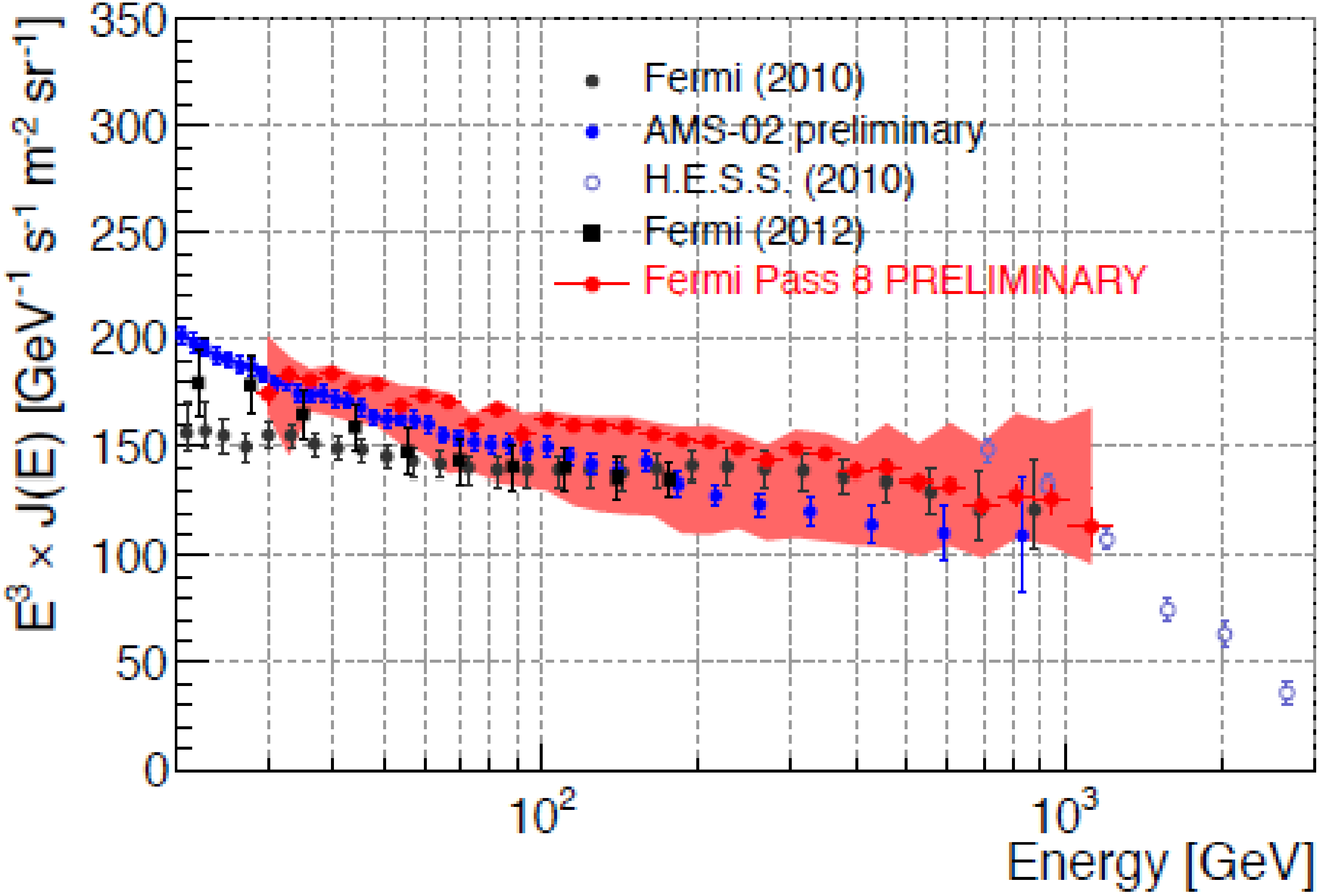
sensitivity

Funk & Hinton (2013

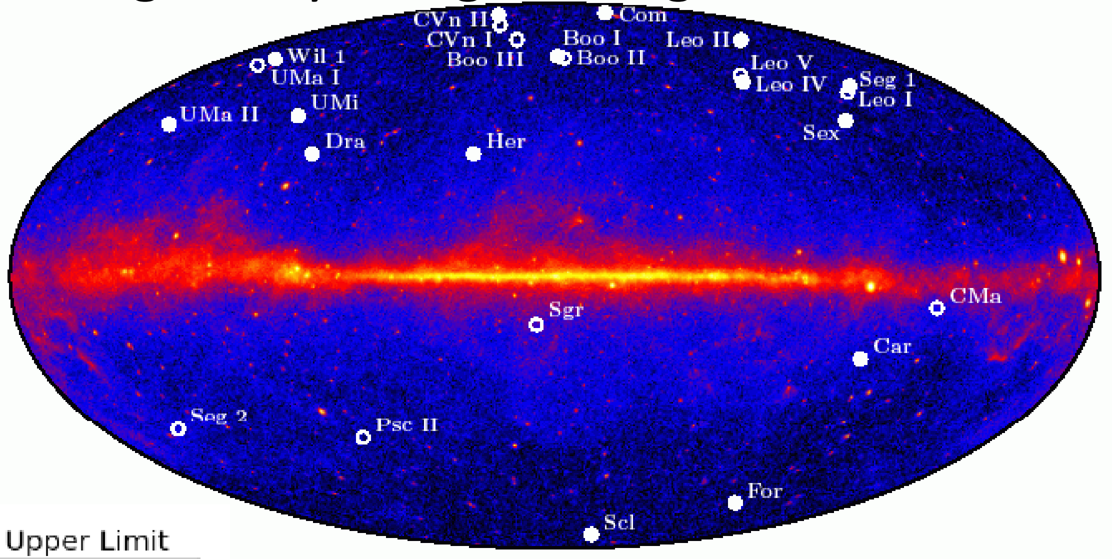


New measurement of cosmic e+e- spectrum exceeding 1 TeV

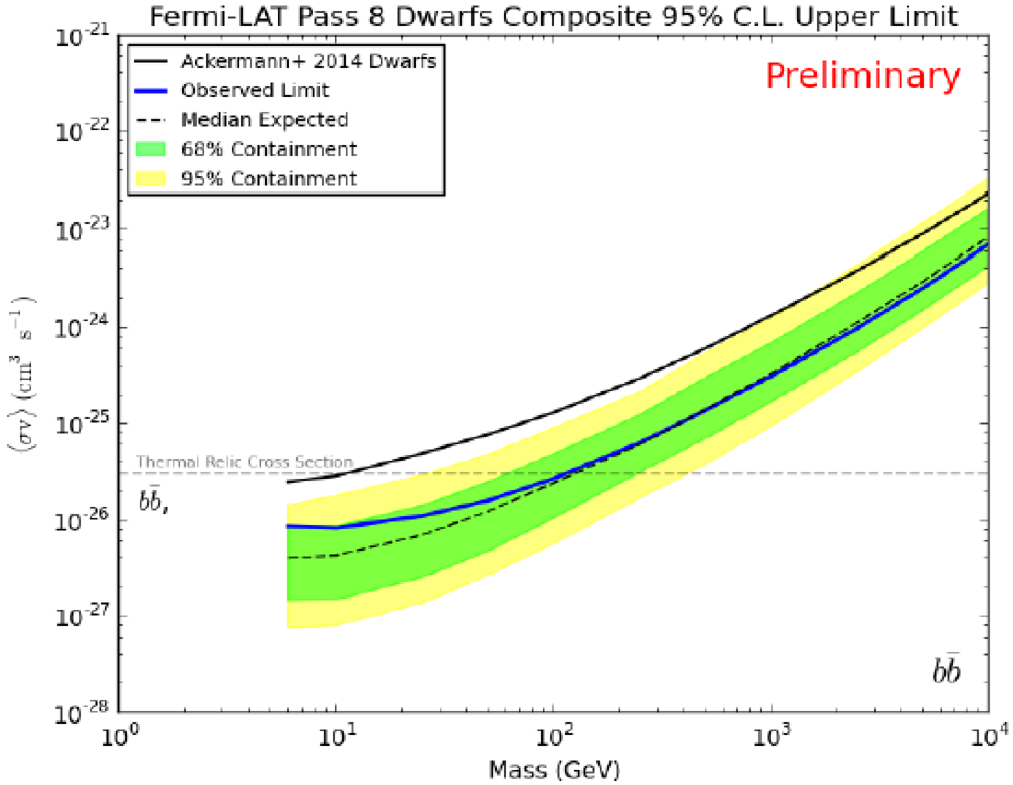
Sgro+14



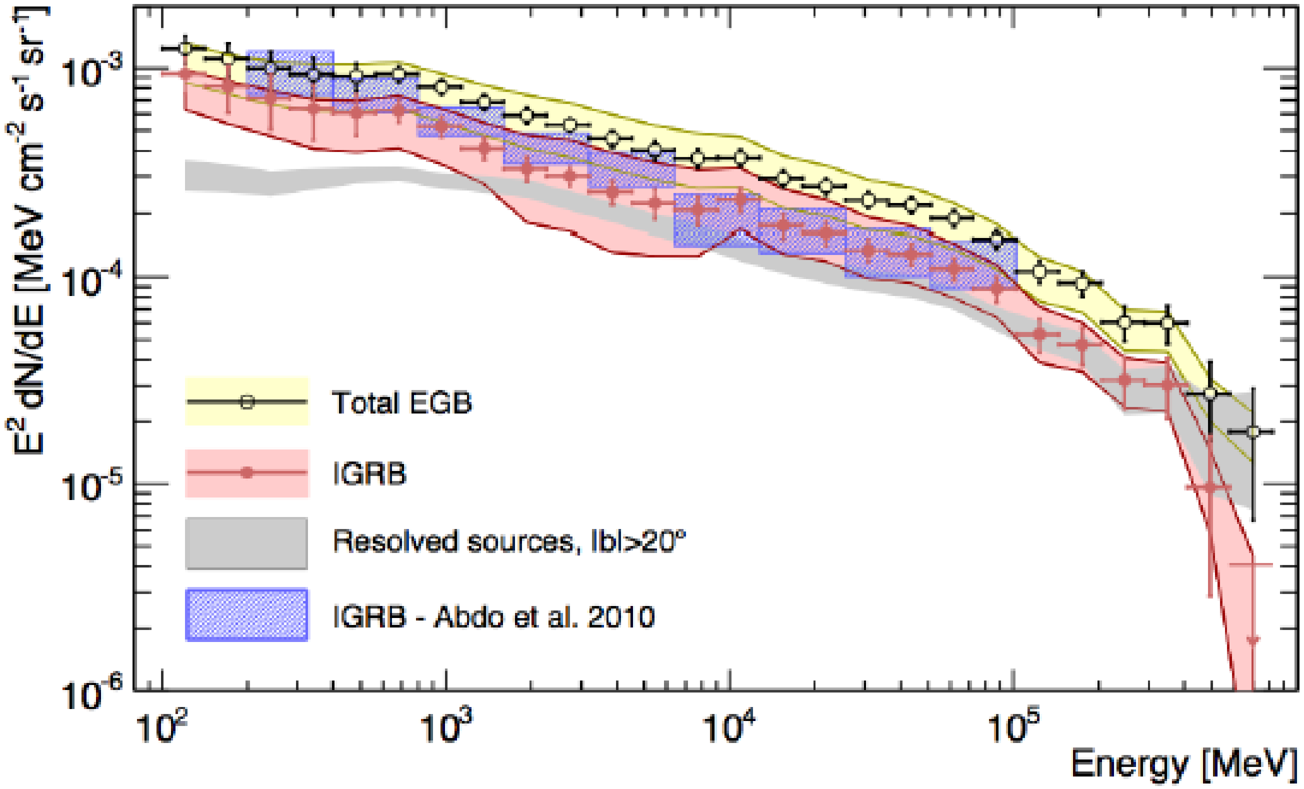
Progress of limit on dark matter signal, by using dwarf galaxies



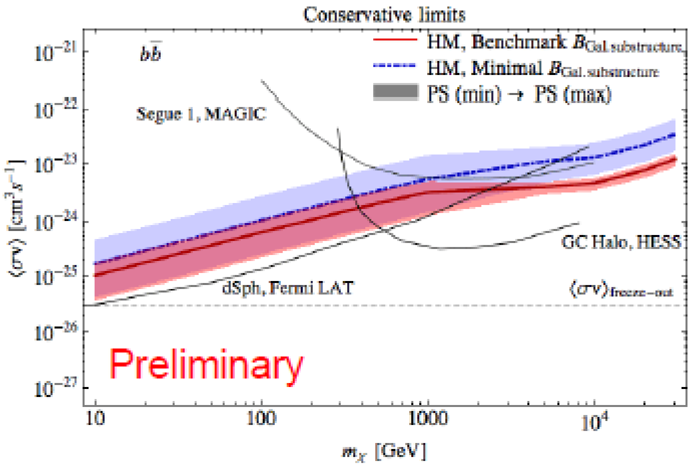
Anderson+14



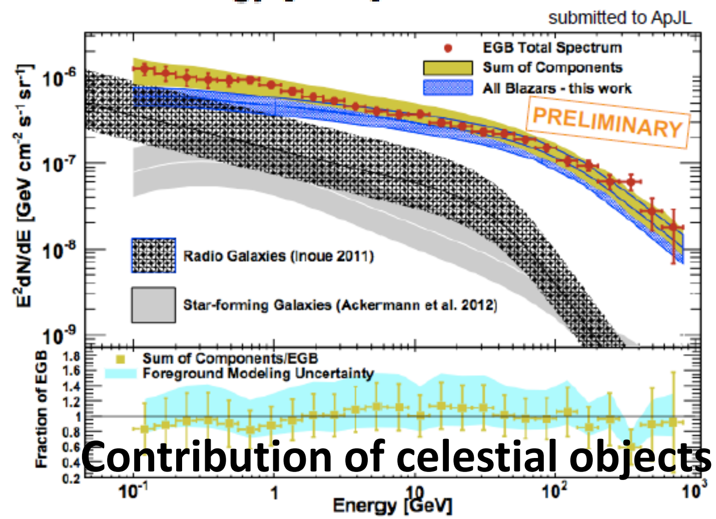
Accurate measurement of isotropic diffuse gamma-ray background



Limit on dark matter



Wood+14

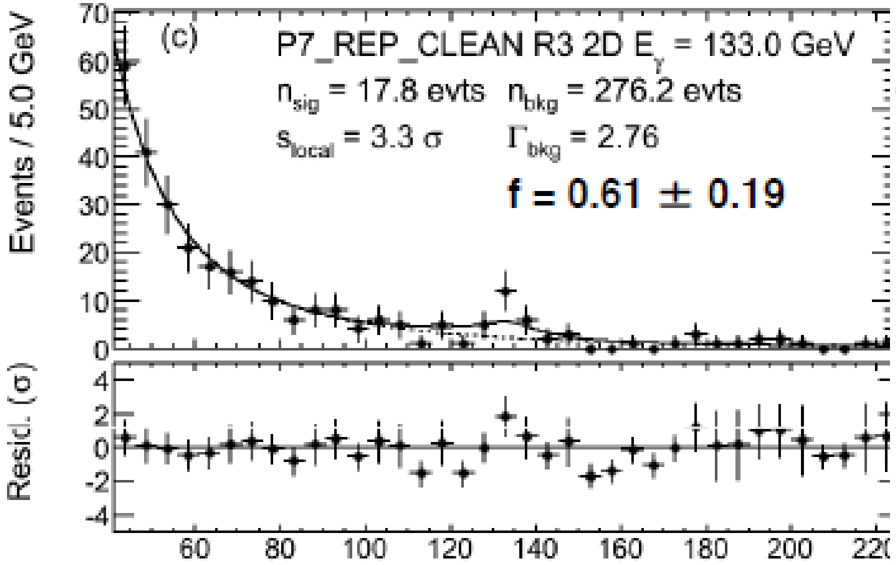


Contribution of celestial objects

Albert+14

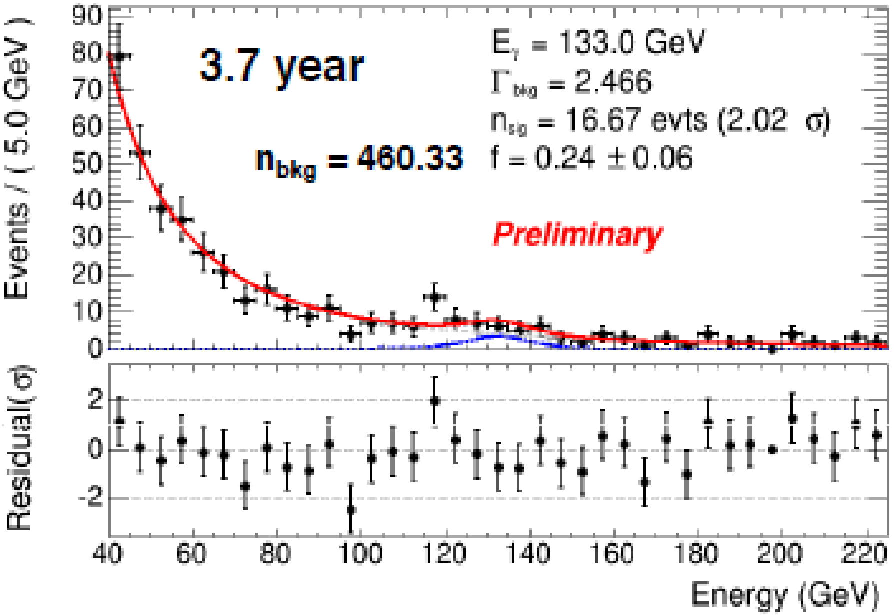
Line-like Feature near 133 GeV

P7REP_Clean



Ackerman et al. (The Fermi LAT Col.)
PRD 88, 082002 (2013)

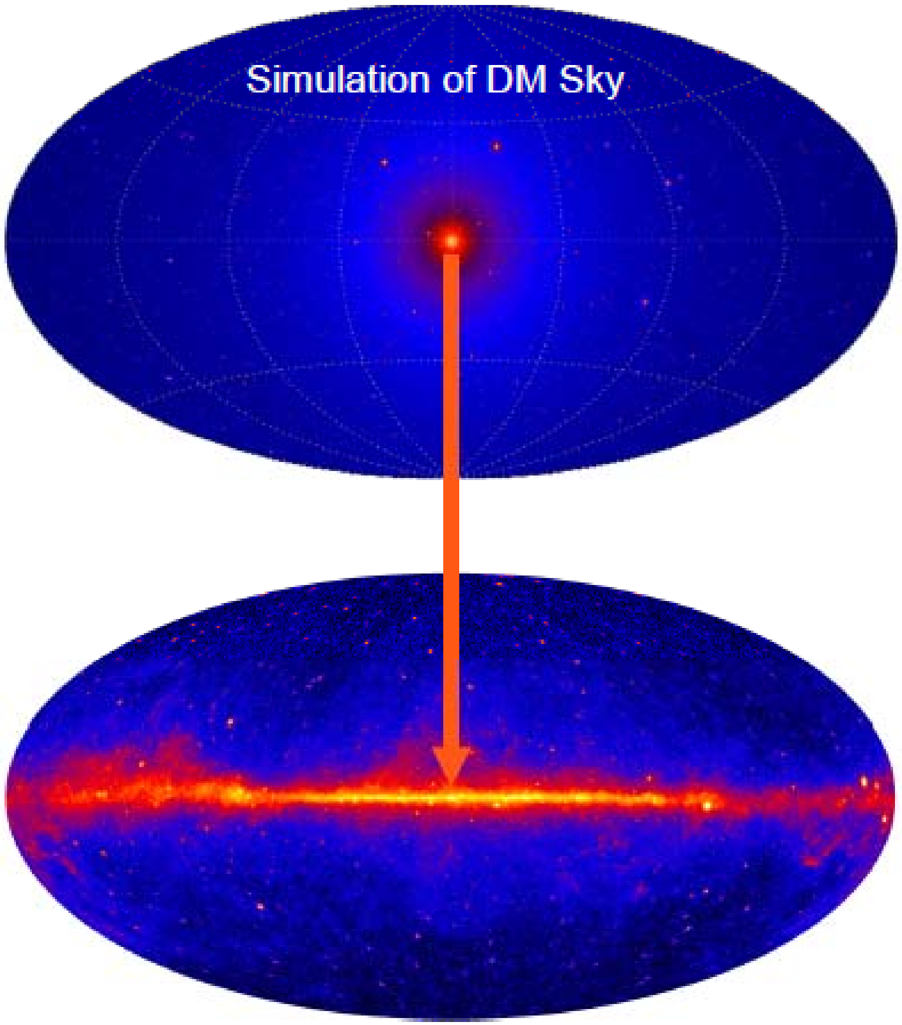
P8_Clean



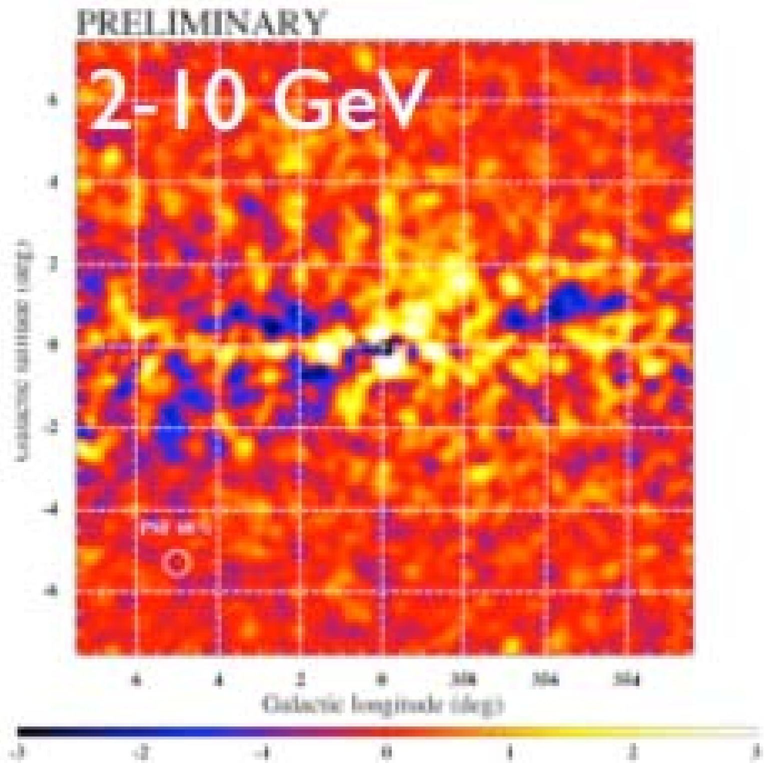
- Same fit parameters as 3.7 year line search (Ackerman et al. PRD 88, 082002 (2013))
  - Fits in R3, 3.7 year, $\pm 6\sigma_E$ fit window
- No strong evidence of 133 GeV Feature in Pass 8
  - Lower fractional size and significance
  - Energy recon. in P7 vs. P8 changes within expected energy resolution

Excess of GeV gamma-rays at the Galactic center ?

Currently, within the systematics.



Murgia+14



2FHL (2^{nd} Fermi Hard Source List)

Numbers are not definitive since depend on IRFs and Diffuse emission model which are subject to change

- Analysis
  - 50 GeV – 2 TeV
  - ~6 years of data
  - Pass 8

- Detections (preliminary numbers, will change somewhat)
  - ~320 sources
  - 71 detected by ACTs (TeVCat)
  - 206 detected in 1FHL
  - 234 detected in 3FGL (<- 4 years up to 300 GeV)
  - ~60 brand new sources

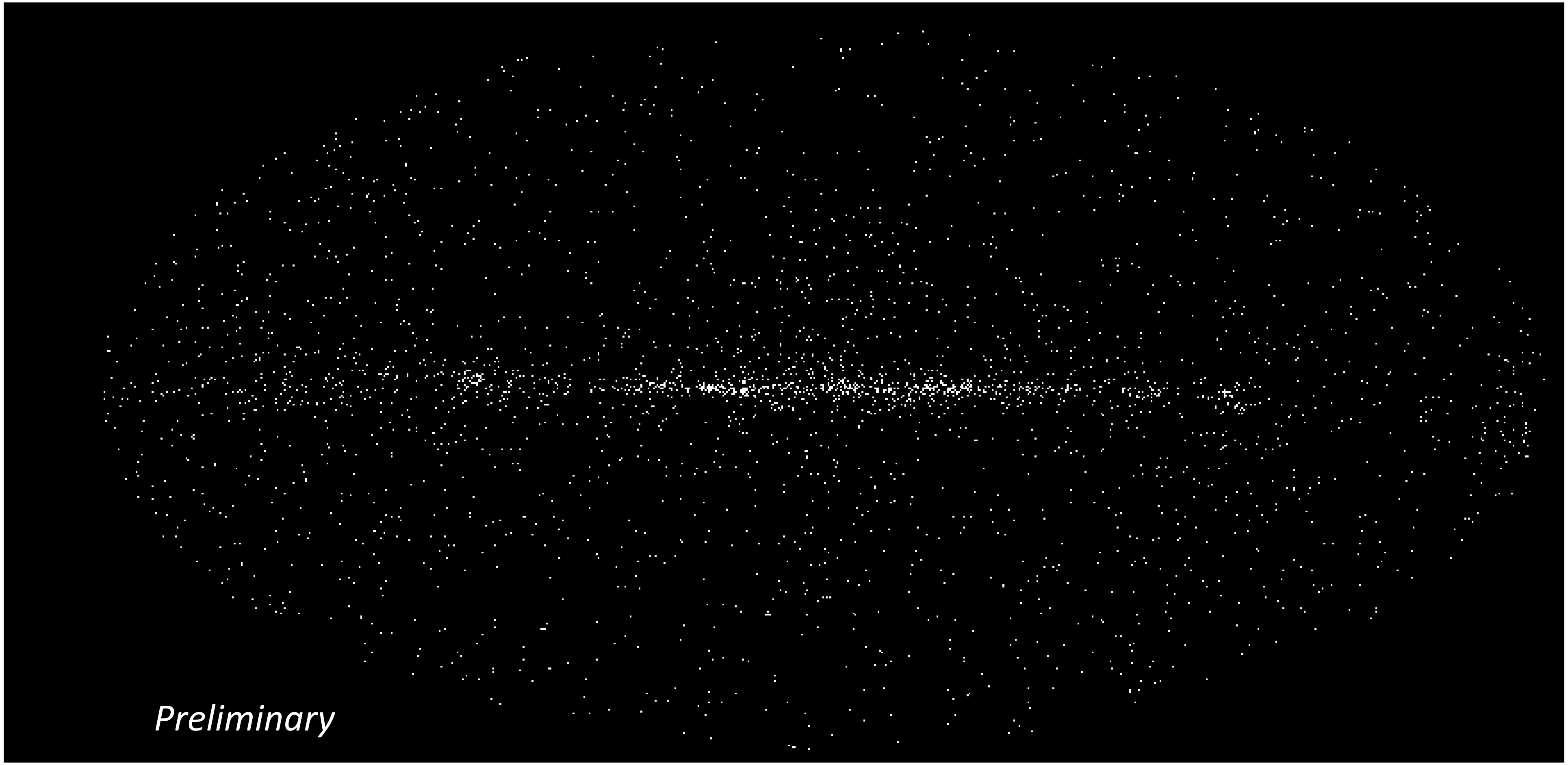
Count Map

Ajello+14

~6 years of P8 data (50 GeV – 2 TeV)

51,000 photons E > 50 GeV
18,000 photons E > 100 GeV
2,000 photons E > 500 GeV

~1 photons every deg^2



Count Map

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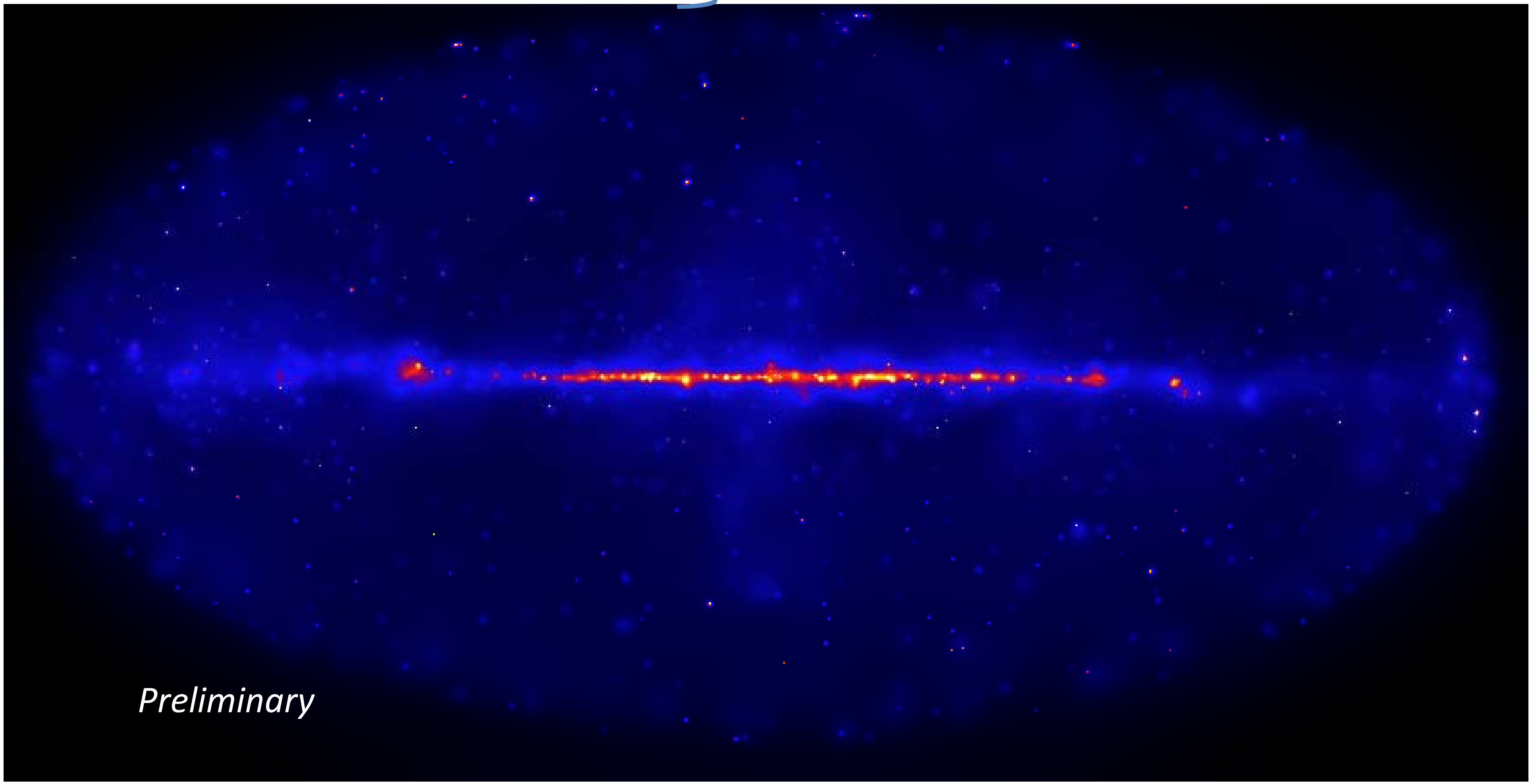
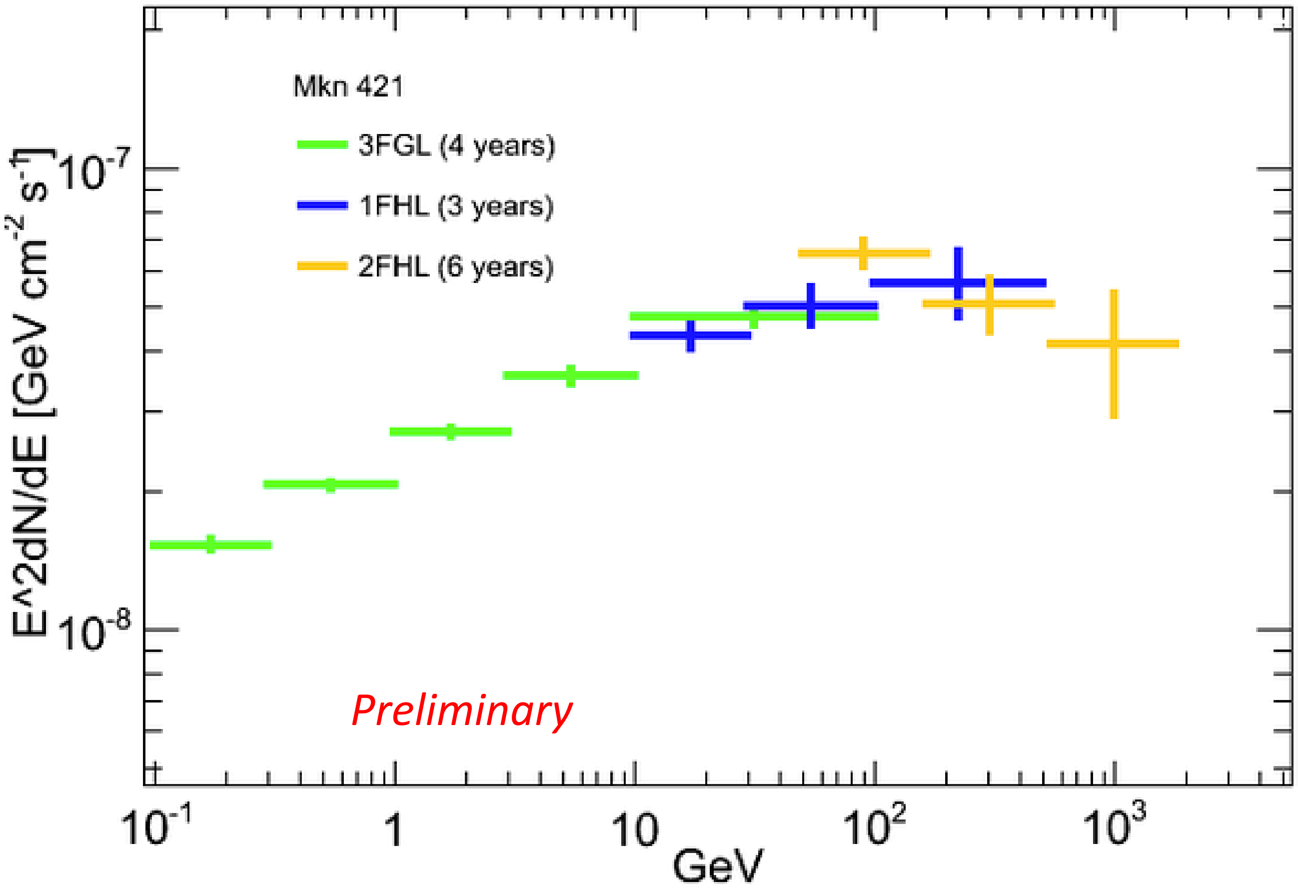


Blazars' Spectra

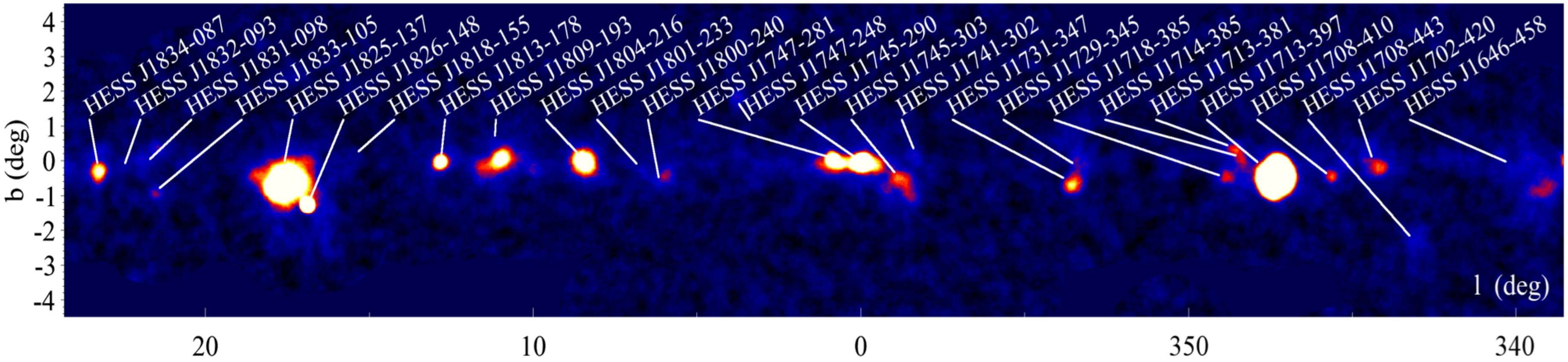
Ajello+14

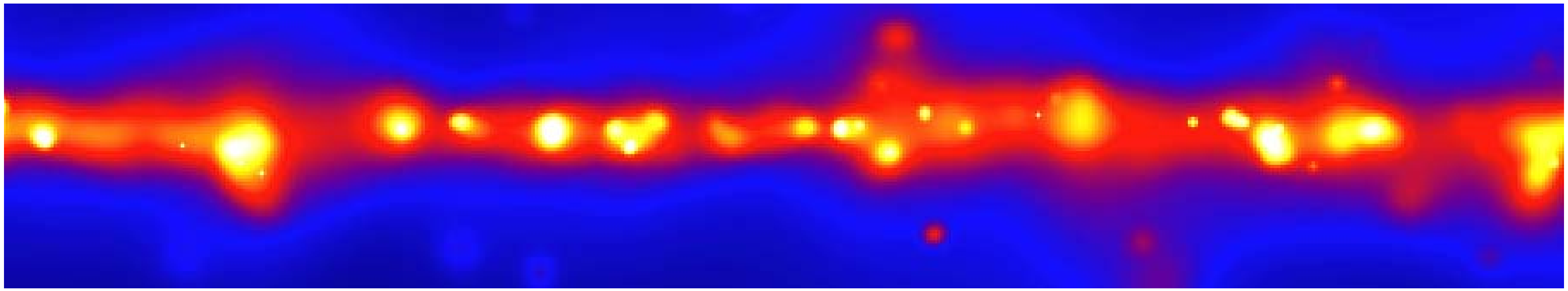
- BL Lacs of the HSP kind typically have their IC peak somewhere at E>100 GeV



Comparison with the H.E.S.S. Galactic Survey

Ajello+14





Close up of map on slide 11

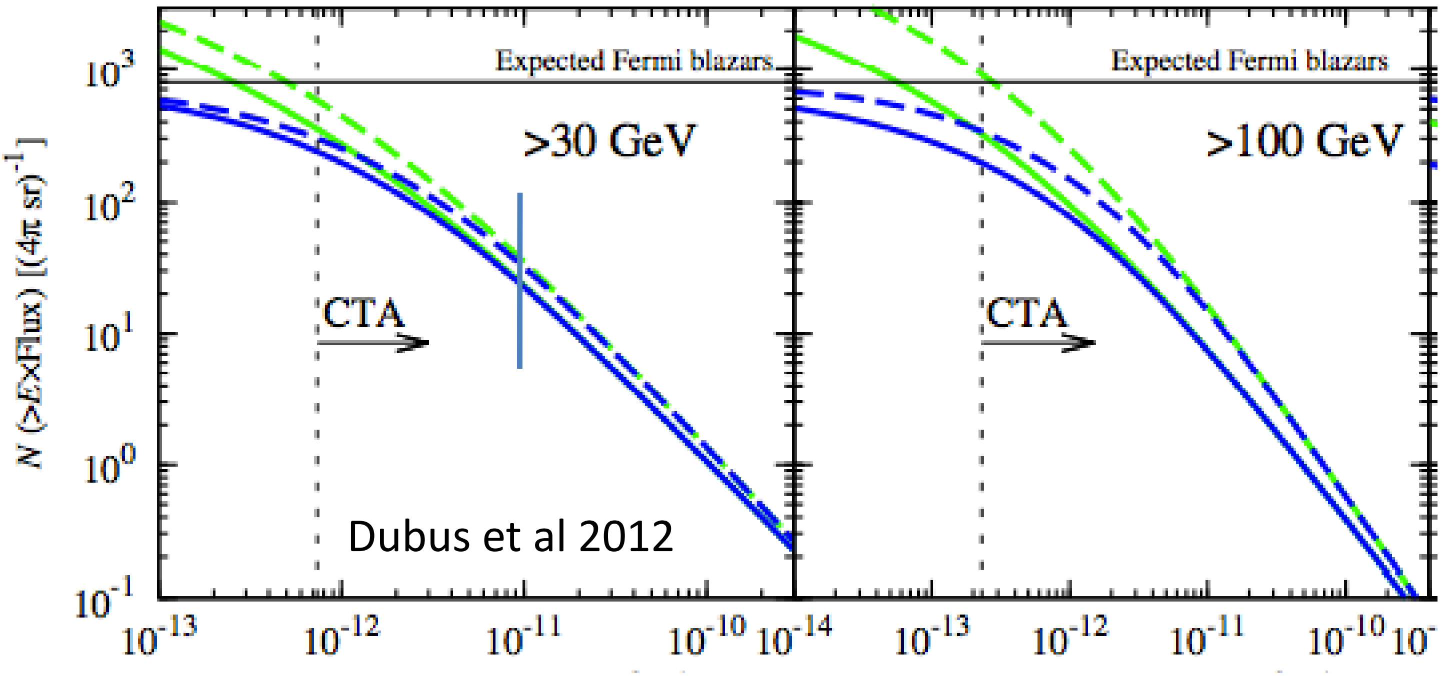
Preliminary

Good match between HESS and *Fermi* maps

Fermi and CTA

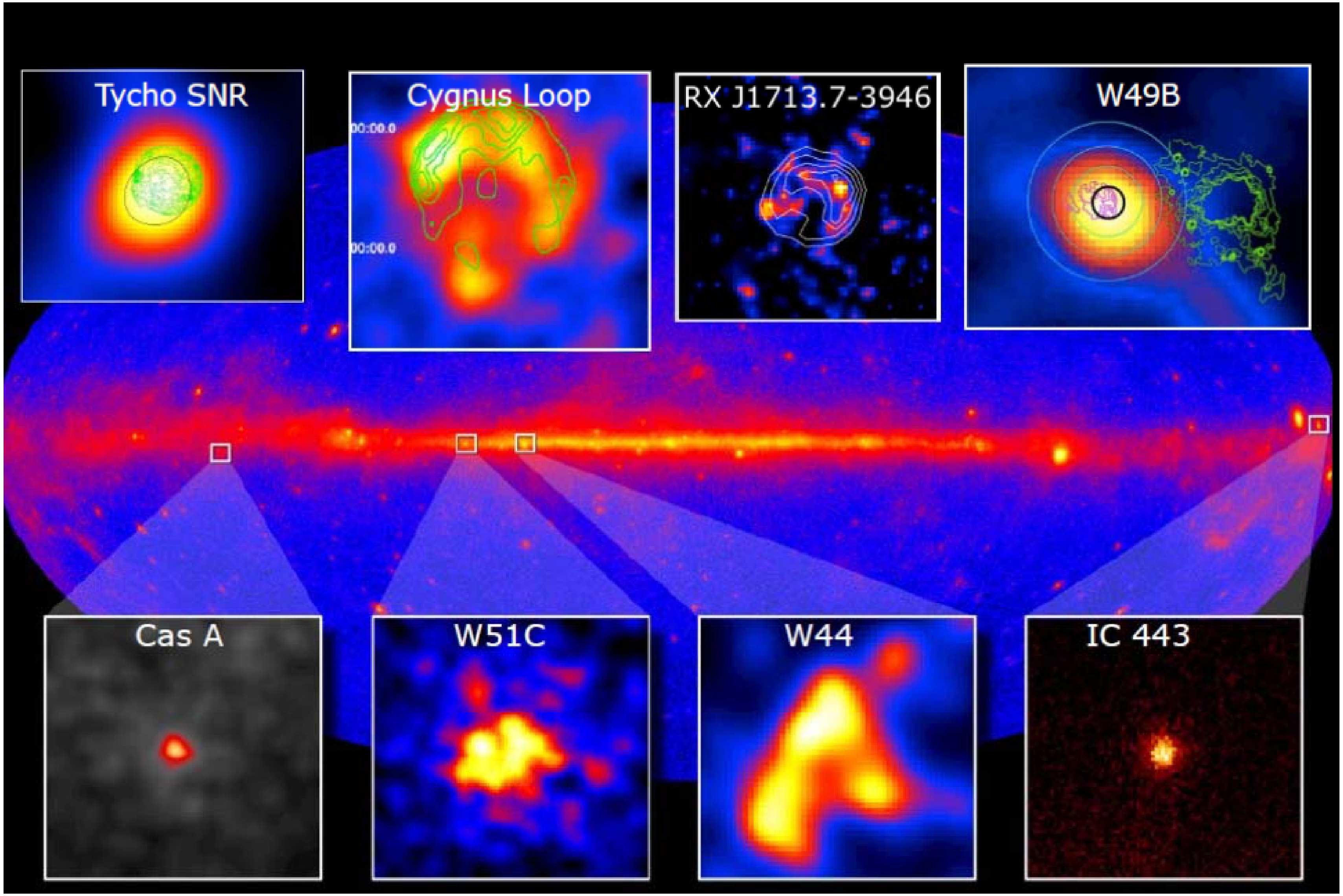
Ajello+14

- A >50 GeV all-sky *Fermi* survey is a perfect complement to future large are surveys performed by CTA

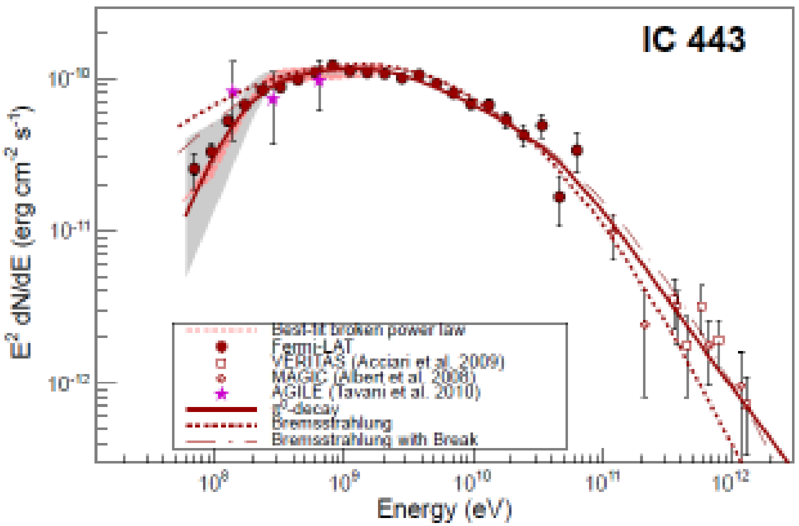


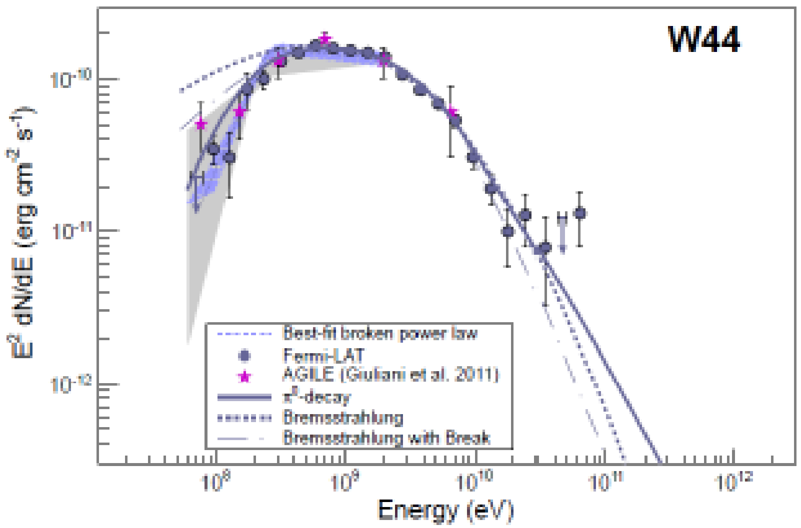
Supernova Remnants (SNR)

GeV-bright SNRs



• **Spectrum below 200 MeV clearly deviates from bremsstrahlung and agrees well with a hadronic scenario**

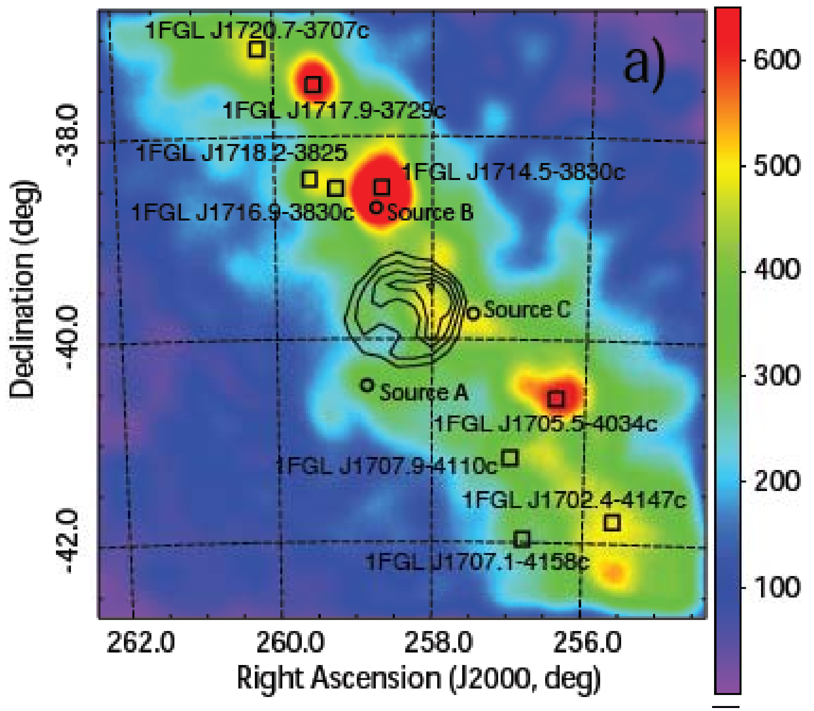




	IC443	W44
W_{SN}	1×10^{51} erg	5×10^{51} erg
W_{CR}	4×10^{49} $(n/20\,cm^{-3})^{-1}$erg	4×10^{49} $(n/100\,cm^{-3})^{-1}$erg

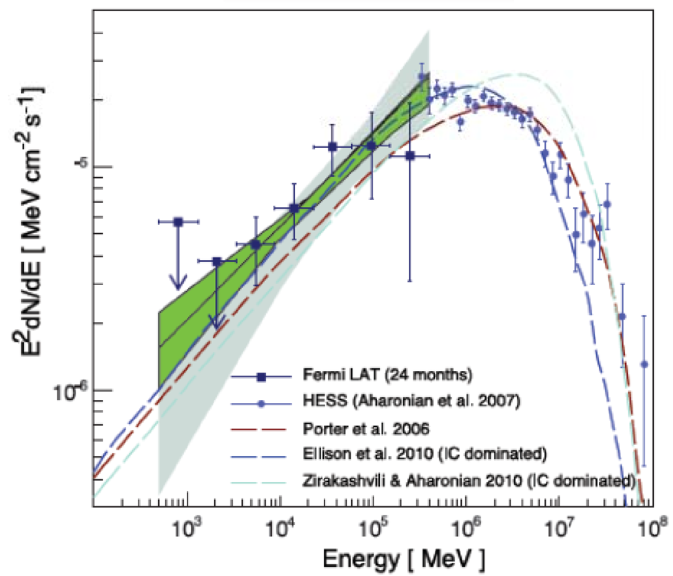
Ackermann+13

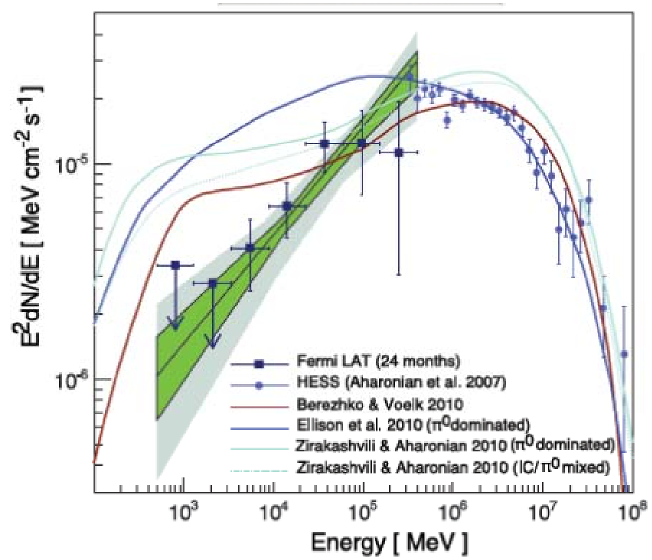
RXJ1713: (age about1600y)



Abdo+11

Leptonic Model





Proton content in leptonic model

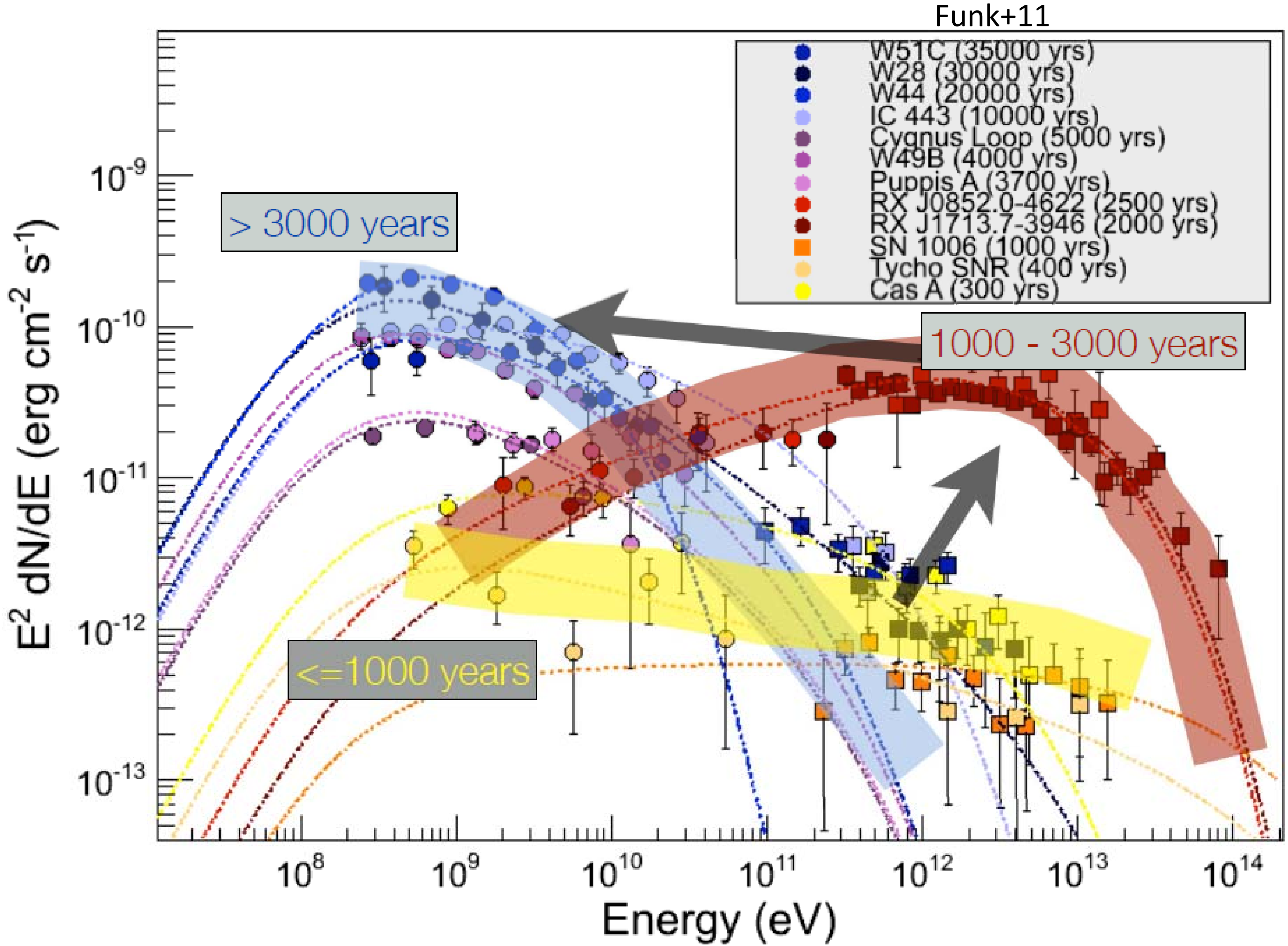
Ee;max 20-40 TeV

$W_p < 0.3\times10^{51}(n_H/0.1\ cm^{-3})^{-1}$erg

d = 1 kpc

Electron index se = $2\Gamma-1$ = 2.0 ± 0.2

B~10uG

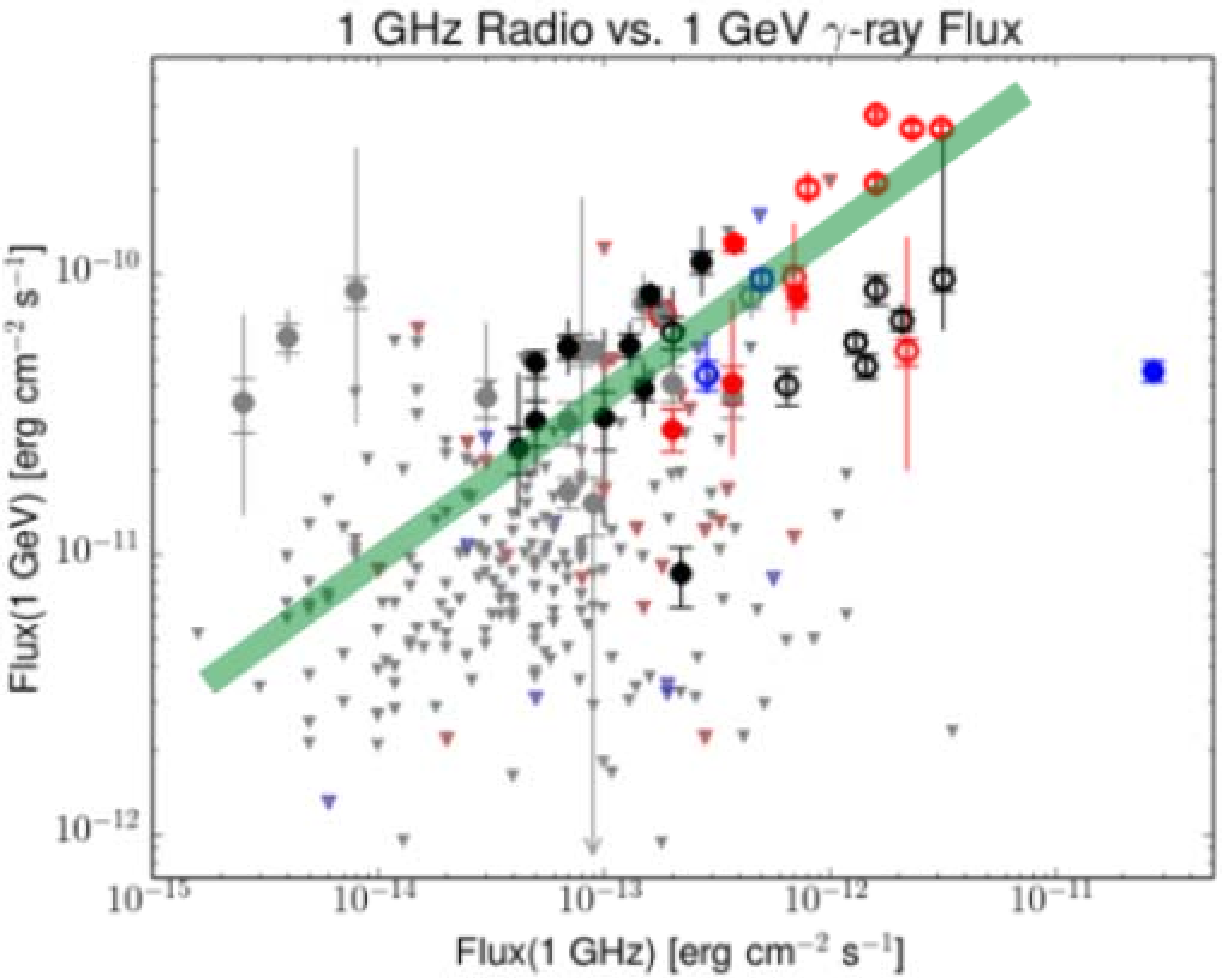


Funk+11
W51C (35000 yrs)
W28 (30000 yrs)
W44 (20000 yrs)
IC 443 (10000 yrs)
Cygnus Loop (5000 yrs)
W49B (4000 yrs)
Puppis A (3700 yrs)
RX J0852.0-4622 (2500 yrs)
RX J1713.7-3946 (2000 yrs)
SN 1006 (1000 yrs)
Tycho SNR (400 yrs)
Cas A (300 yrs)
> 3000 years
1000 - 3000 years
<=1000 years
E^2 dN/dE (erg cm^{-2} s^{-1})
Energy (eV)

Cataloging SNRs with *Fermi* LAT

Hewitt+14

- Search 279 Galactic SNRs (Green 2009) for 1-100 GeV γ-rays and account for systematics (including Interstellar Emission Model)



32 classified GeV SNRs (16 spatially extended)

GeV-Radio correlation?

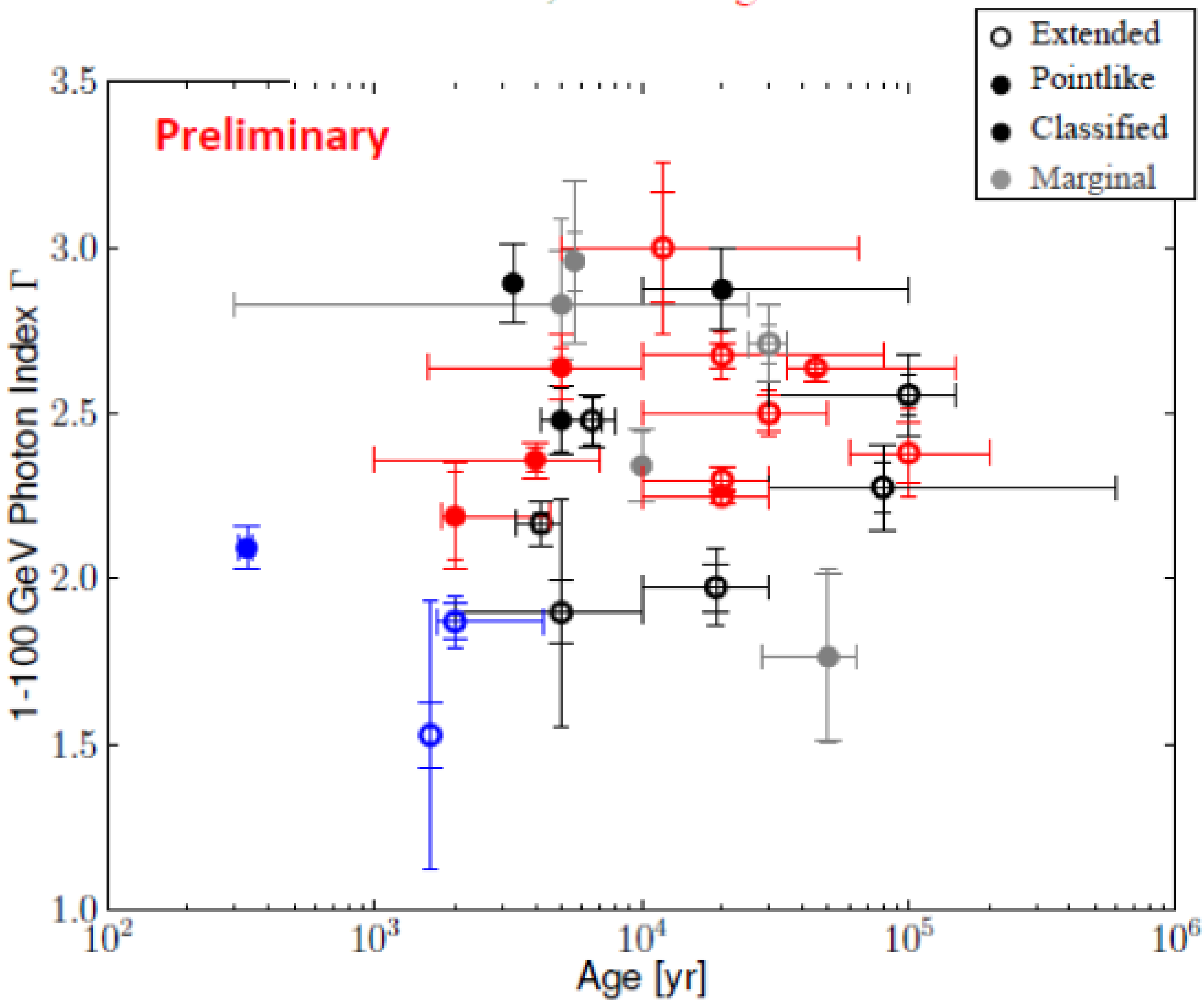
Age v GeV Index

Hewitt+14

Young SNRs tend to be harder than older, interacting SNRs.

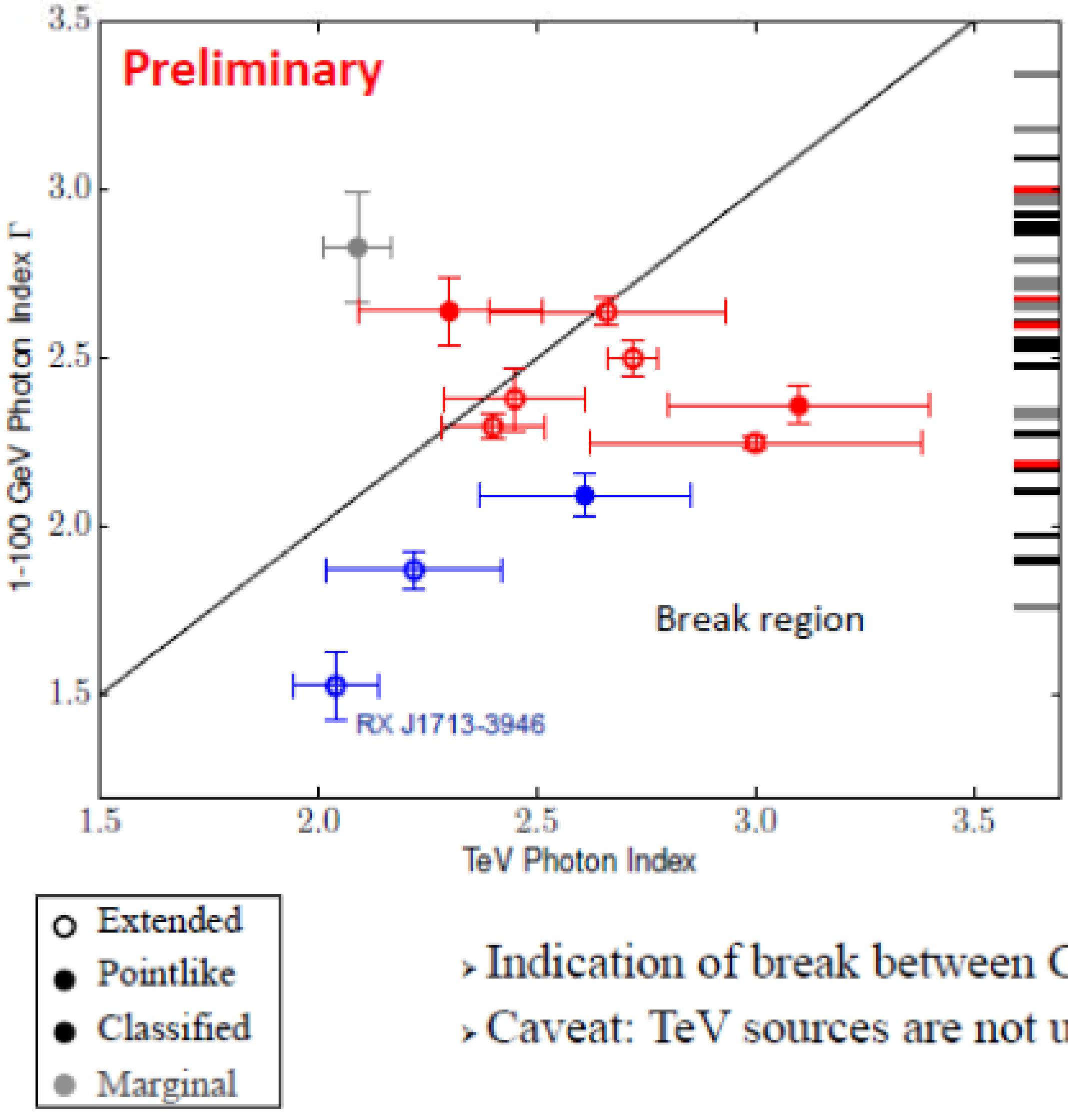
GeV index evolves w time
- apparent increase for older remnants

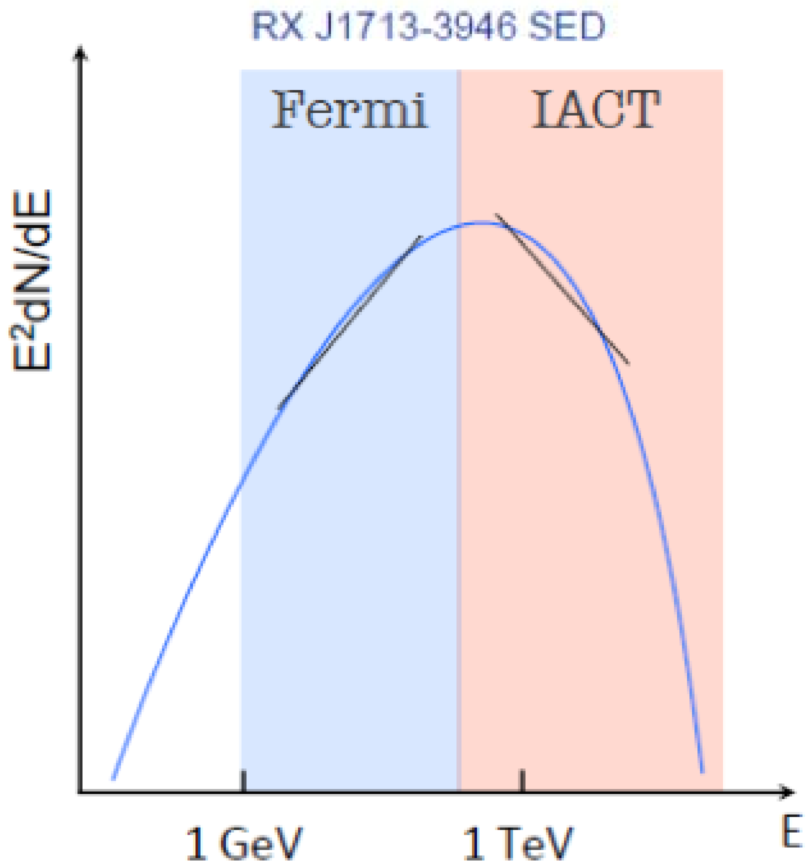
May be due to a combination of:
- decreasing shock speed allowing greater particle escape
- decreasing maximum acceleration energy as SNRs age



GeV-TeV Index

Hewitt+14



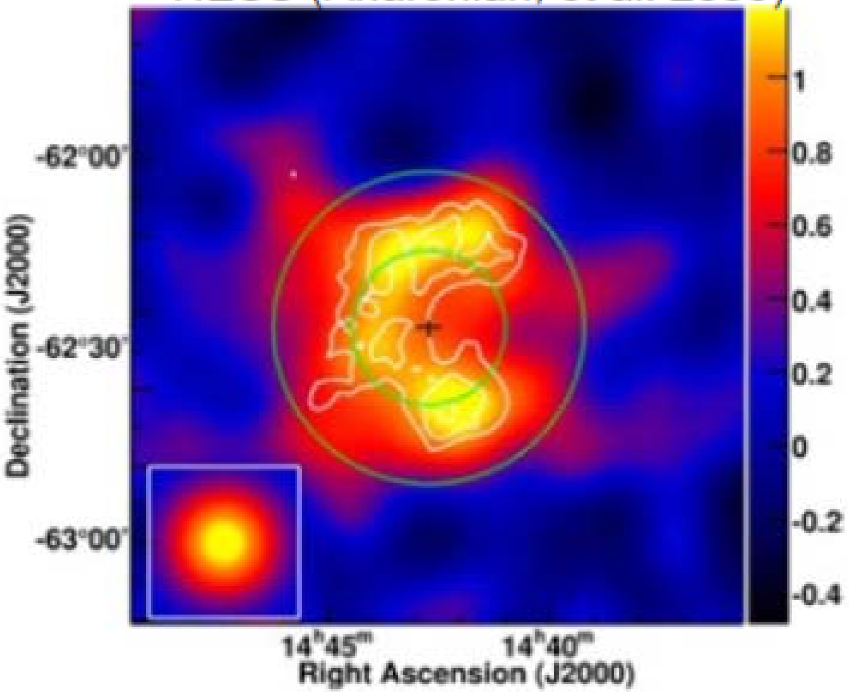


- Indication of break between GeV and TeV
- Caveat: TeV sources are not uniformly surveyed.

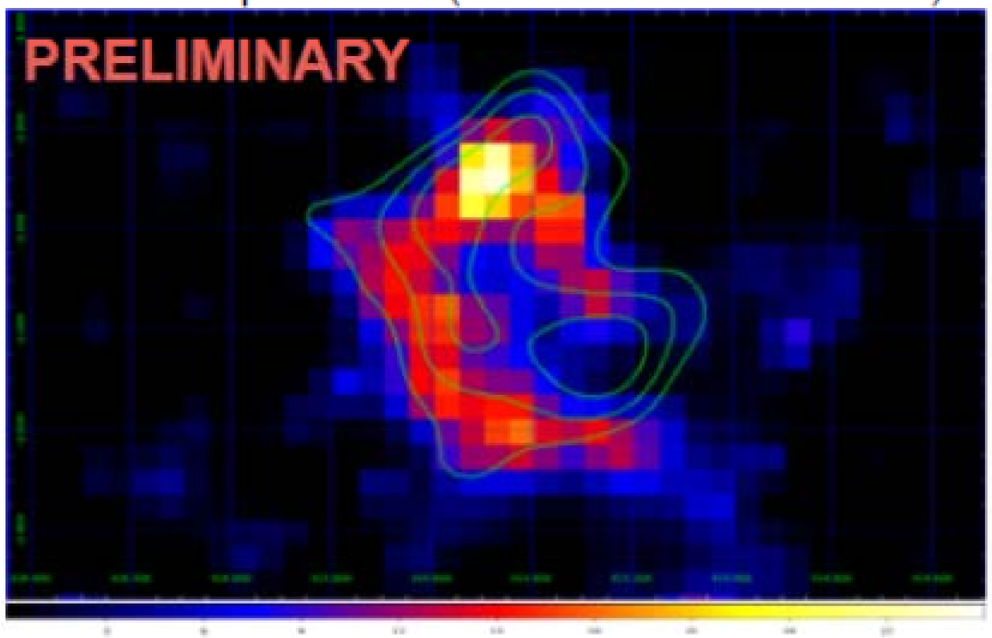
TeV shell-type SNR as seen by Fermi

- RCW 86: TeV shell-type SNR detected by HESS (D = 0.82°)

HESS (Aharonian, et al. 2008)



TS Map >1 GeV (69 months Pass 8 data)



- Pass 8 reveals extended emission
  Diameter = 0.7±0.06°

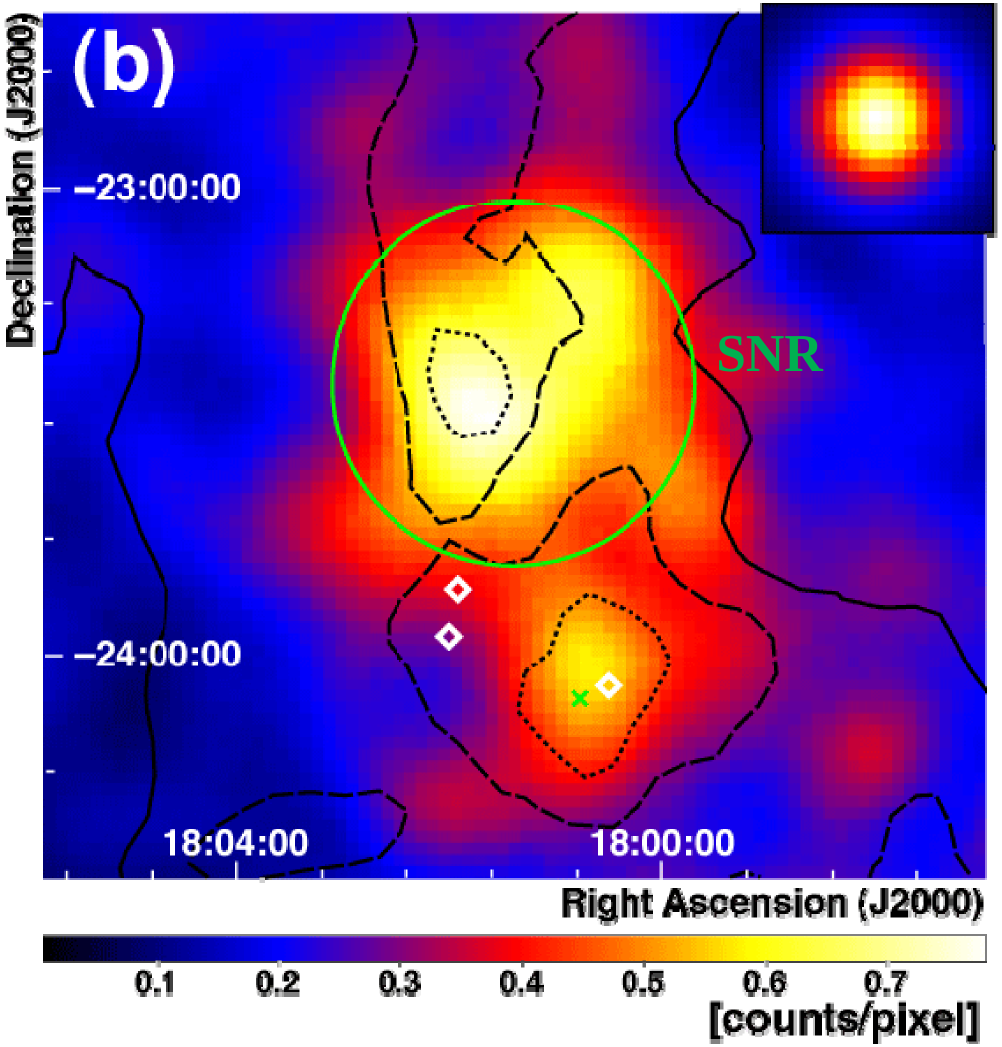
M. Caragiulo

Where is PeVatron ?

Abdo+10, Hanabata+14

The W28 Case

2-10GeV with NANTEN CO(J=1-0) contours

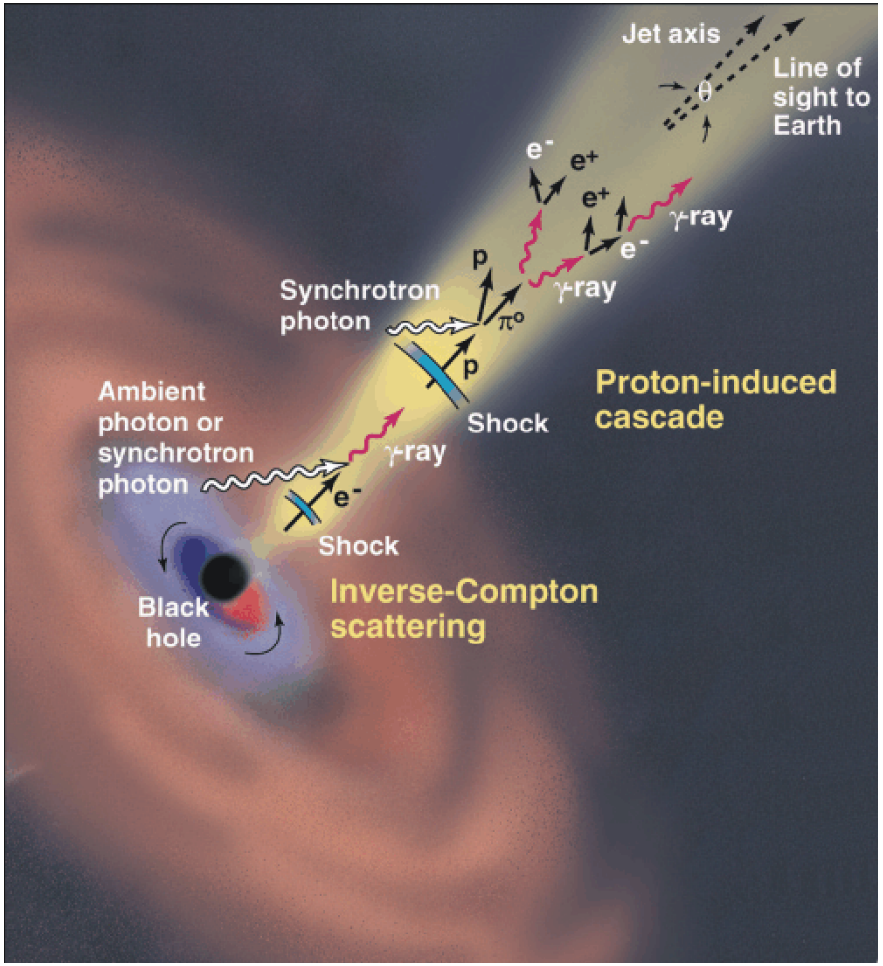


G8.7-0.1 (Ajello+12)

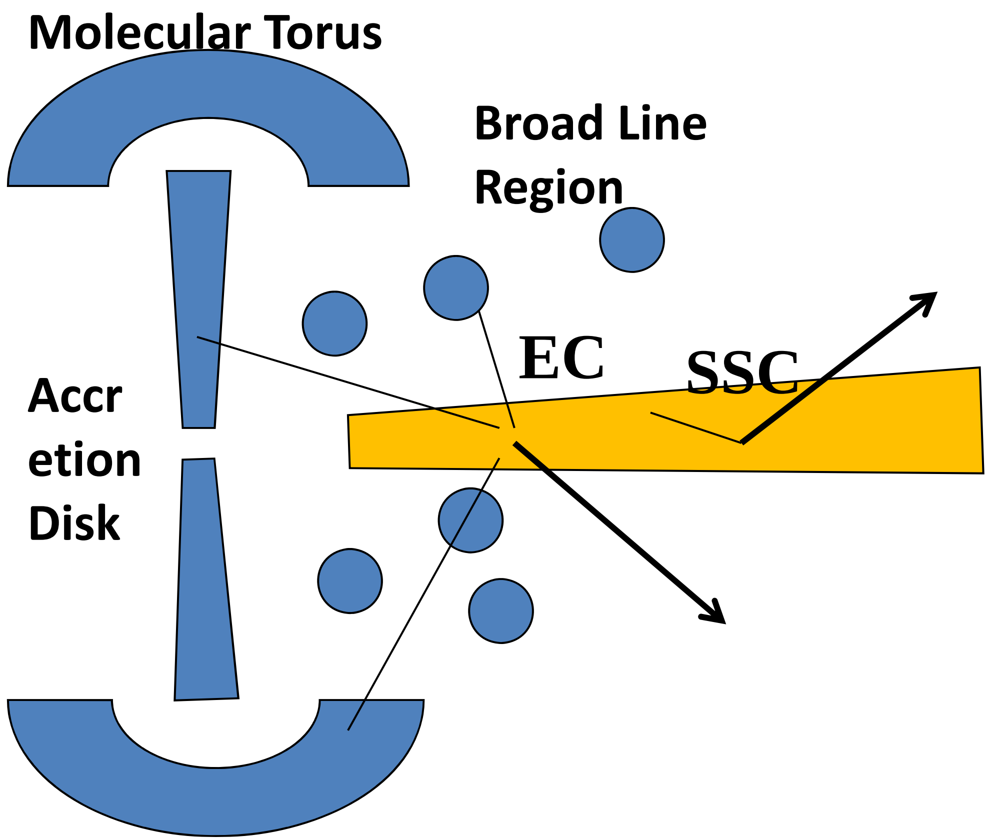
HESS SNR

Escaping cosmic rays from SNRs are interacting with molecular clouds.

Blazars

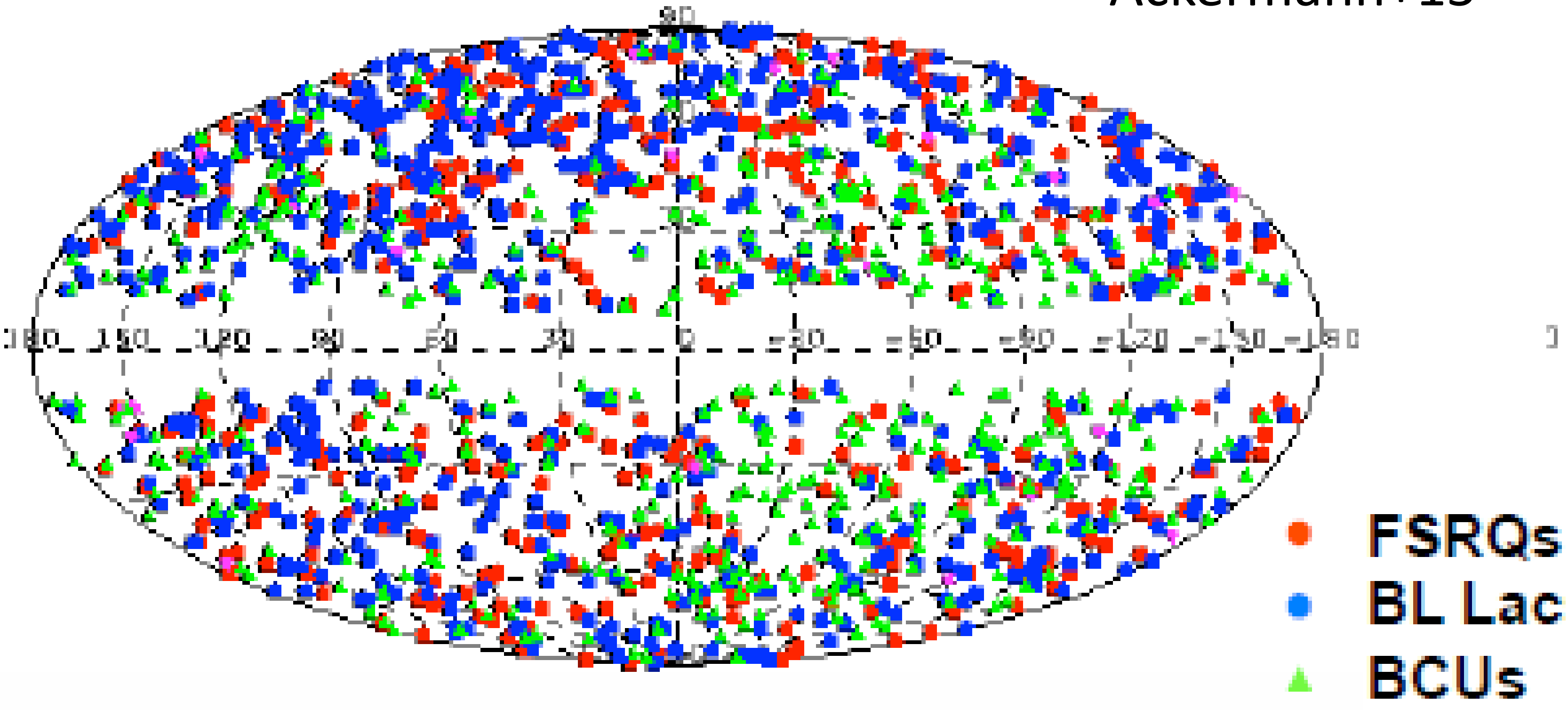


(credit:J. Buckley)



3LAC (3rd AGN Catalog)

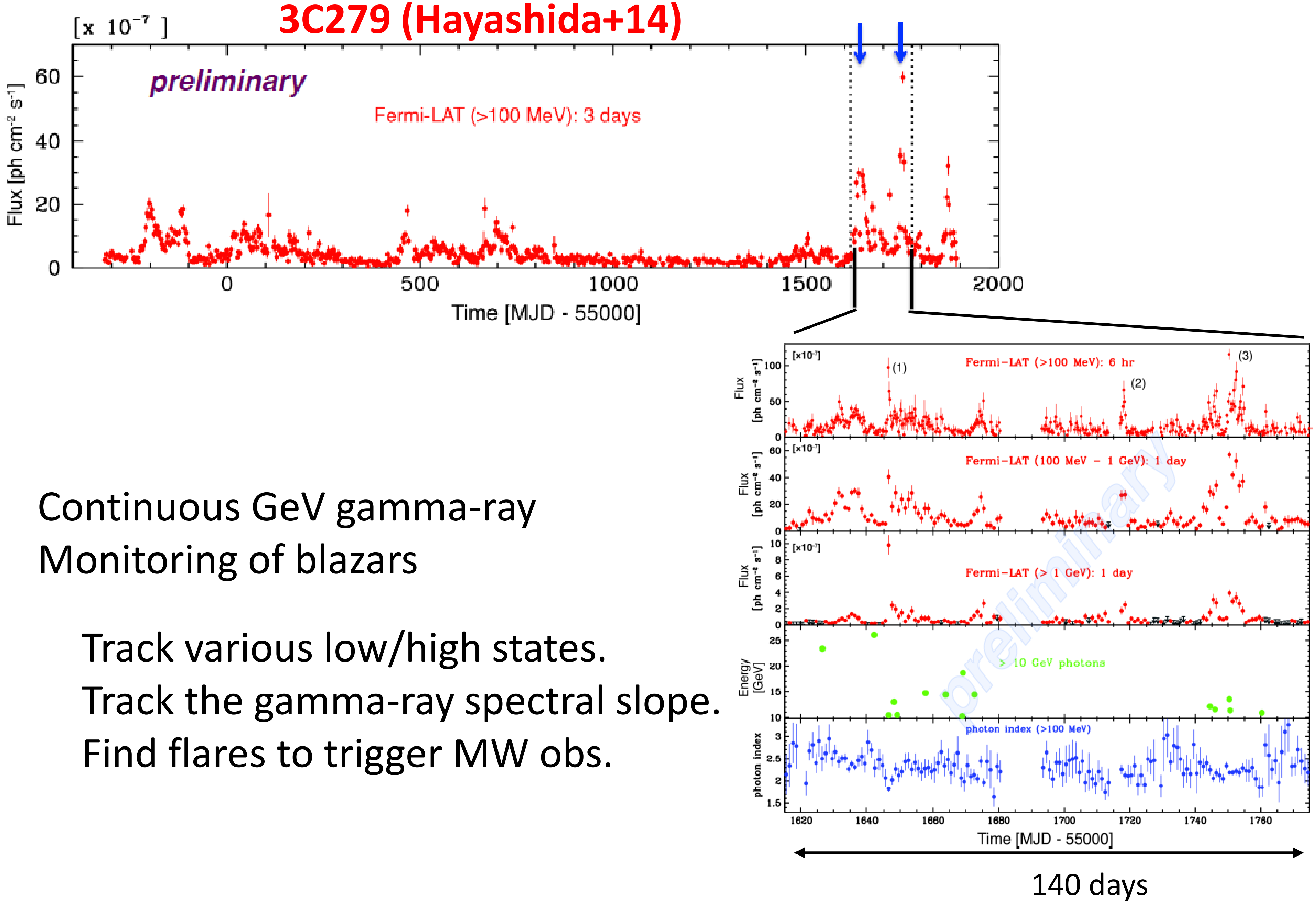
Ackermann+15



All	1444
FSRQ	34%
BL Lac	52%
Unknowns	14%

- 2008 August – 2014 August measured by Fermi-LAT

3C279 (Hayashida+14)



Continuous GeV gamma-ray
Monitoring of blazars

Track various low/high states.
Track the gamma-ray spectral slope.
Find flares to trigger MW obs.

BL Lac (HBL)

TeV BLAZAR

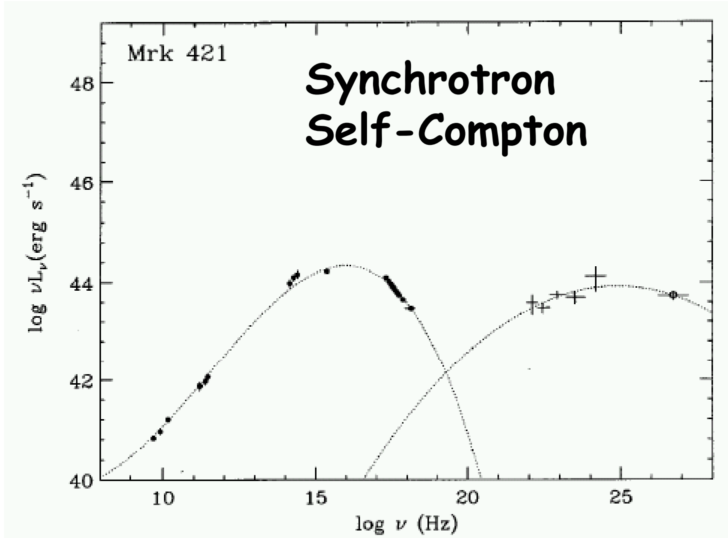
Nearby, Low-L

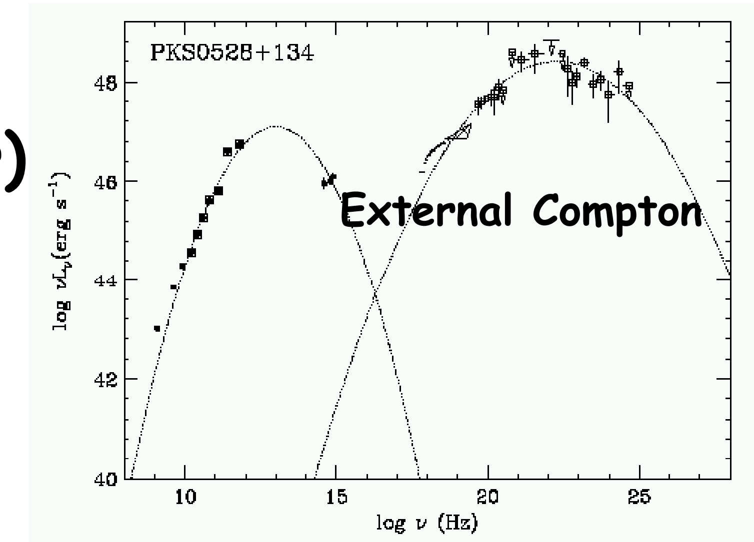
↕

FSRQ
(flat spectrum radio-loud quasor)

GeV BLAZAR

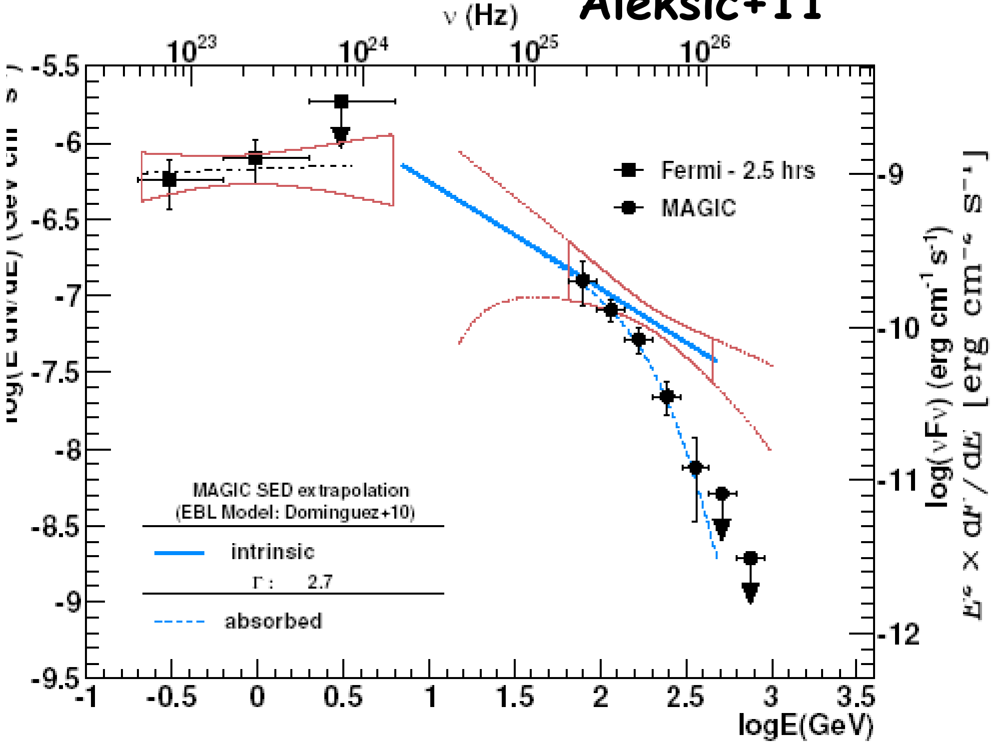
Distant, High-L



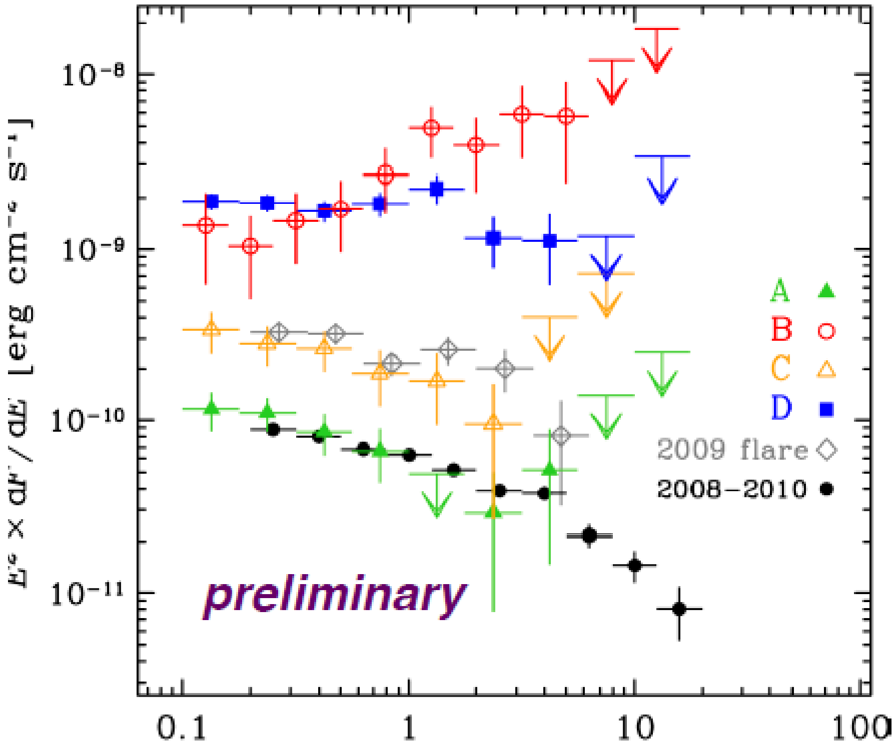


FSRQa are sometimes detected up to TeV

FSRQ 4C+21.35 **Tanaka+11 Aleksic+11**



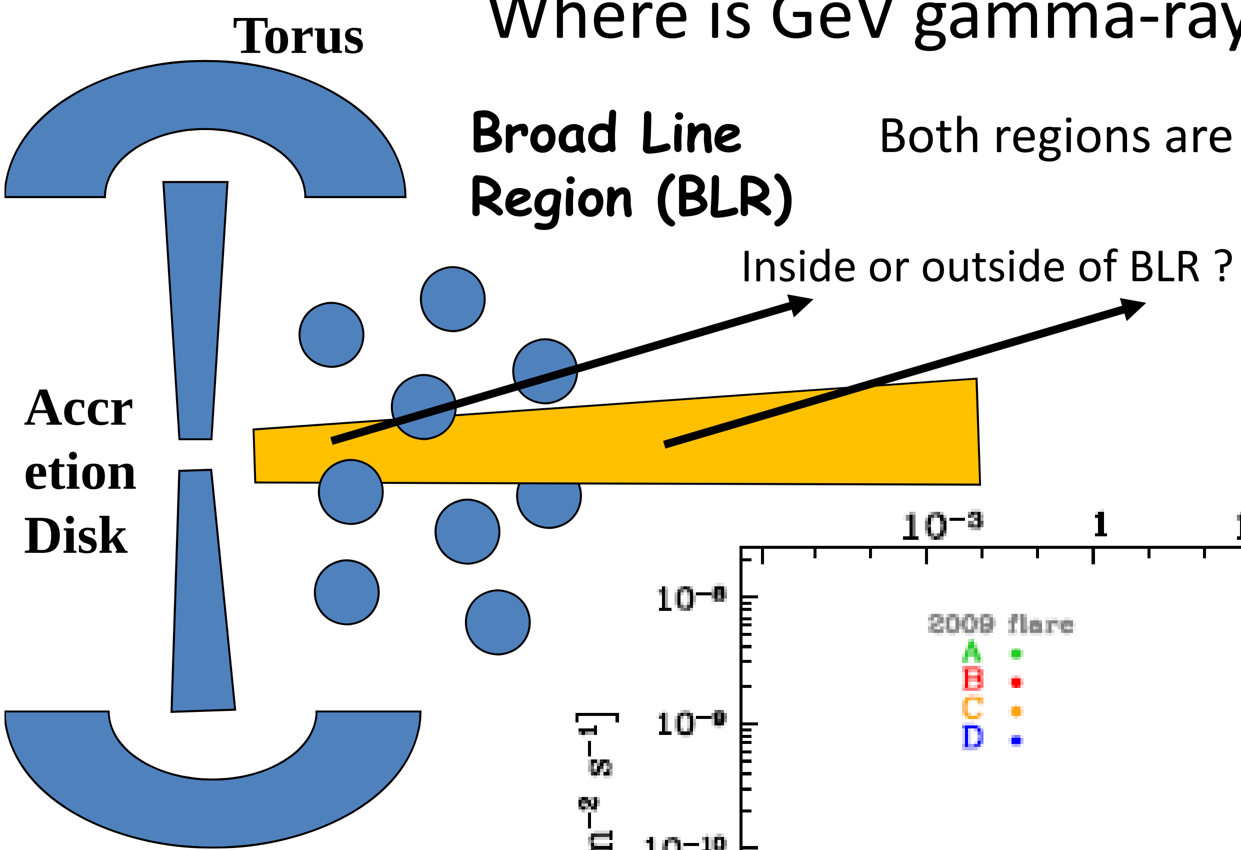
3C279 (Hayashida+14)



PKS1222+21(MAGIC 2011)
PKS1510-089(MAGIC)

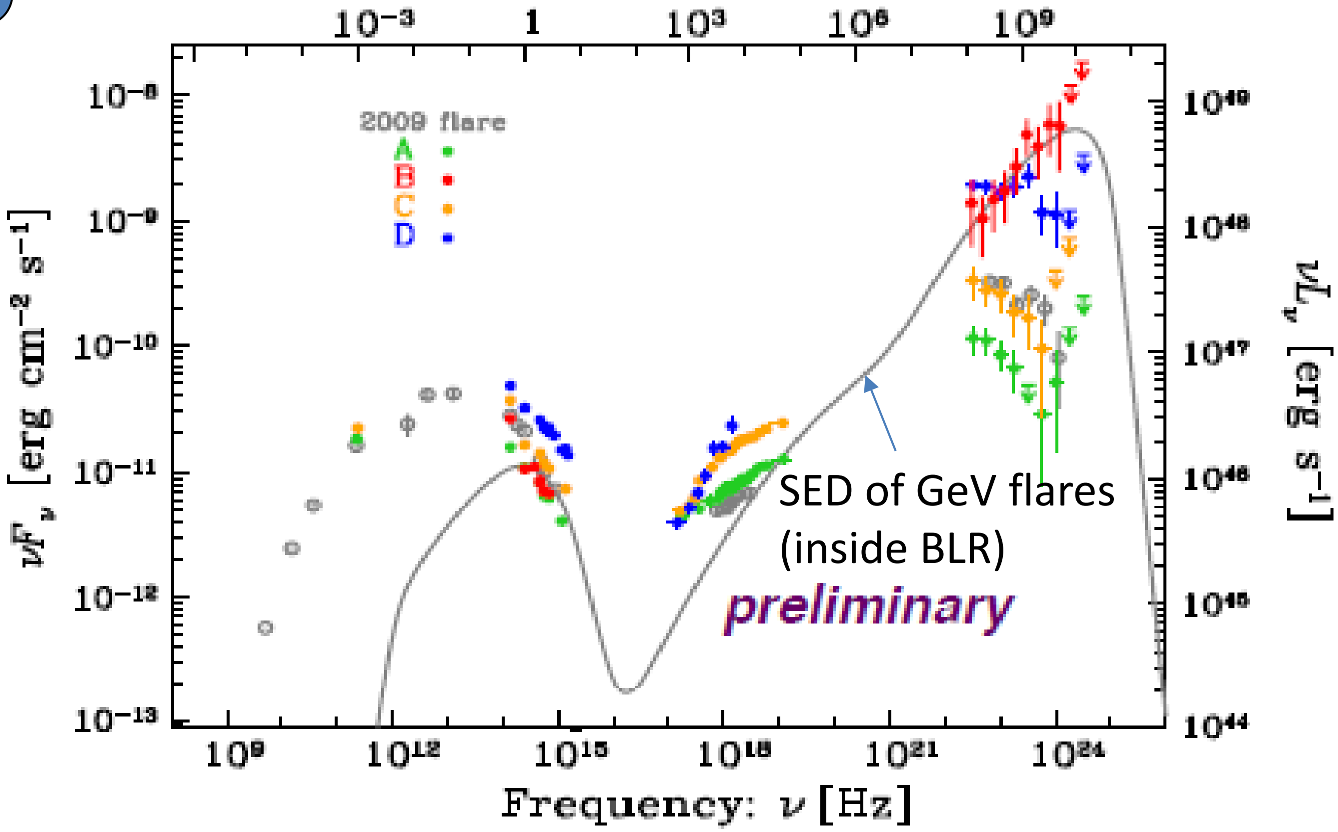
Where is GeV gamma-ray emitting region ?

Both regions are possible for some objects.



3C279 (Abdo+10)
Optical polarization change favors the region outside BLR.

3C279 (Hayashida+14)



TeV Blazars

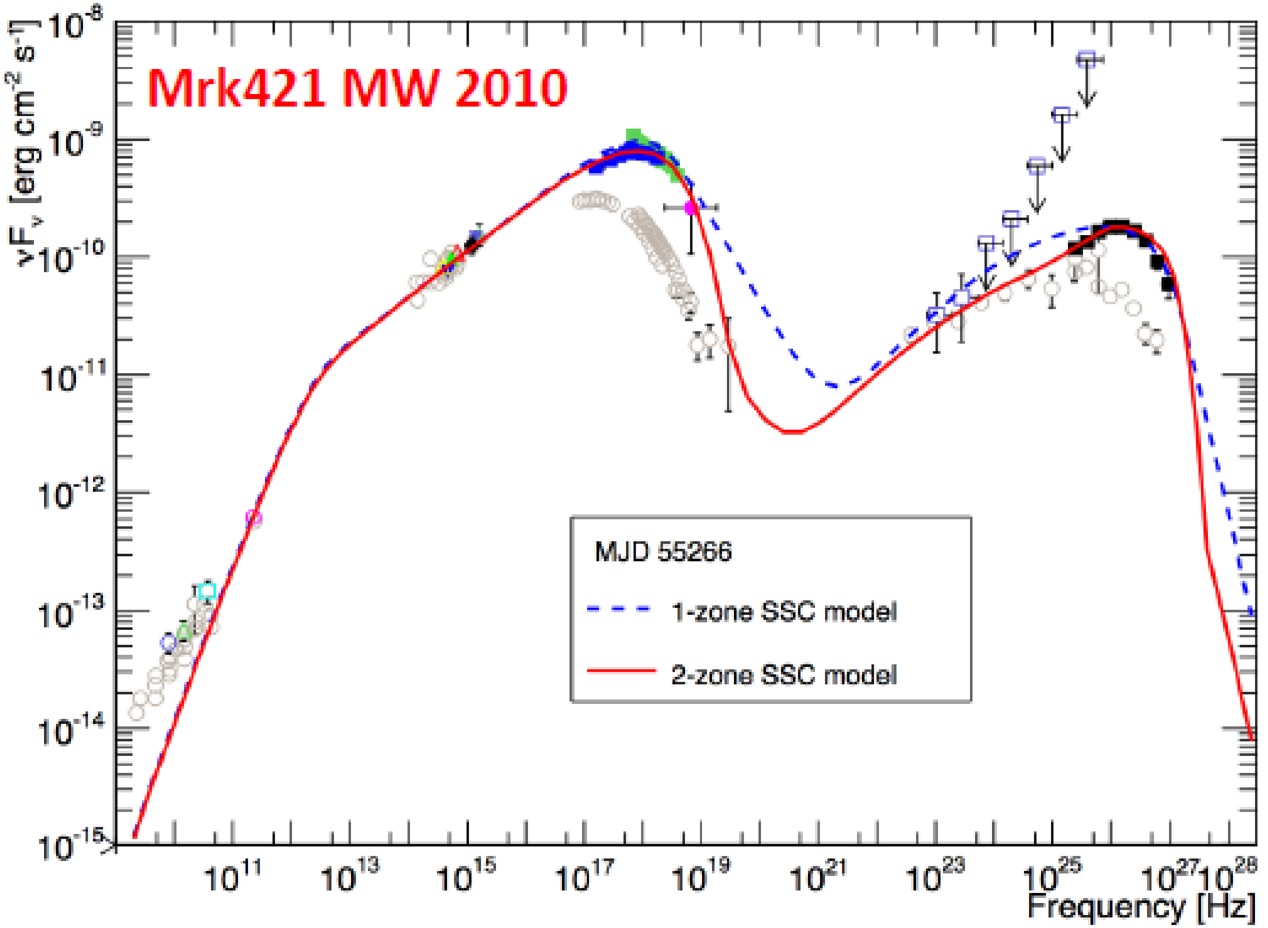
Typically, one-zone model fits SED.

One-zone vs two-zone SSC model

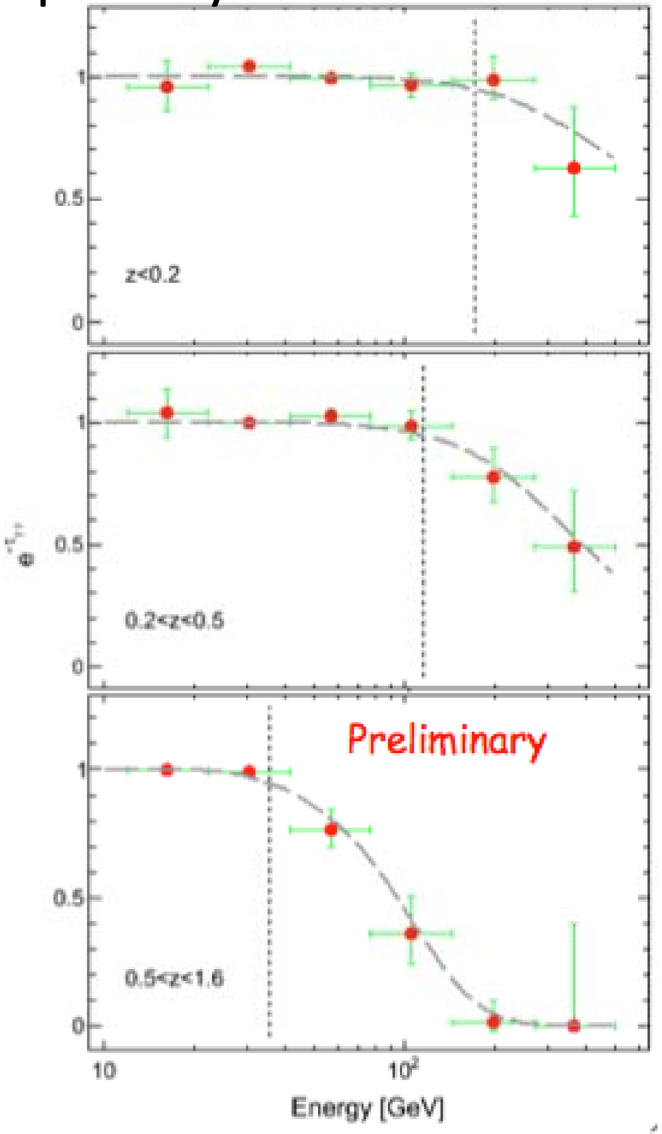
Paneque+14

→ <u>Both of them provide reasonably good agreement</u>

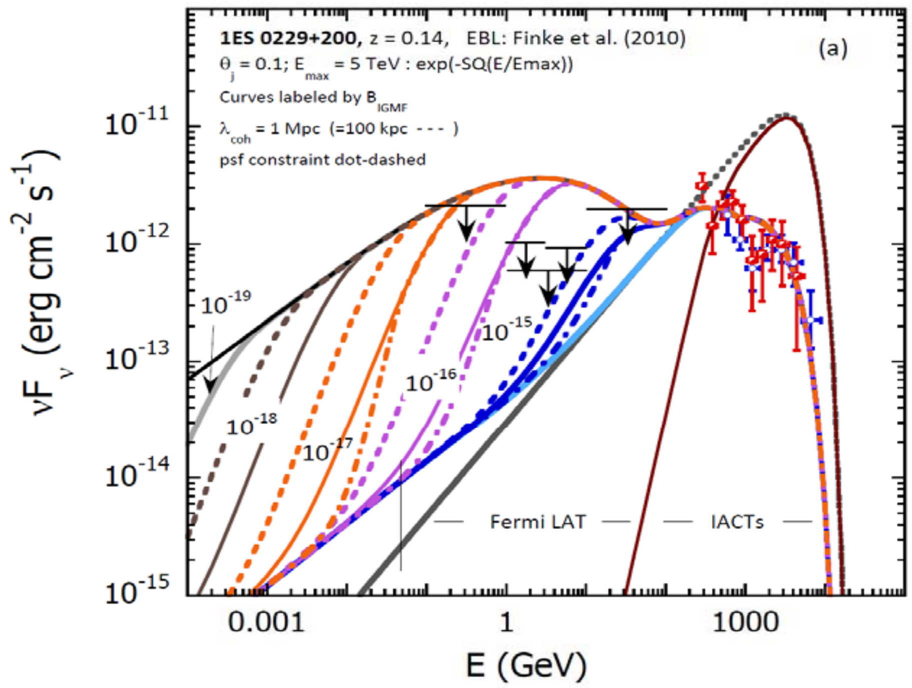
→ Two-zone SSC describes slightly better the narrow peaks



Redshift-dependent high-energy spectral changes of blazars used to quantify EBL. Ackermann+12



Constraint intergalactic magnetic field



$\Rightarrow B_{IGMF} > 10^{-15}$ G

(Neronov & Vovk 2010; Tavecchio et al. 2010)

$\Rightarrow B_{IGMF} > 10^{-18}$ G

(Consider time variability)

(Dermer 2011)

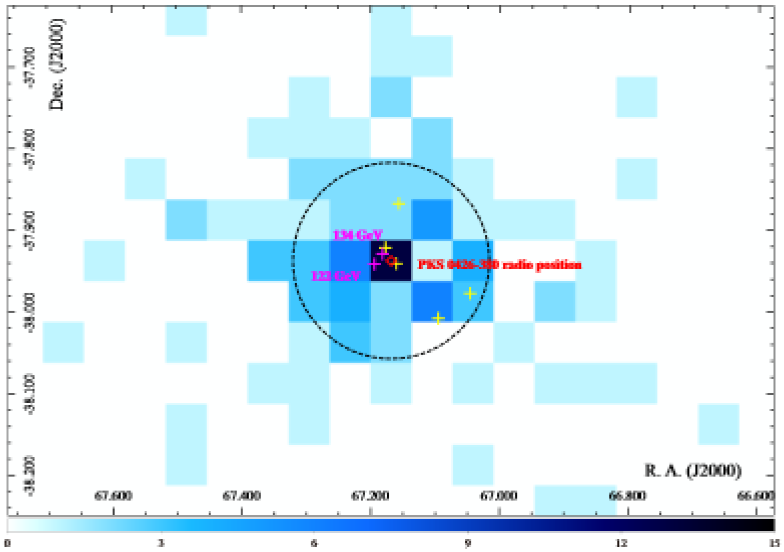
>100 GeV photons from a distant blazar PKS0426-380 (z=1.1)

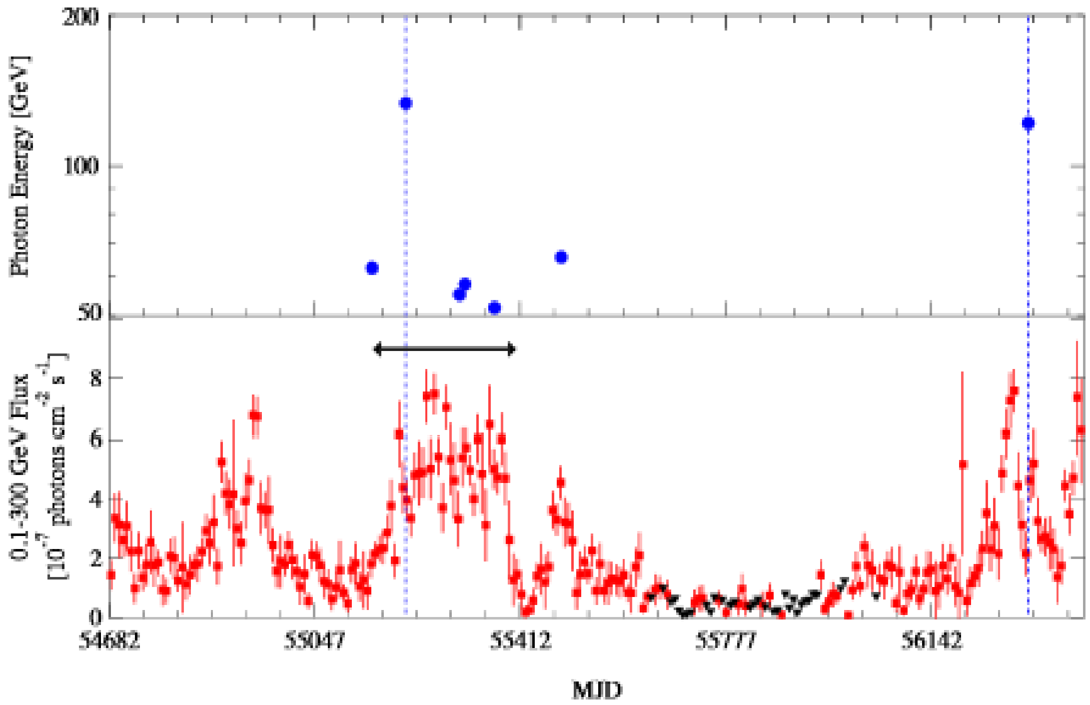
A possible source to constrain the intergalactic magnetic field and the extragalactic background light (EBL).

CTA accurate studies of these sources are important for further constraint.

Tanaka+13

5-300 GeV

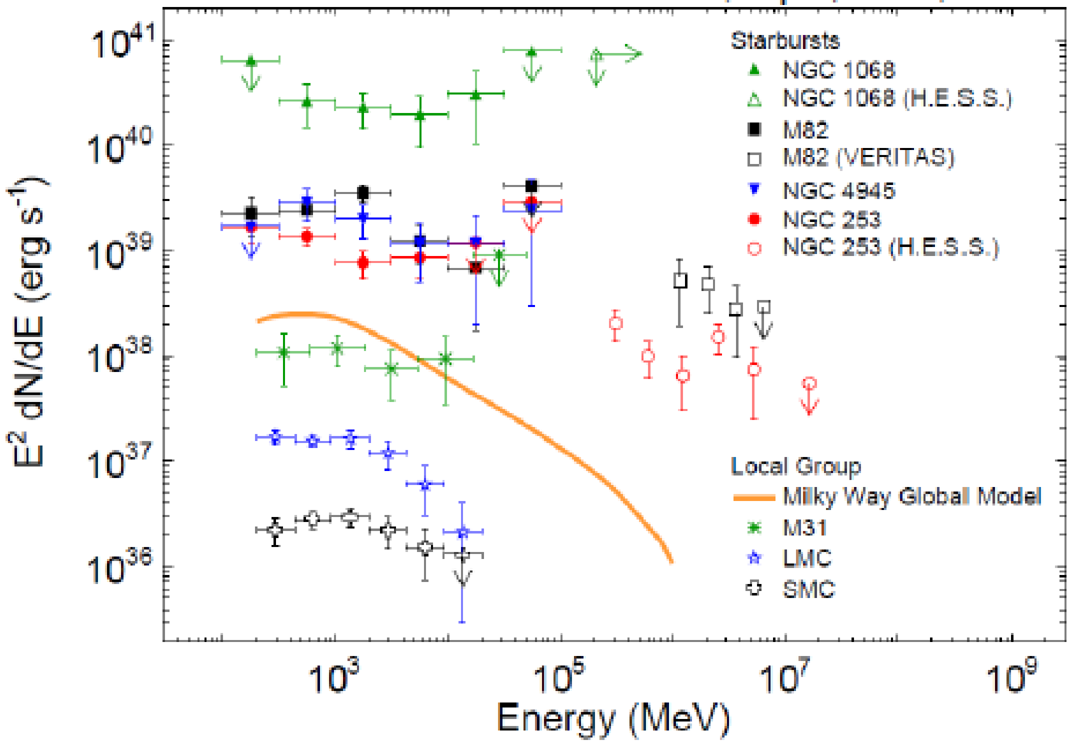




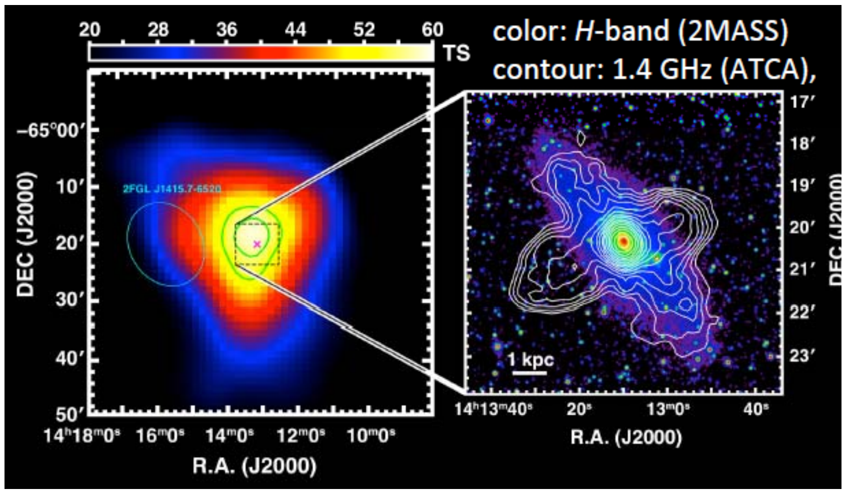
Normal galaxies and Starburst galaxies

TeV sources … M82/NGC253

Ackermann et al. 2012, ApJ, 755, 164



Circinus Galaxy (Hayashida+13)



Fermi Gamma-ray Space Telescope

Misaligned AGNs

Lott+14

Preliminary

Name	3FGL	2FGL	1FGL	Type	Photon index
NGC 1218	J0308.6+0408	···	J0308.3+0403	FRI	2.07±0.11
IC 310	J0316.6+4119	J0316.6+4119	···	FRI/BLL	1.90±0.14
NGC 1275	J0319.8+4130	J0319.8+4130	J0319.7+4130	FRI	2.07±0.01
For A	(J0322.5-3721)	J0322.4-3717	···	FRI	2.20±0.11
TXS 0331+391	J0334.2+3915	···	···	FRI/BLL?	2.11±0.17
TXS 0348+013	J0351.1+0128	···	···	SSRQ	2.43±0.18
3C 111	J0418.5+3813	···	J0419.0+3811	FRII	2.79±0.08
Pictor A	J0519.2-4542	···	···	FRII	2.49±0.18
PKS 0625-35	J0627.0-3529	J0627.1-3528	J0627.3-3530	FRI/BLL	1.87±0.06
3C 189	J0758.7+3747	···	···	FRI	2.16±0.16
4C +39.23B	J0824.9+3916	···	···	CSS	2.44±0.10
3C 207	J0840.8+1315	J0840.7+1310	J0840.8+1310	SSRQ	2.47±0.09
4C +39.26	J0934.1+3933	···	···	SSRQ	2.28±0.12
3C 264	J1145.1+1935	···	···	FRI	1.98±0.20
4C +04.40	J1205.4+0412	···	···	SSRQ	2.64±0.16
M87	J1230.9+1224	J1230.8+1224	J1230.8+1223	FRI	2.04±0.07
3C 275.1	J1244.1+1615	···	···	SSRQ	2.43±0.17
Cen A Core	J1325.4-4301	J1325.6-4300	J1325.6-4300	FRI	2.70±0.03
3C 286	J1330.5+3023	···	···	SSRQ/CSS	2.60±0.16
Cen B	J1346.6-6027	J1346.6-6027	···	FRI	2.32±0.01
3C 303	J1442.6+5156	···	···	FRII	1.92±0.18
NGC 6251	J1630.6+8232	J1629.4+8236	J1635.4+8228	FRI	2.22±0.08
3C 380	J1829.6+4844	J1829.7+4846	J1829.8+4845	SSRQ/CSS	2.37±0.04
Circinus	J1413.2-6518	(J1415.7-6520)	···	Seyfert	2.43±0.10
ESO 323-G77	···	J1306.9-4028	J1307.0-4030		
3C 120	···	···	···	FRI	
3C 407	···	J2008.6-0419	J2008.6-0419		
NGC 6951	···	···	J2038.1+6552		
NGC 6814	···	J1942.5-1024	···		

gone sources

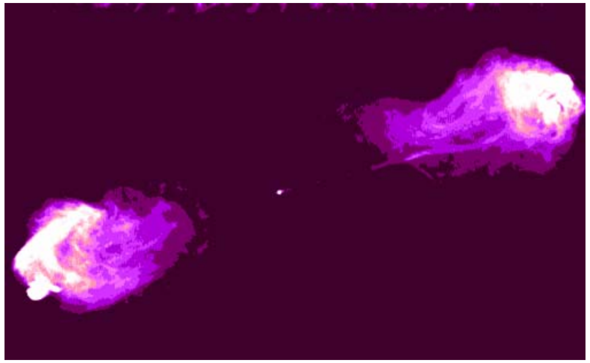
12 FRI
3 FRII
8 SSRQ or CSS

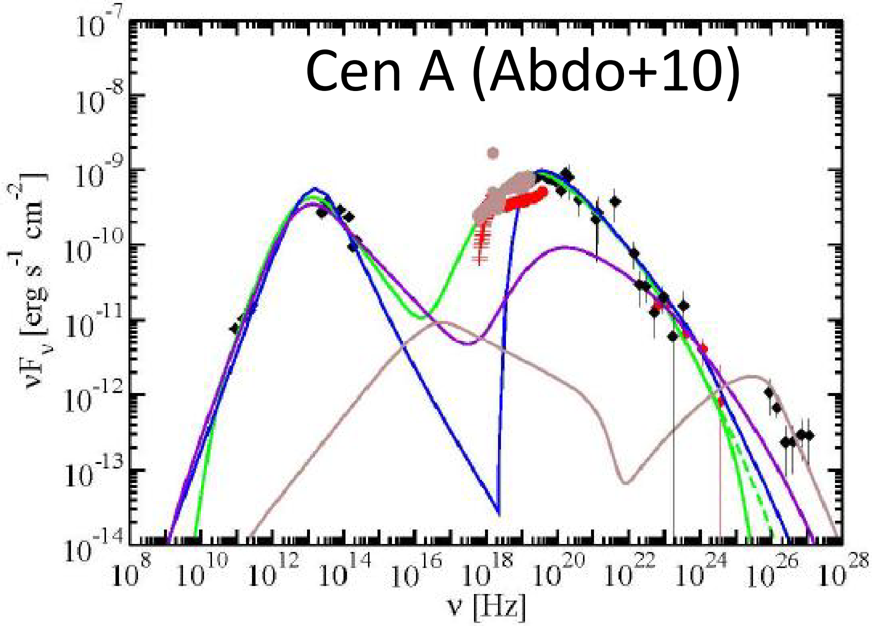
+ five NLSyI

CSS: compact steep spectrum
SSRQ: steep-spectrum radio source

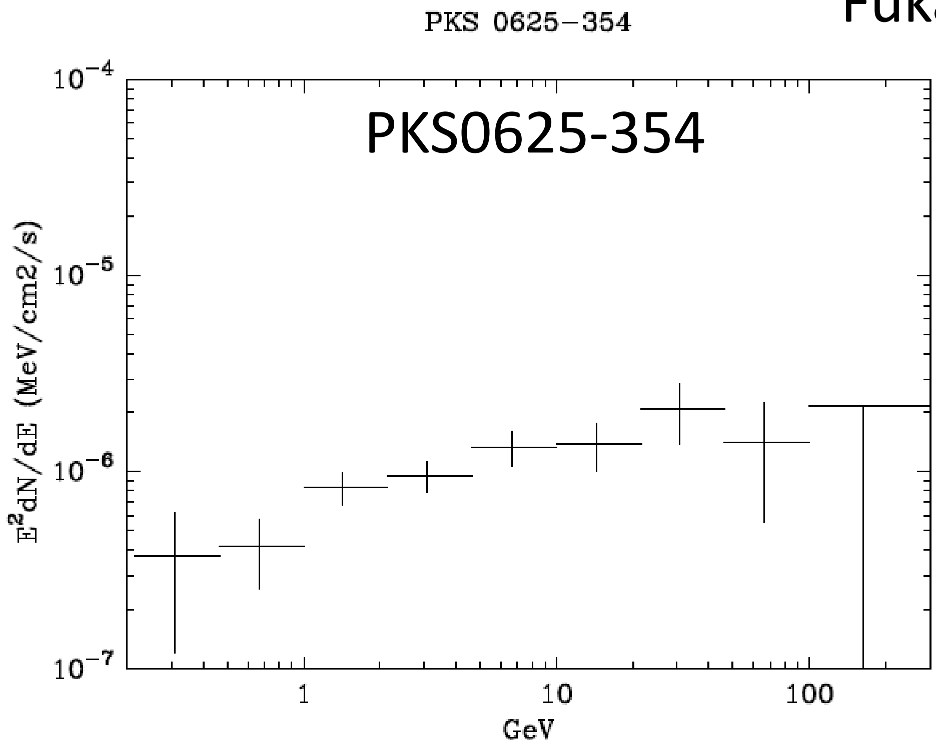
Radio Galaxies (FR-I)
Possible TeV AGNs

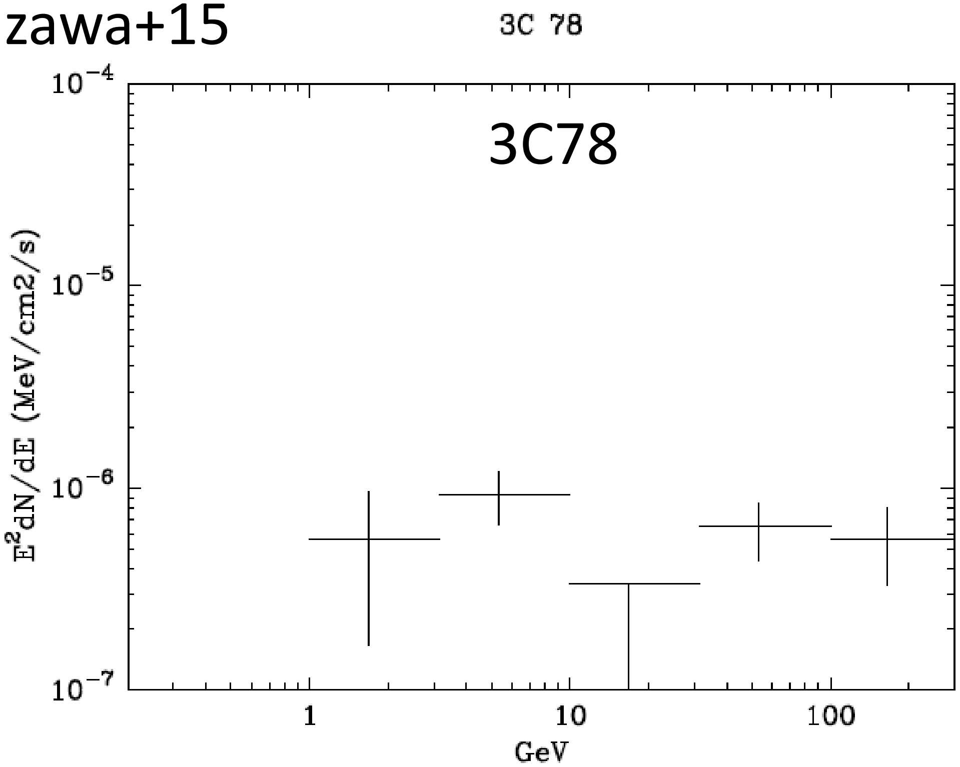
TeV-detected …. NGC1275/M87/Cen A
Other faint sources will be detected with TeV.





Fukazawa+15





Summary

- Fermi sensitivity is being better; compatible with CTA.
  ---- PASS-8, Increasing Photon Statistics
- Fermi-LAT Catalogs based on all-sky survey are very useful for CTA.
- Finding transient objects with Fermi-LAT are also important to trigger MW obs. with CTA.