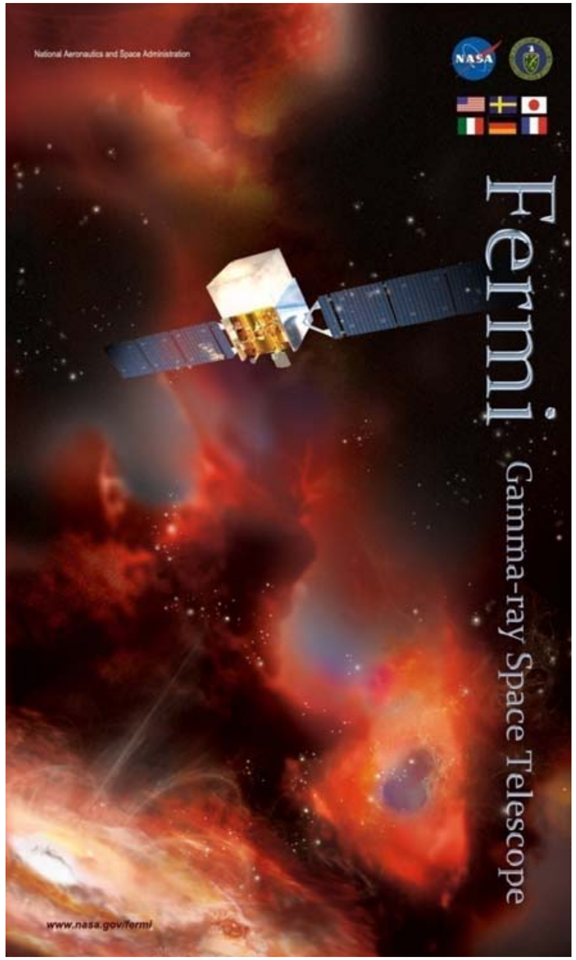
2016.12.16 CTA-Japan conference
“The extreme Universe viewed in very-high-energy gamma-rays 2016”

Recent Fermi results of extragalactic objects and CTA

Fermi Gamma-ray Space Telescope



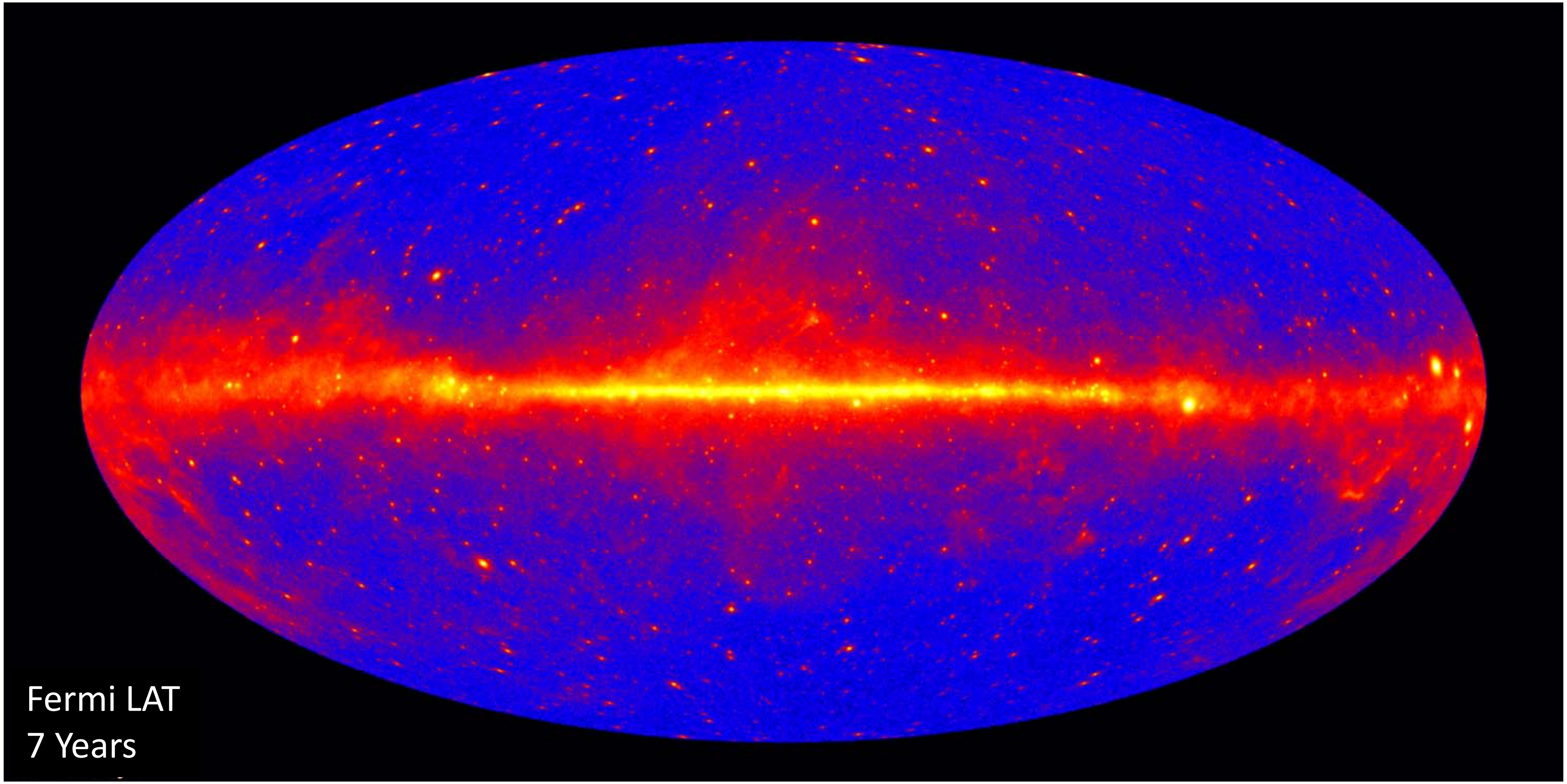
Yasushi Fukazawa
Hiroshima University

Contents

- Recent LAT source/AGN catalogues
- Blazars
- Blazars-related topics
- Other AGNs

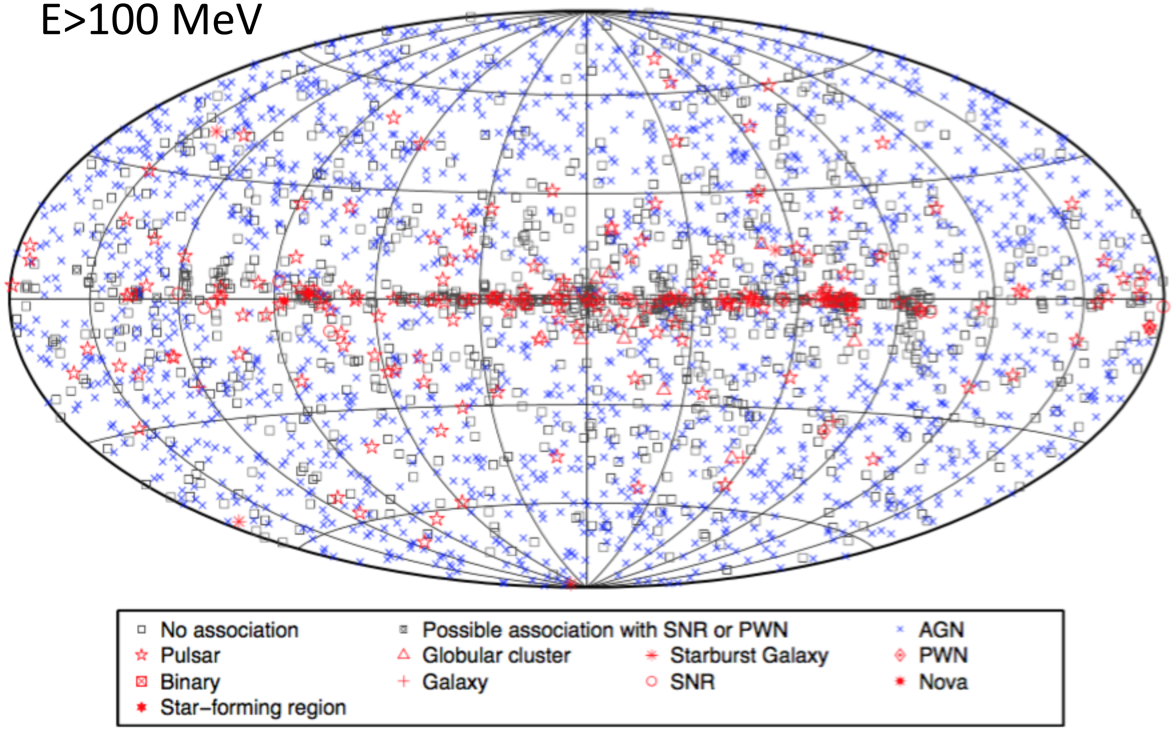
- Recent LAT source/AGN catalogues

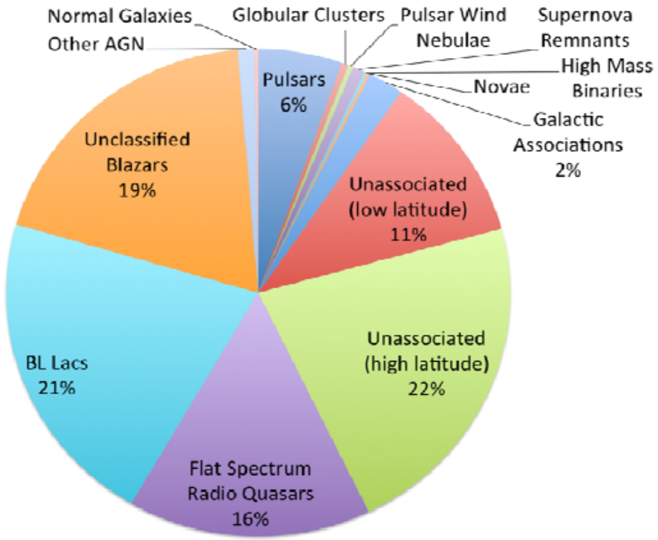
The High Energy γ-ray Sky



3FGL (3rd LAT source catalog)

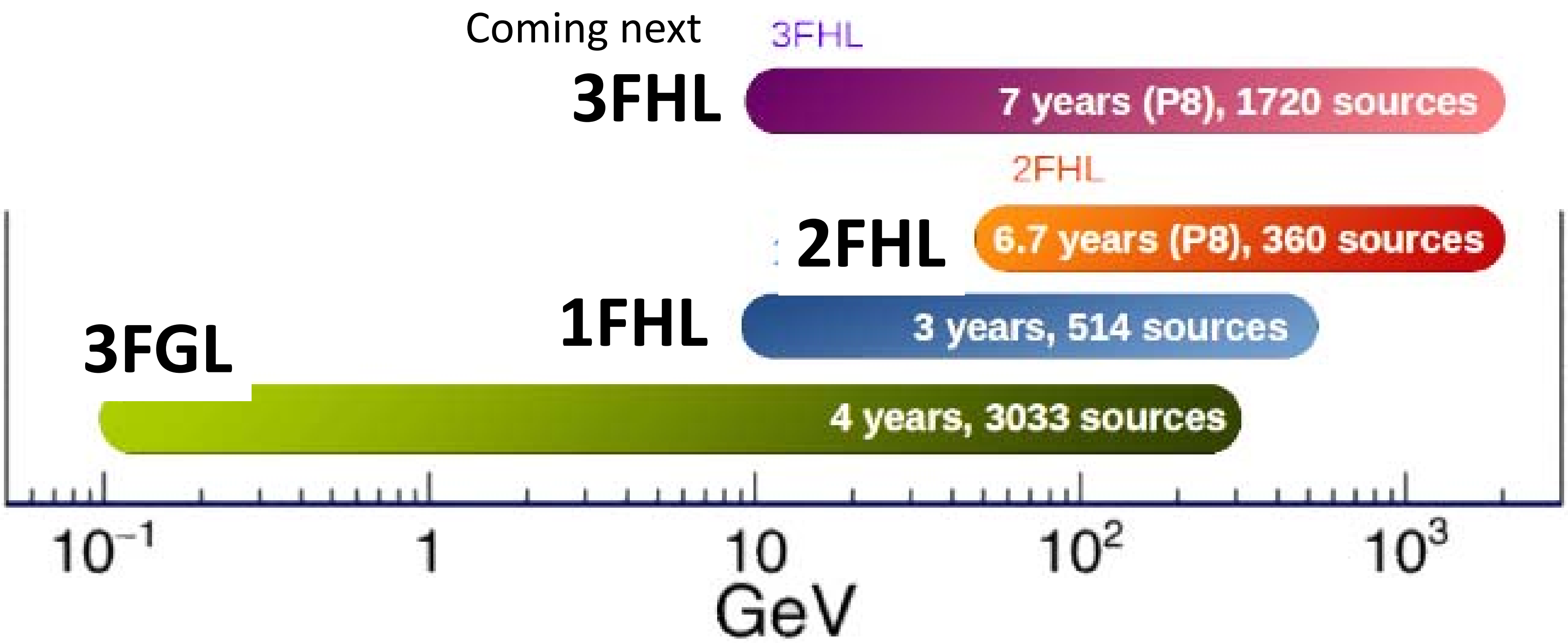
3033 sources
48 months
E>100 MeV



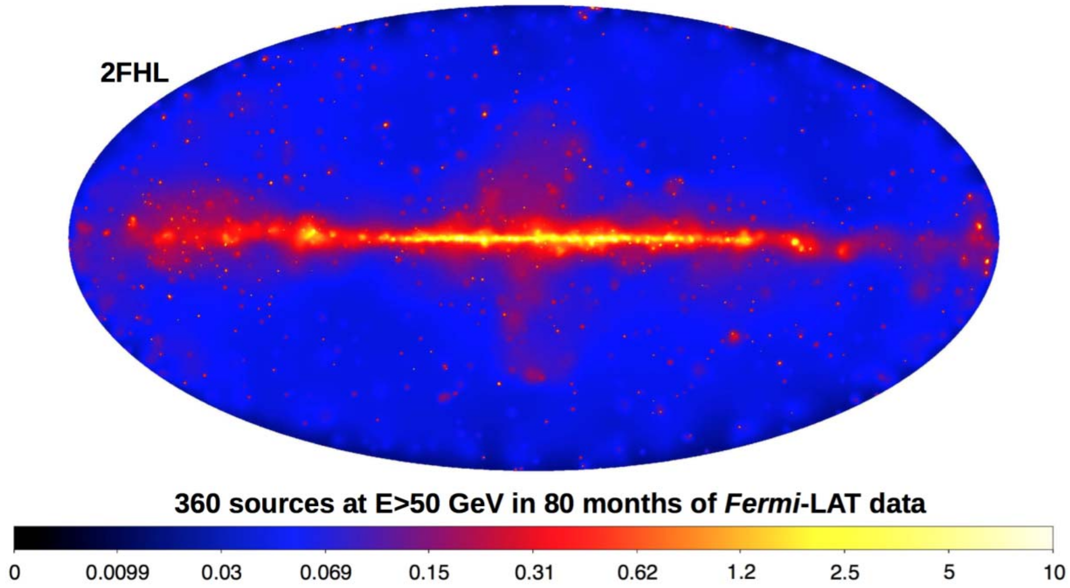


7-year catalog and diffuse model in development.

Recent LAT source catalogs



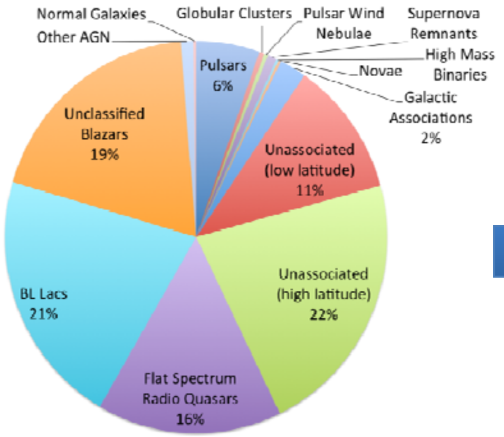
Cataloging Hard Sources



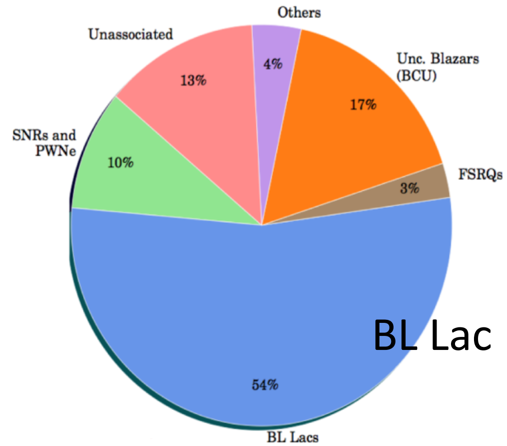
Ackermann et al. (2016)

- Angular resolution is very good
- Background is very low
- Source confusion mostly not an issue
- Transition in types of sources found

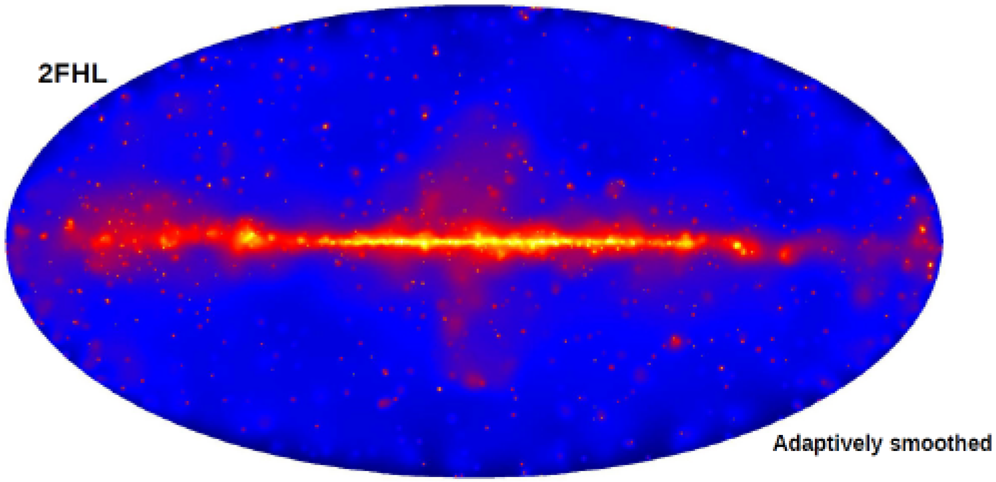
3FGL



2FHL



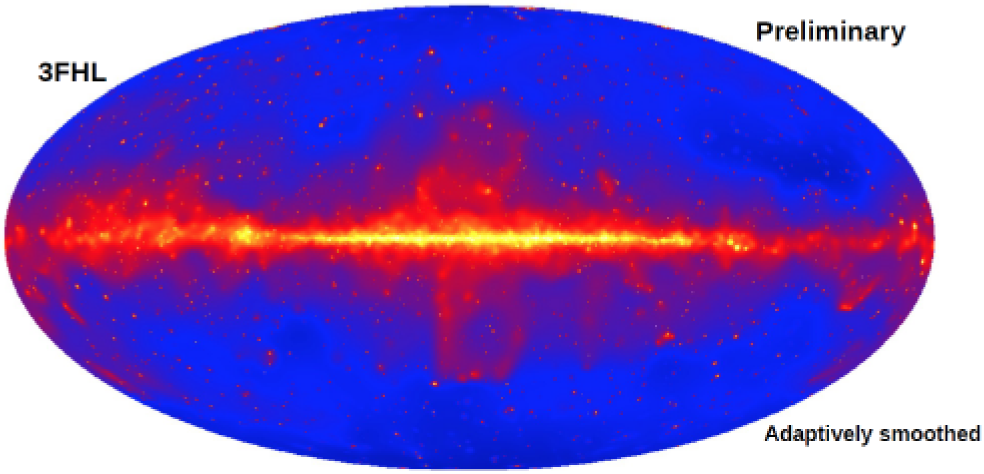
2FHL



2FHL: E>50 GeV
360 sources in 80 months

75% blazars,
11% Galactic sources,
14% unassociated

3FHL

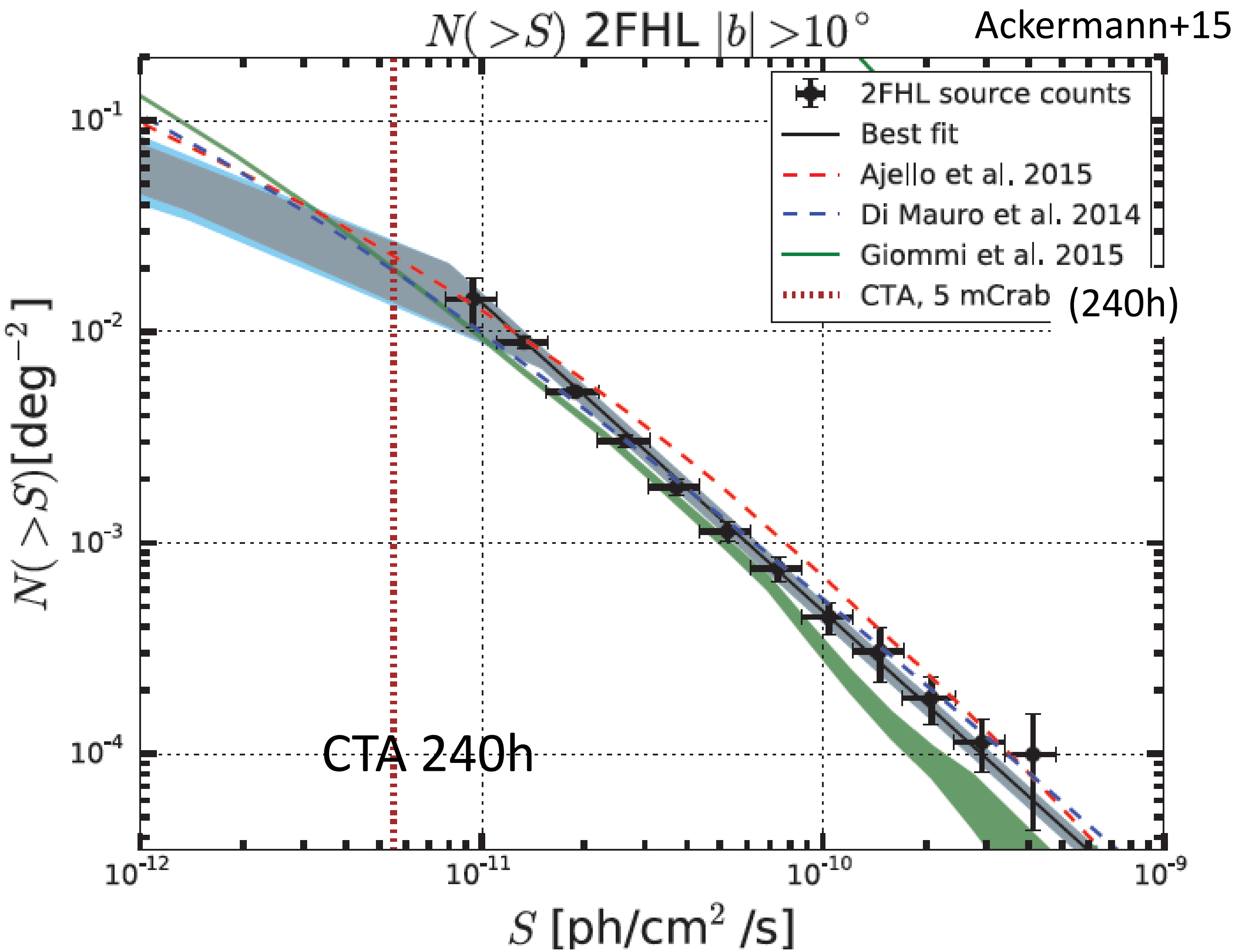


PRELIMINARY

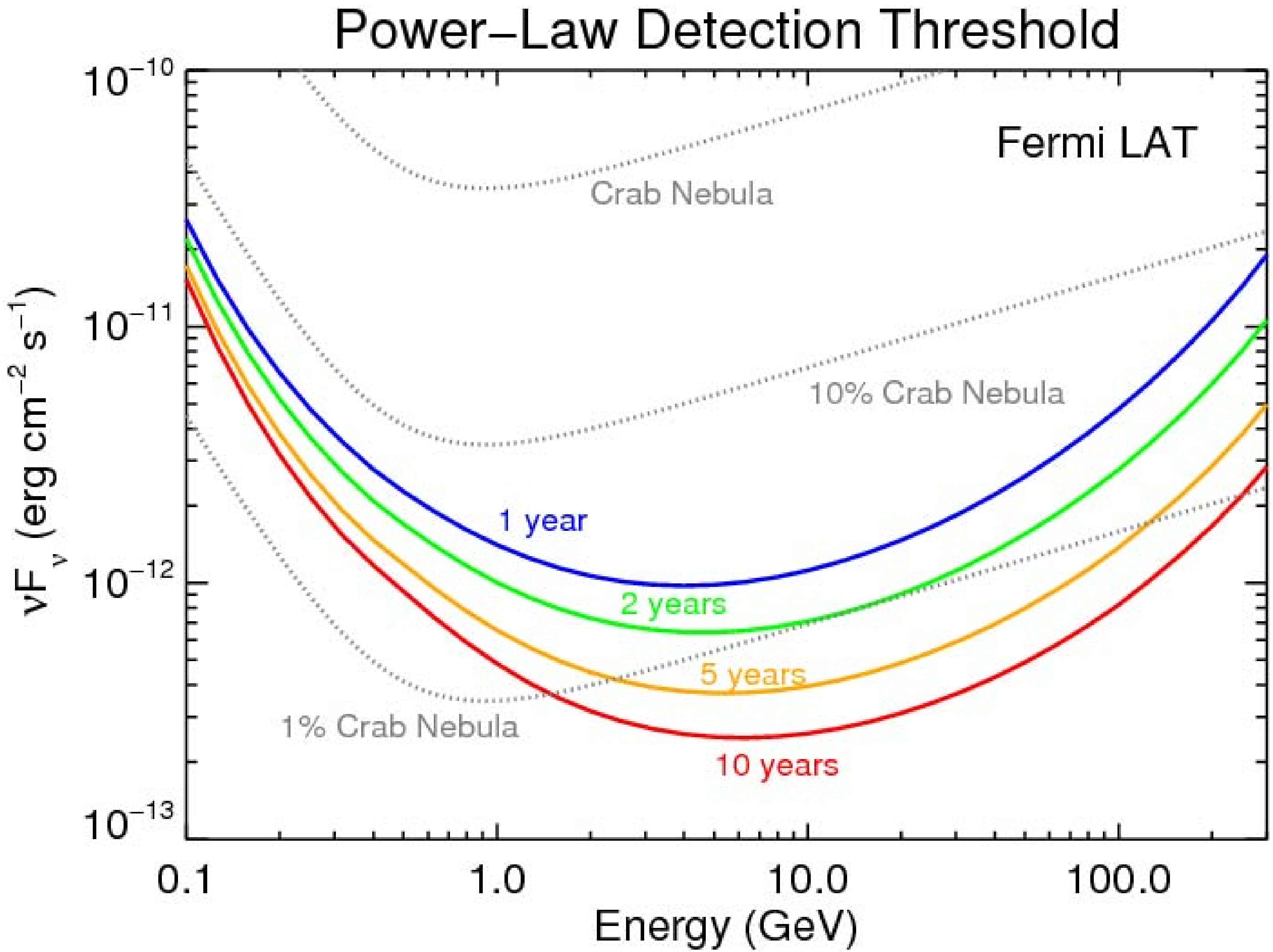
3FHL: E> 10GeV
1720 sources in 84 months

74% extragalactic, 7% Galactic sources, 19% unassociated

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



Sensitivity Improvement

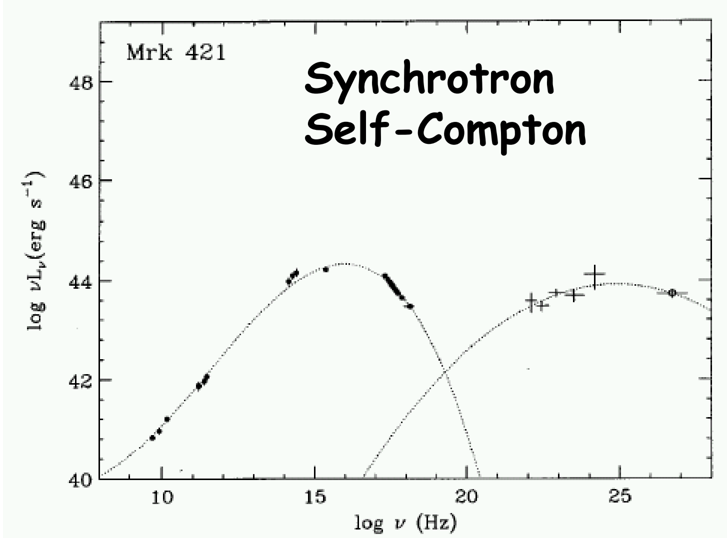


- Blazars

BL Lac (HBL)

TeV BLAZAR

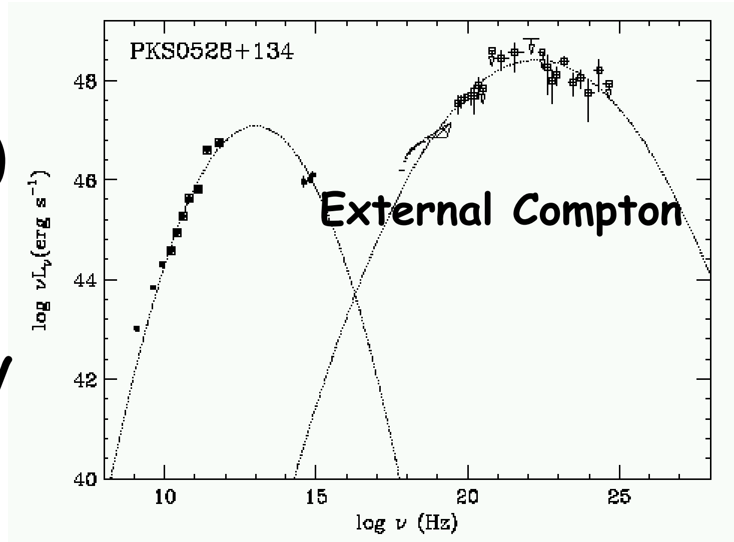
Nearby, Low-L
SED peak : UV/X, TeV



FSRQ
(flat spectrum radio-loud quasor)

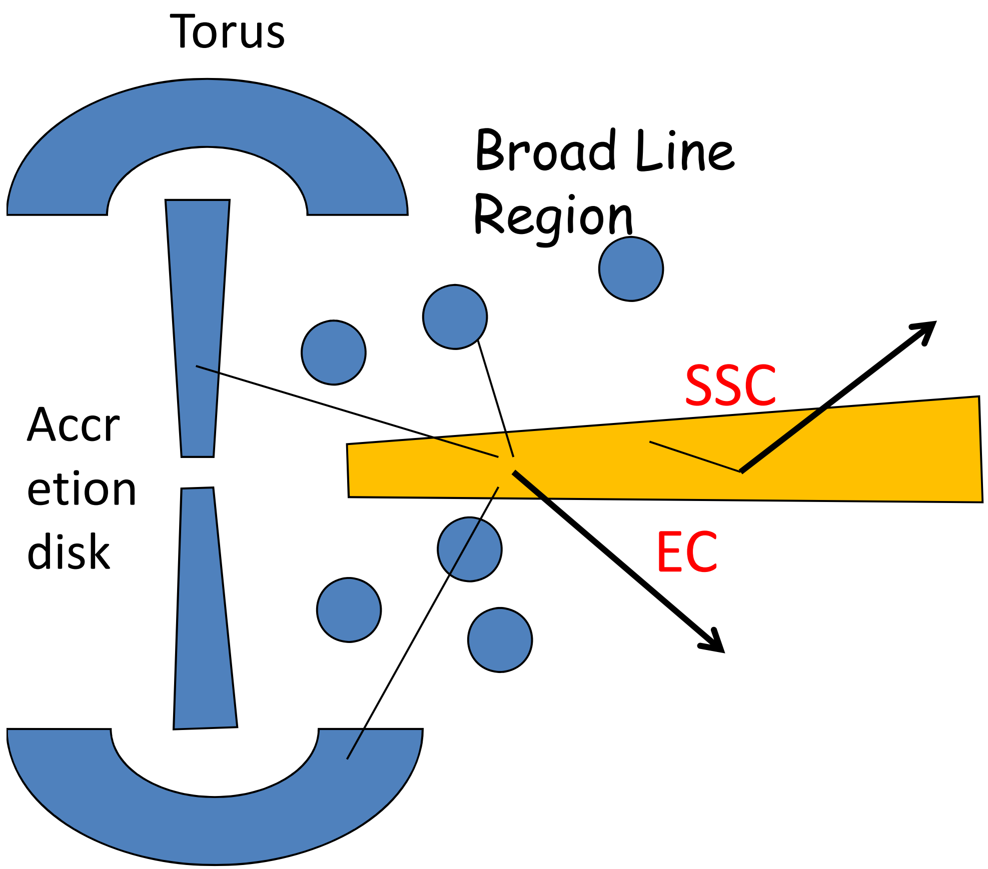
GeV BLAZAR

Distant, High-L
SED-peak : IR/Optical, MeV/GeV



BLAZAR emisson

Leptonic model



Synchrotron Self-Compton

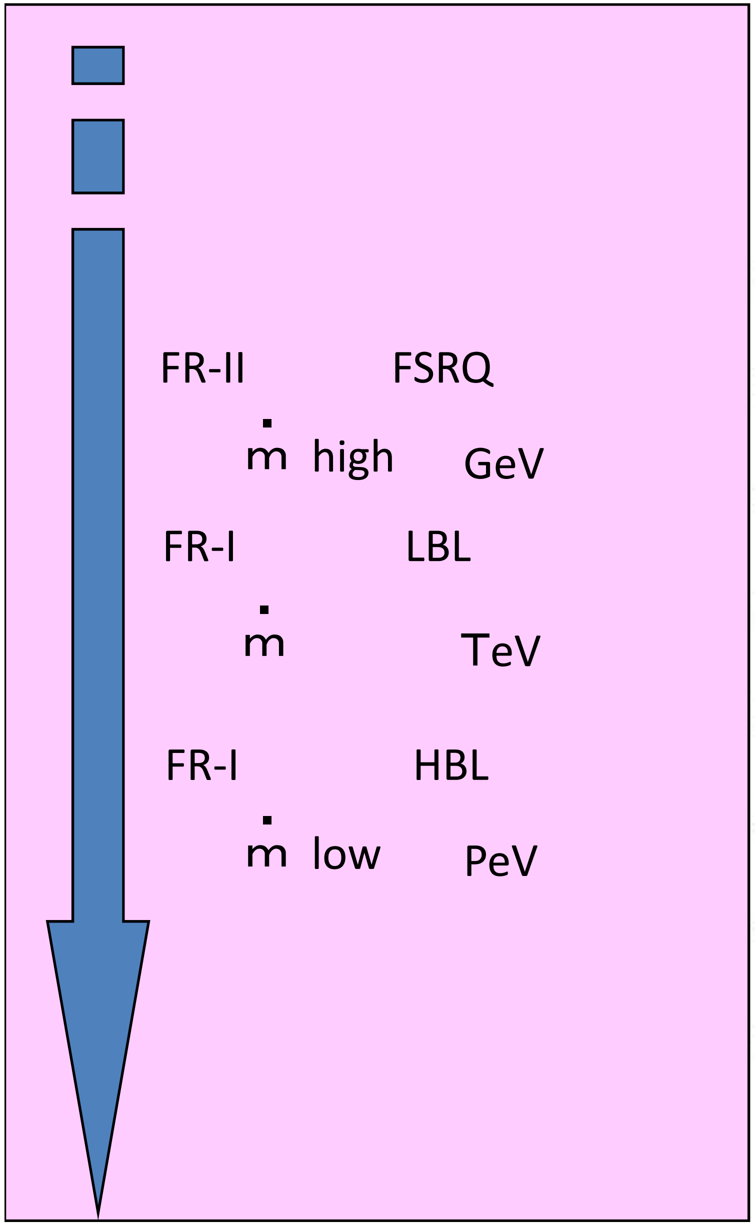
BL Lac, FSRQ

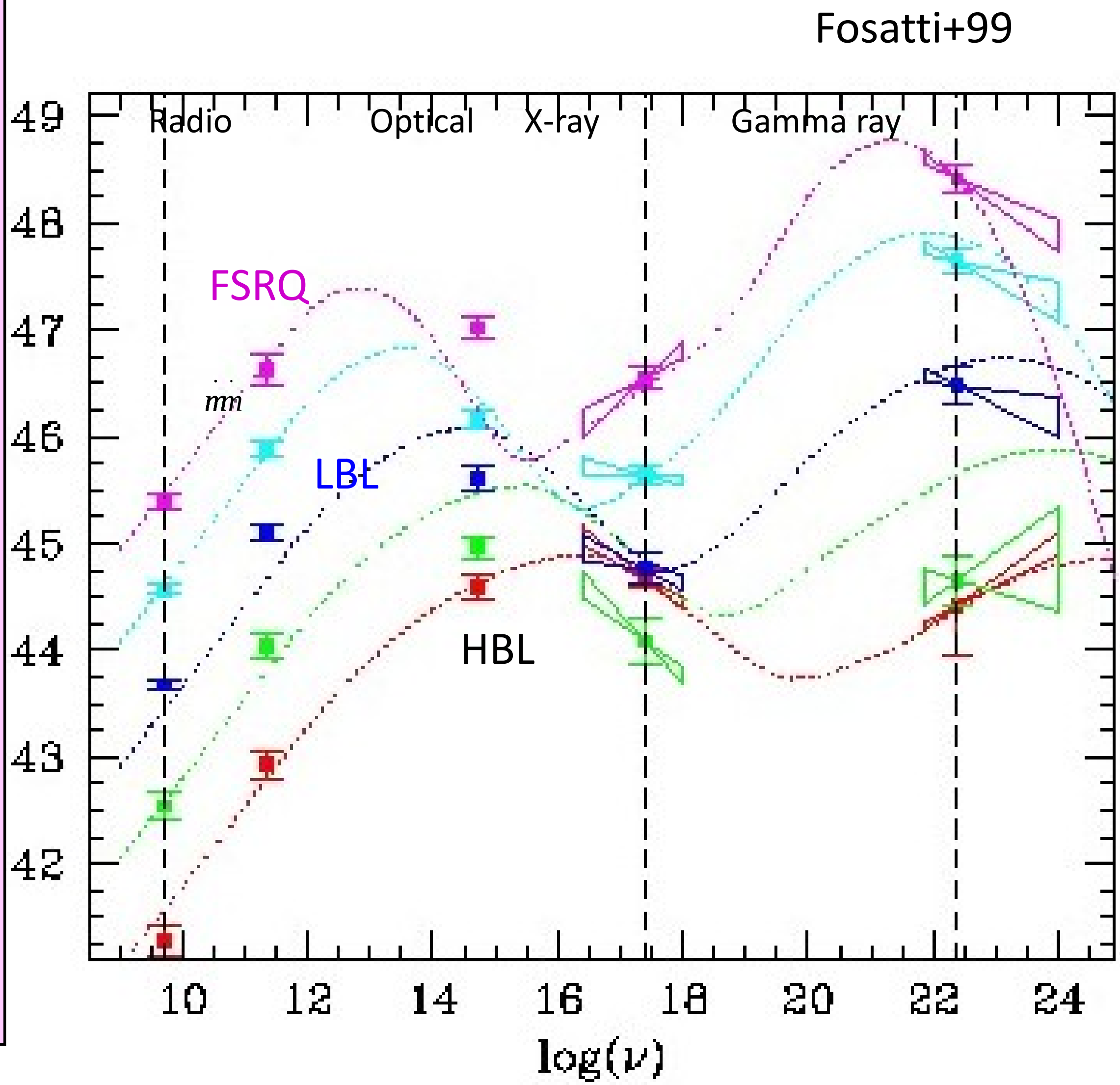
External Compton

Seed photons: disk (UV), broad line region(UV,Opt), Torus(FIR)

FSRQ

BLAZAR Sequence





Blazar Science expected with Fermi

Continuous gamma-ray monitoring and multi-wavelength campaign

Catch big flares

(understanding flares, extracting important parameters,
one-zone or two-zone, interesting phenomena ….)

Successful and Progressed !

Where is gamma-ray emitting region ?

Progressed but not-yet fully resolved

Emission mechanism : leptonic or hadronic ?

Progressed but not-yet resolved

Evolution of blazars

logN-logS, luminosity function, **Progressed but not-yet fully resolved**

extragalactic gamma-ray background

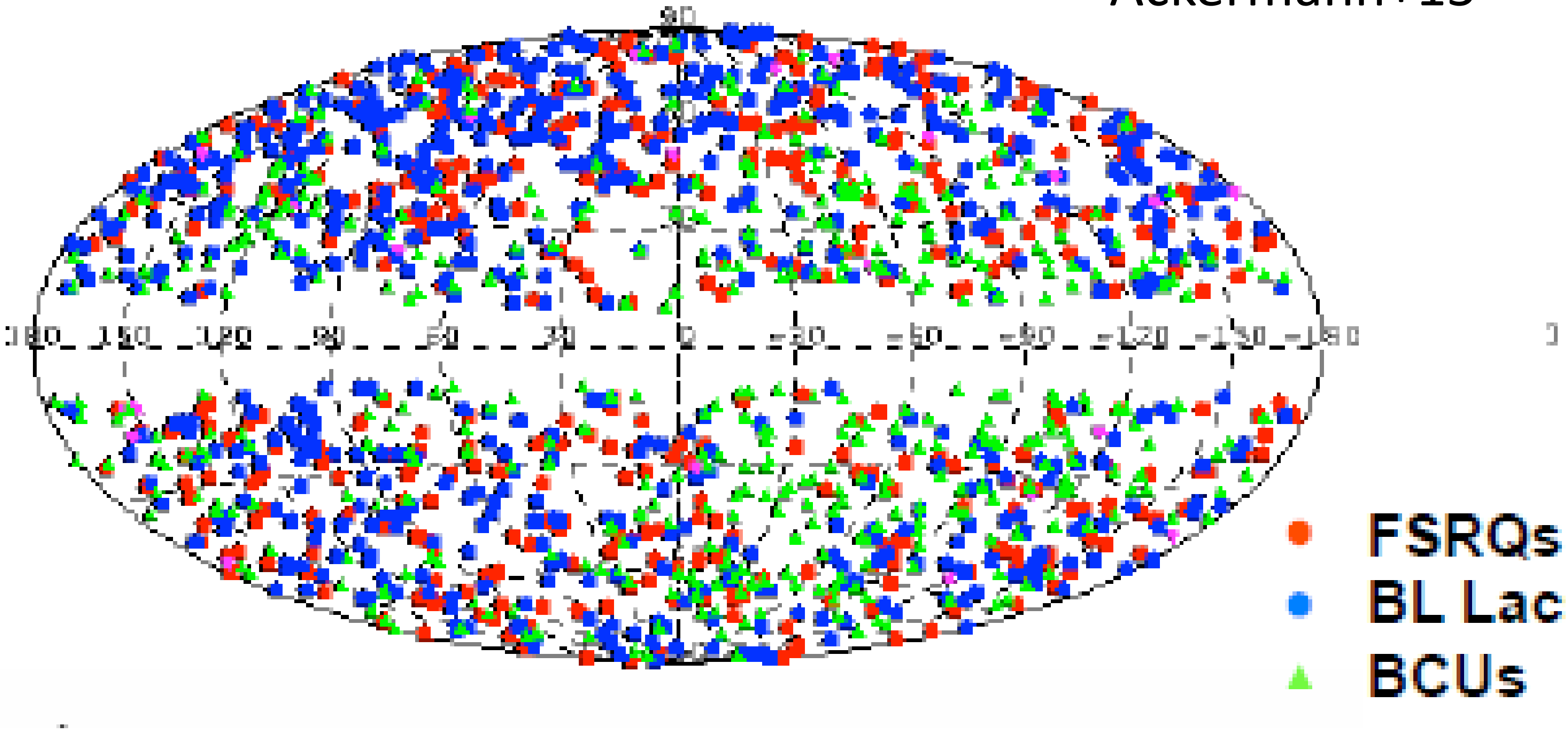
Probe of distant universe **Progressed**

New population of gamma-ray AGNs other than blazars ?

Found and Progressed !

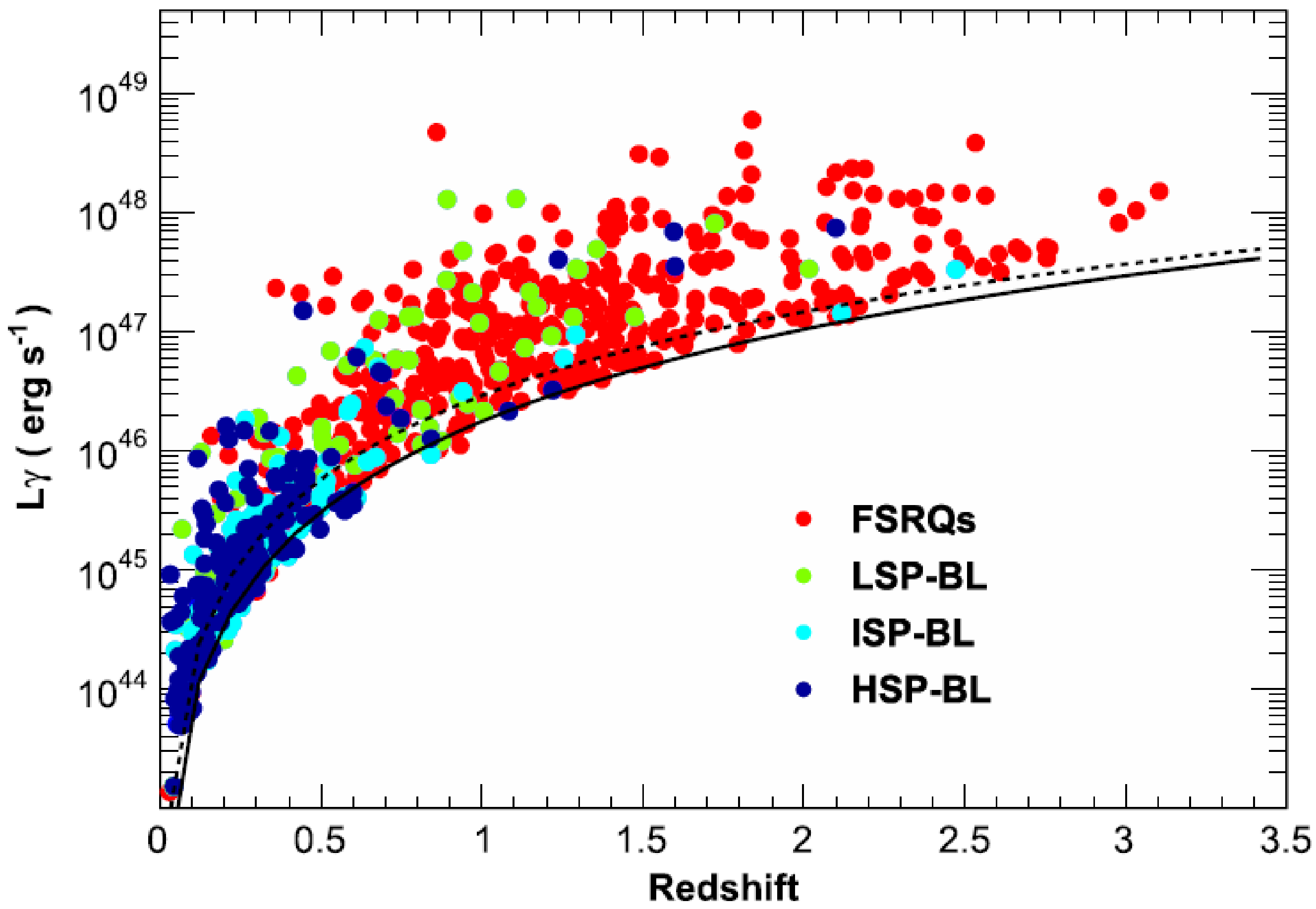
3LAC (3rd AGN Catalog)

Ackermann+15



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

3LAC

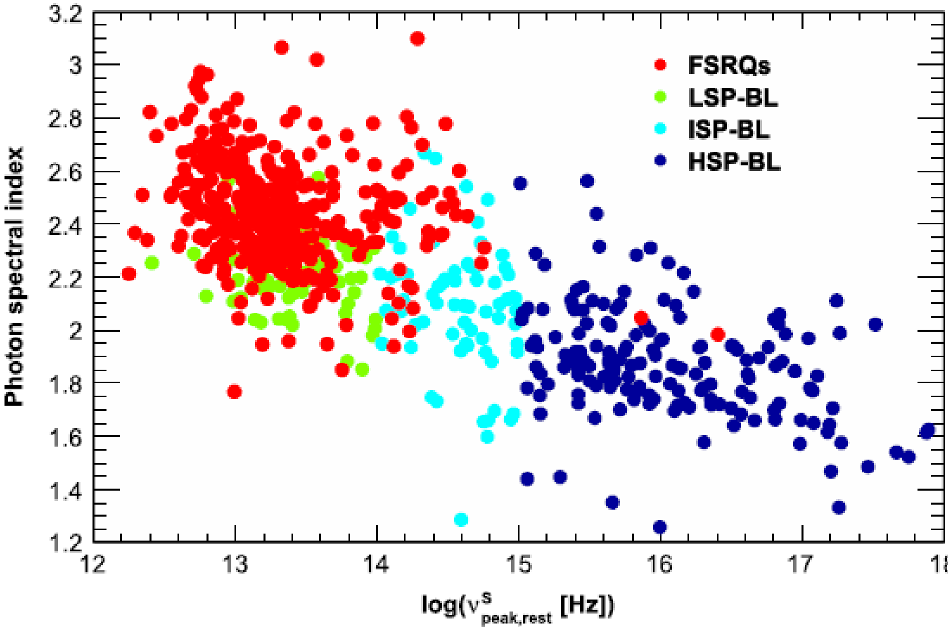


10^{49}
10^{48}
10^{47}
10^{46}
10^{45}
10^{44}
Lγ (erg s^{-1})
0
0.5
1
1.5
2
2.5
3
3.5
Redshift
FSRQs
LSP-BL
ISP-BL
HSP-BL

Most of gamma-ray blazars follow the canonical blazar sequence.

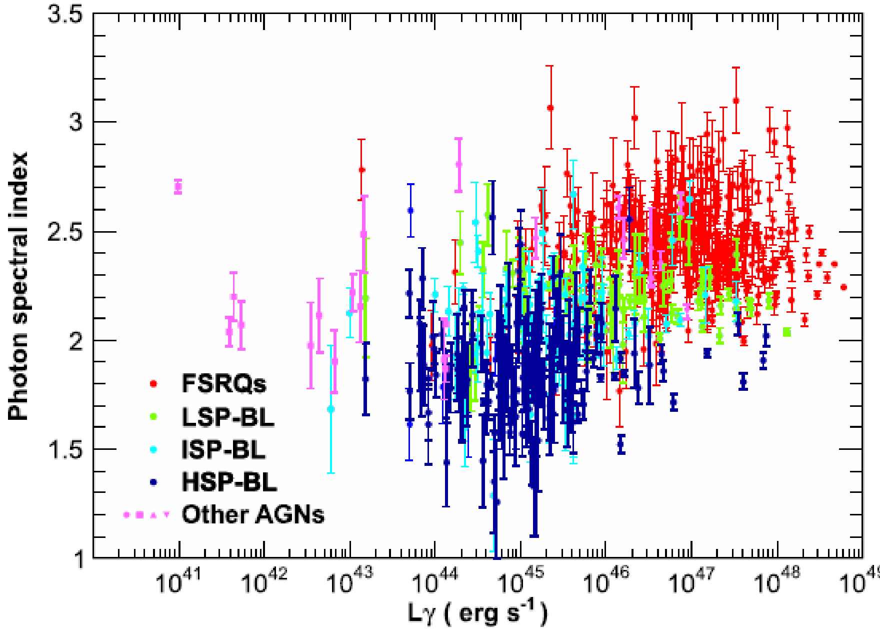
3LAC

Gamma-ray photon index



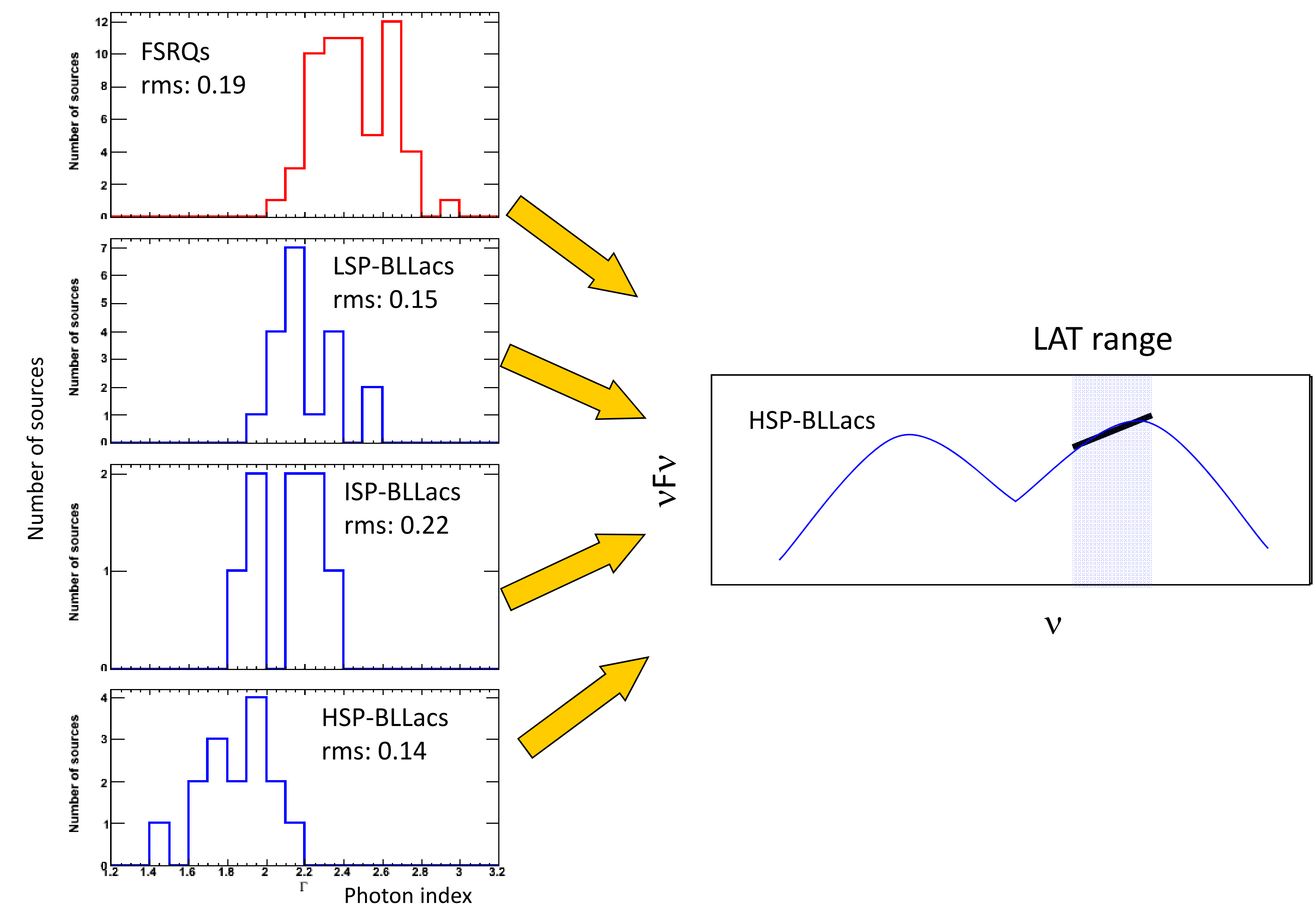
Synchrotron peak frequency

Gamma-ray photon index



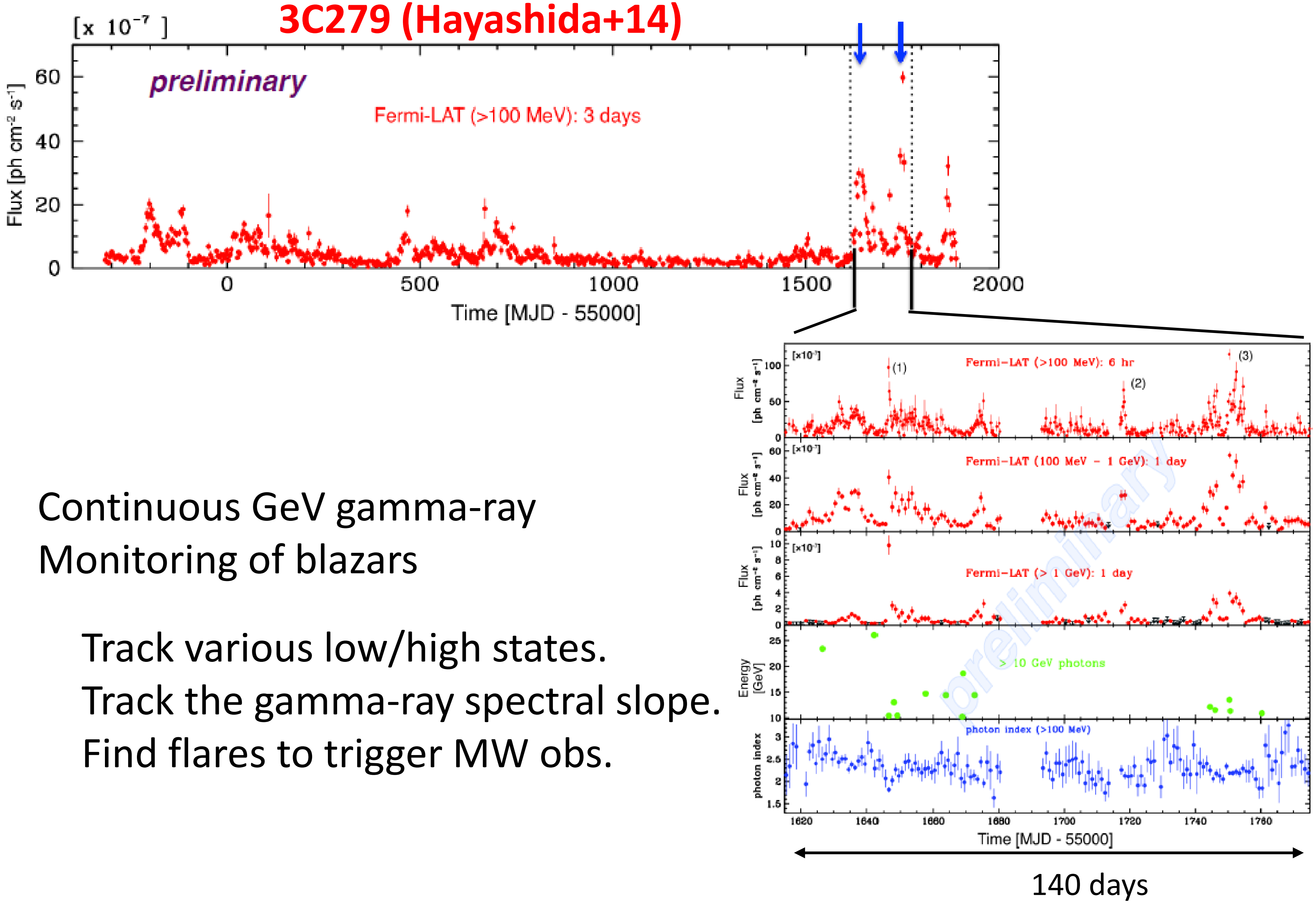
Gamma-ray luminosity

Distribution of gamma-ray photon index



- 2008 August – 2014 August measured by Fermi-LAT

3C279 (Hayashida+14)

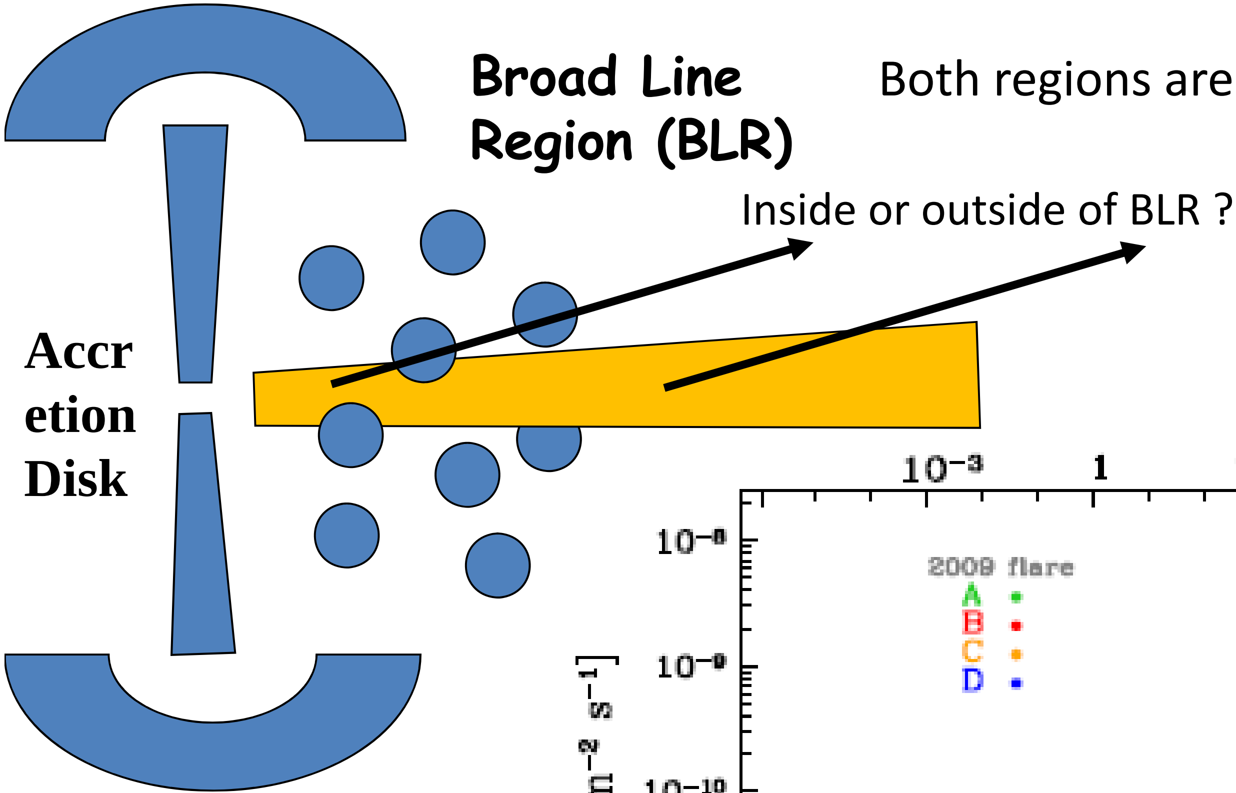


Continuous GeV gamma-ray
Monitoring of blazars

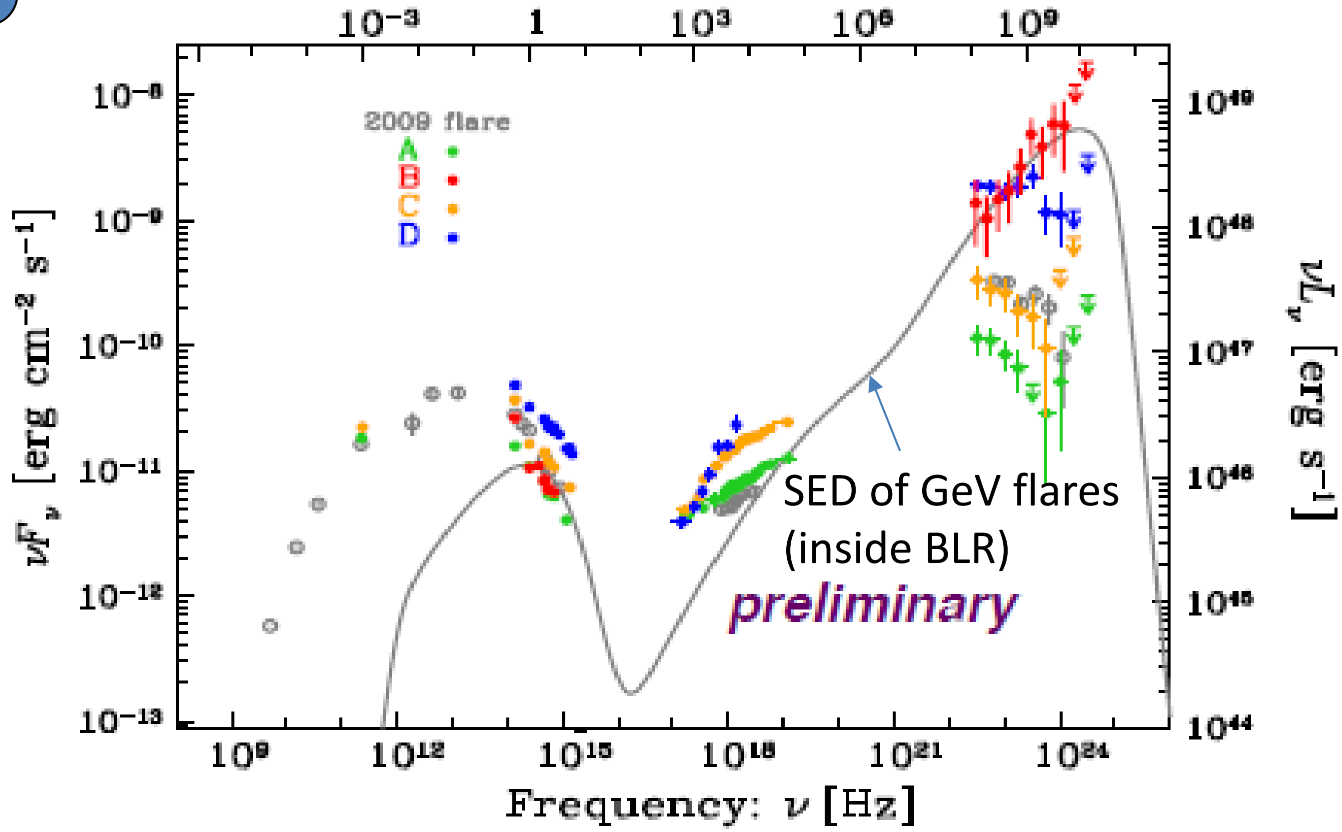
Track various low/high states.
Track the gamma-ray spectral slope.
Find flares to trigger MW obs.

Where is GeV gamma-ray emitting region ?

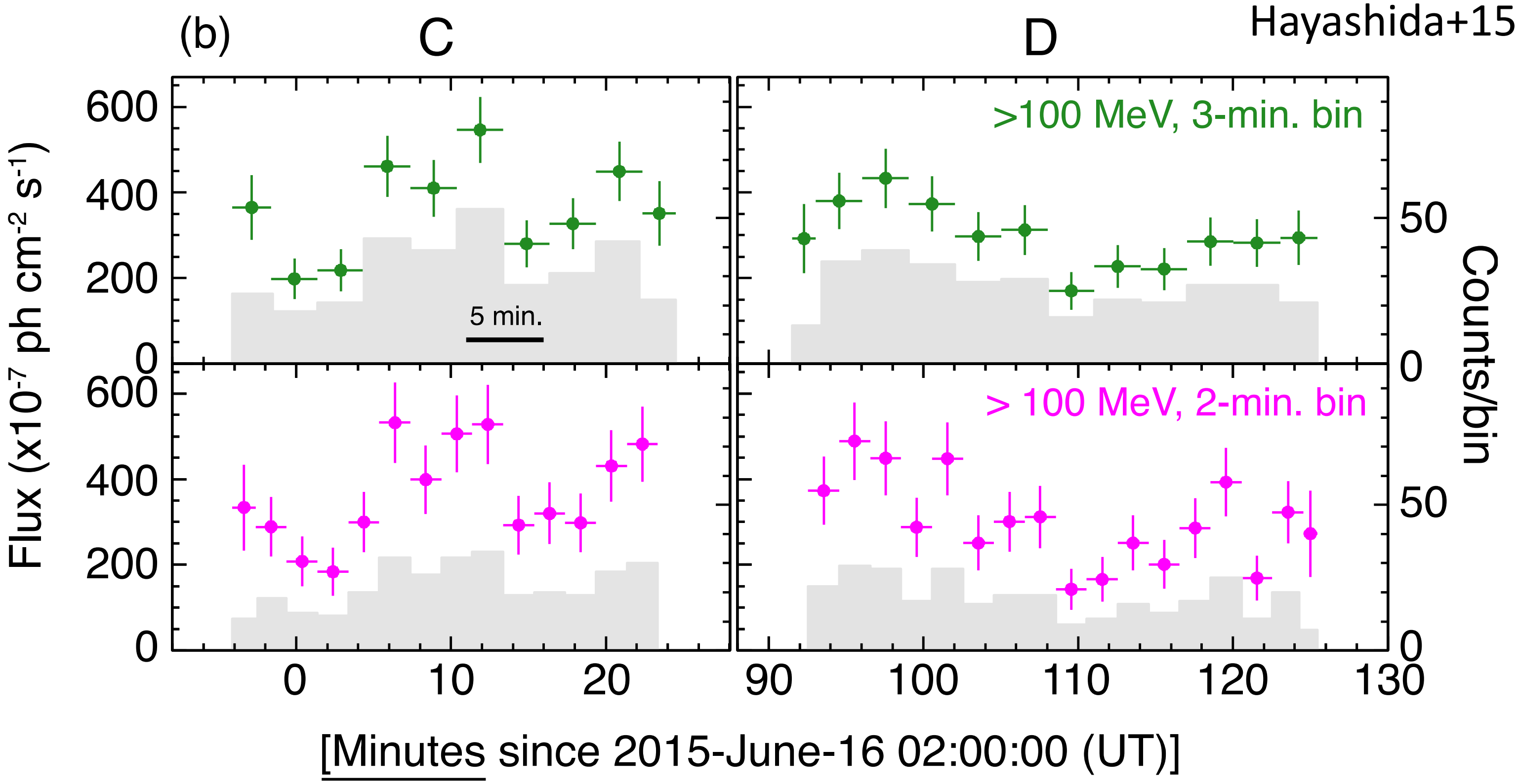
Both regions are possible for some objects.



3C279 (Hayashida+14)



3C279 in 2015: Minute-scale variability by Fermi-LAT



flux reached ~5x10^{-5} ph cm^{-2} s^{-1}

the > 100 MeV flux doubled in ~ 5 minutes

→***minute-scale variability***

Hayashida+15

variability time scale: 5 minutes

- $\boldsymbol{r_{dyn}}$ (emission region size) ~ 10^{-4} (δ/50) pc (~3×10^{14} cm)
- $\boldsymbol{R_{location}}$ (emission location) ~r_{dyn}/θ_o ~ 0.005 $(\Gamma/50)^2$ $(\Gamma\theta_o)^{-1}$ pc (~10^{16}cm)

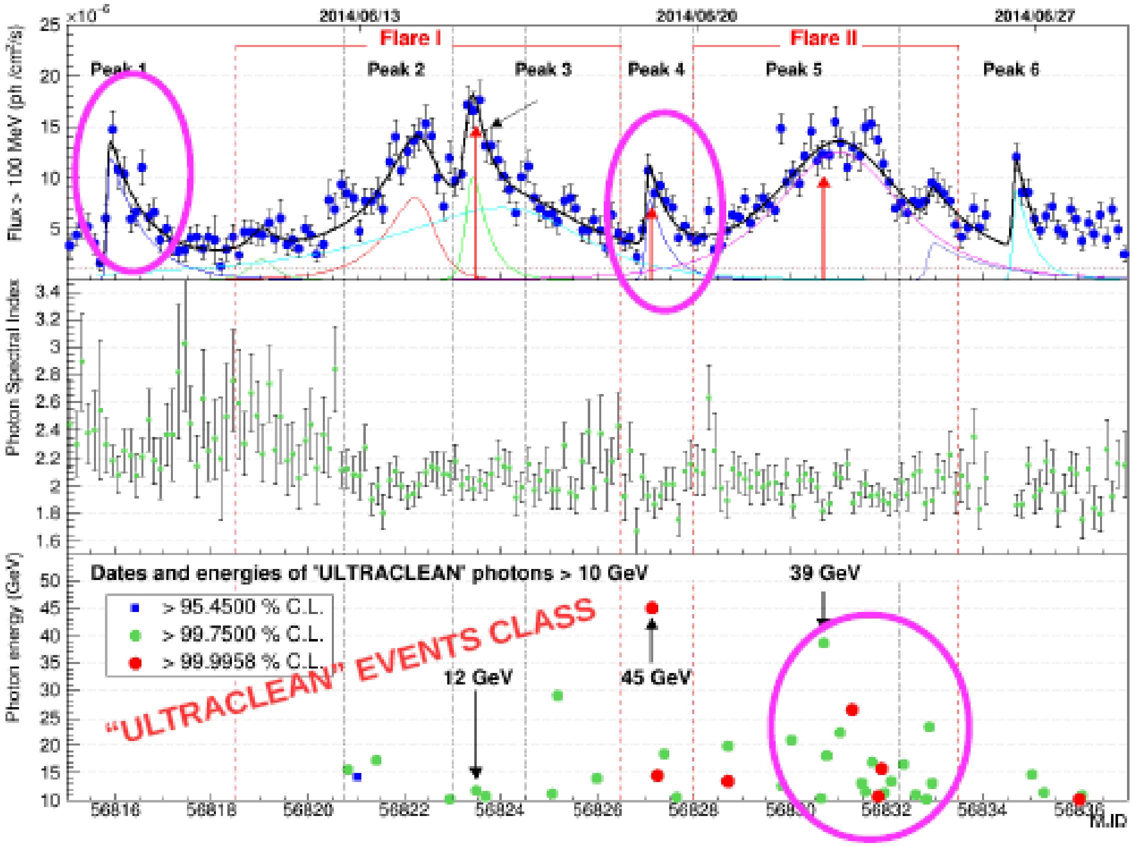
  (R_{BLR} (broad line region size) ~ 0.05 pc)

→ ***very near to BH (inside BLR)*** **~ 100$(\Gamma/50)^2 R_g$**

(R_g ~ 5×10^{-5} pc @ $5 \times 10^8 M_{solar}$)

3C454.3 in 2014 : 10-30 minutes variability

7-29 June 2014 Britto+16



Inside or around BLR

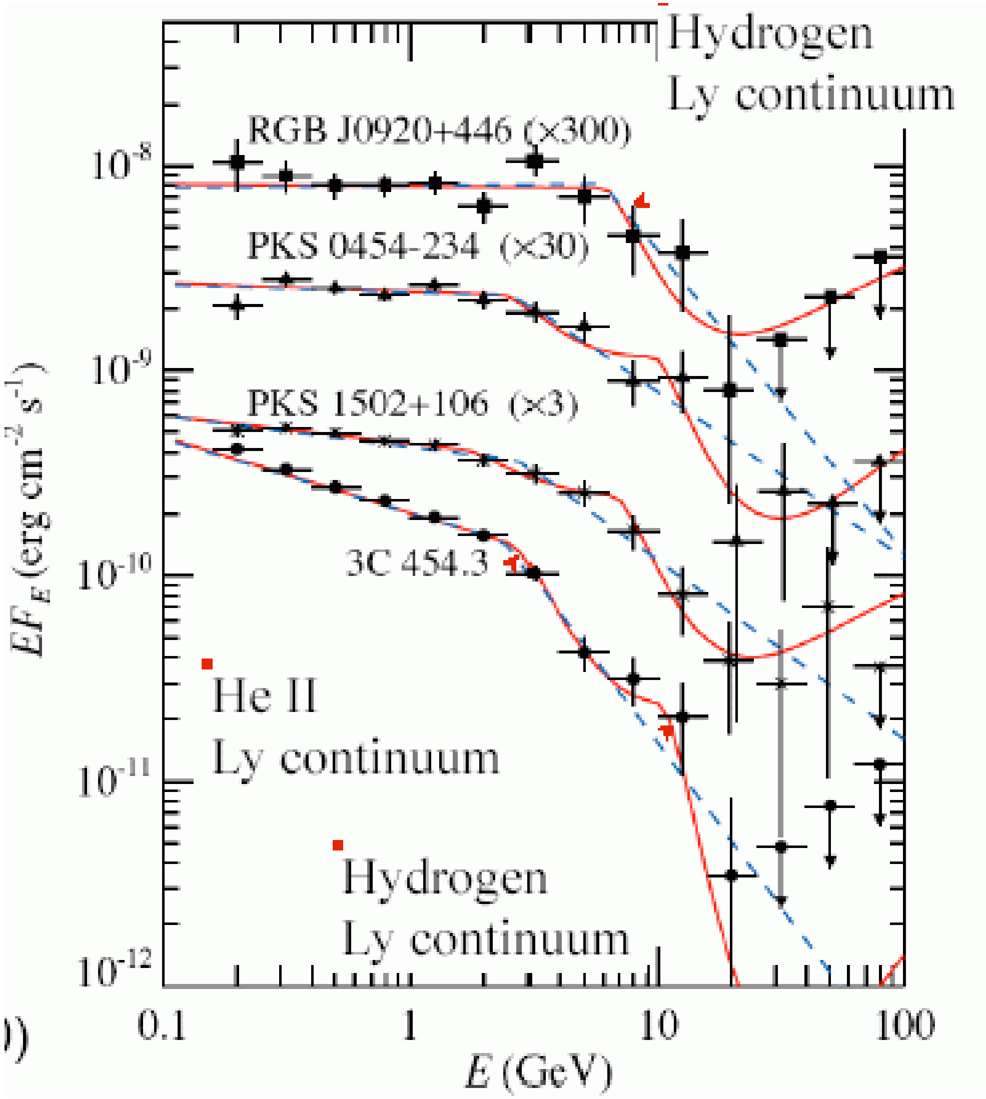
- **Peak 3:** we find **δ ≥ 19** ⟶ **R ≥ 1.6 x 10^{16} cm** ⟶ **Γ_{jet} ~ 10** (12 GeV)
- **Peak 4:** we find **δ ≥ 29** ⟶ **R ≥ 1.0 x 10^{16} cm** ⟶ **Γ_{jet} ~ 16** (45 GeV)
- **Peak 5:** we find **δ ≥ 14** ⟶ **R ≥ 1.4 x 10^{17} cm** ⟶ **Γ_{jet} ~ 7** (39 GeV)

Spectral breaking around GeV in FSRQ
Gamma-ray absorption with He Lyman continuum photons in BLR

Poutanen & Stem 2010

Not Ly α for GeV- break

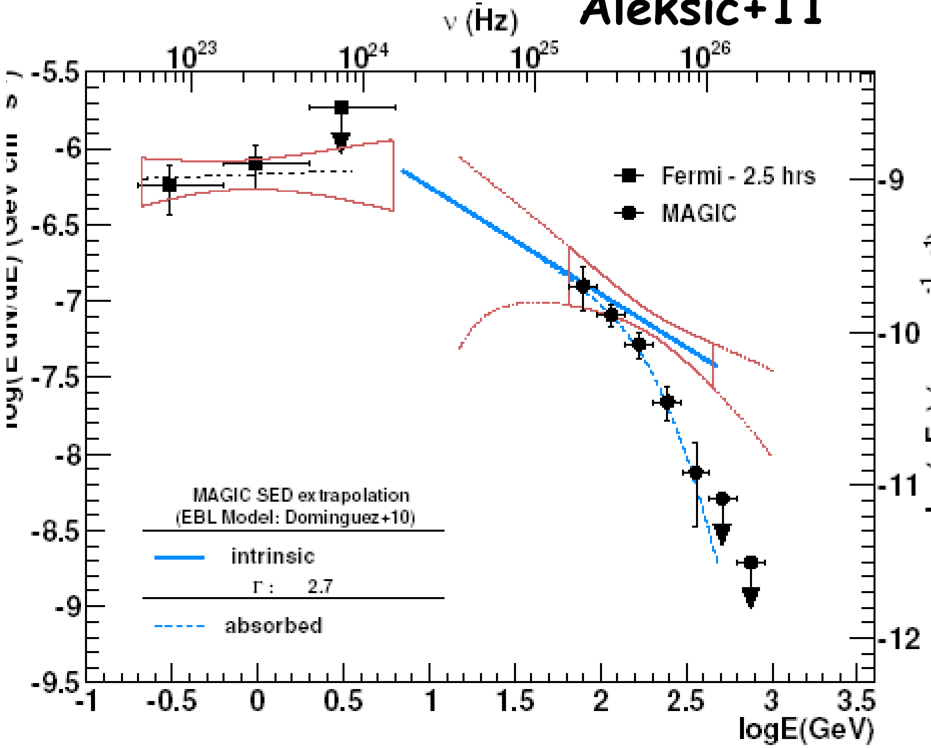
	"Line" energy	Threshold
H I Ly α	10.2 eV –	25.6 GeV
H I Ly cont.	13.6 eV –	19.2 GeV
He II Ly α	40.8 eV –	6.4 GeV
He II Ly cont.	54.4 eV –	4.8 GeV



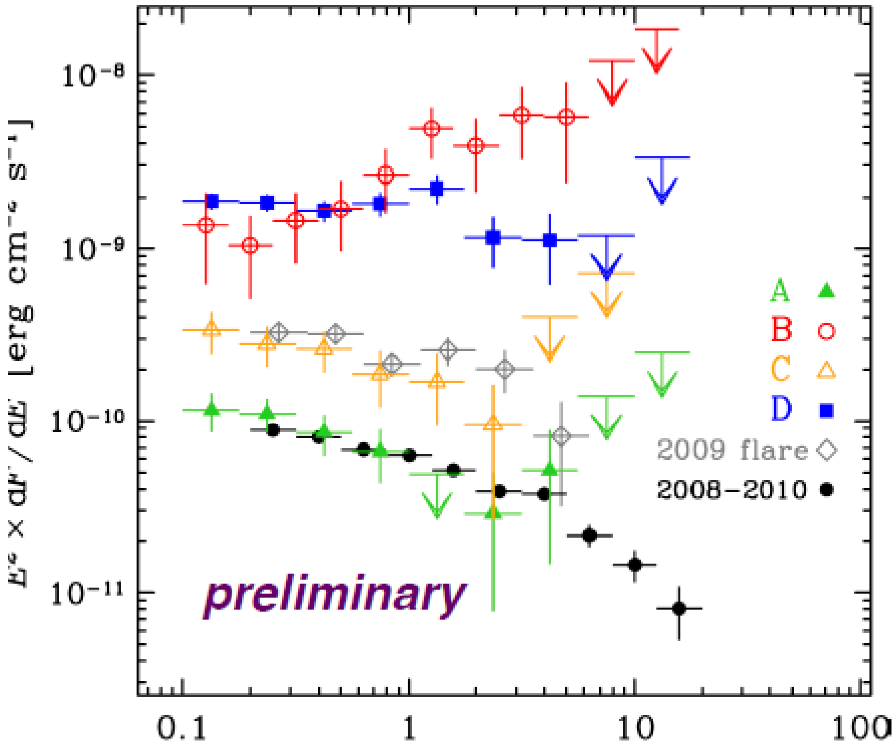
FSRQa are sometimes detected up to TeV

Outside BLR ?

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

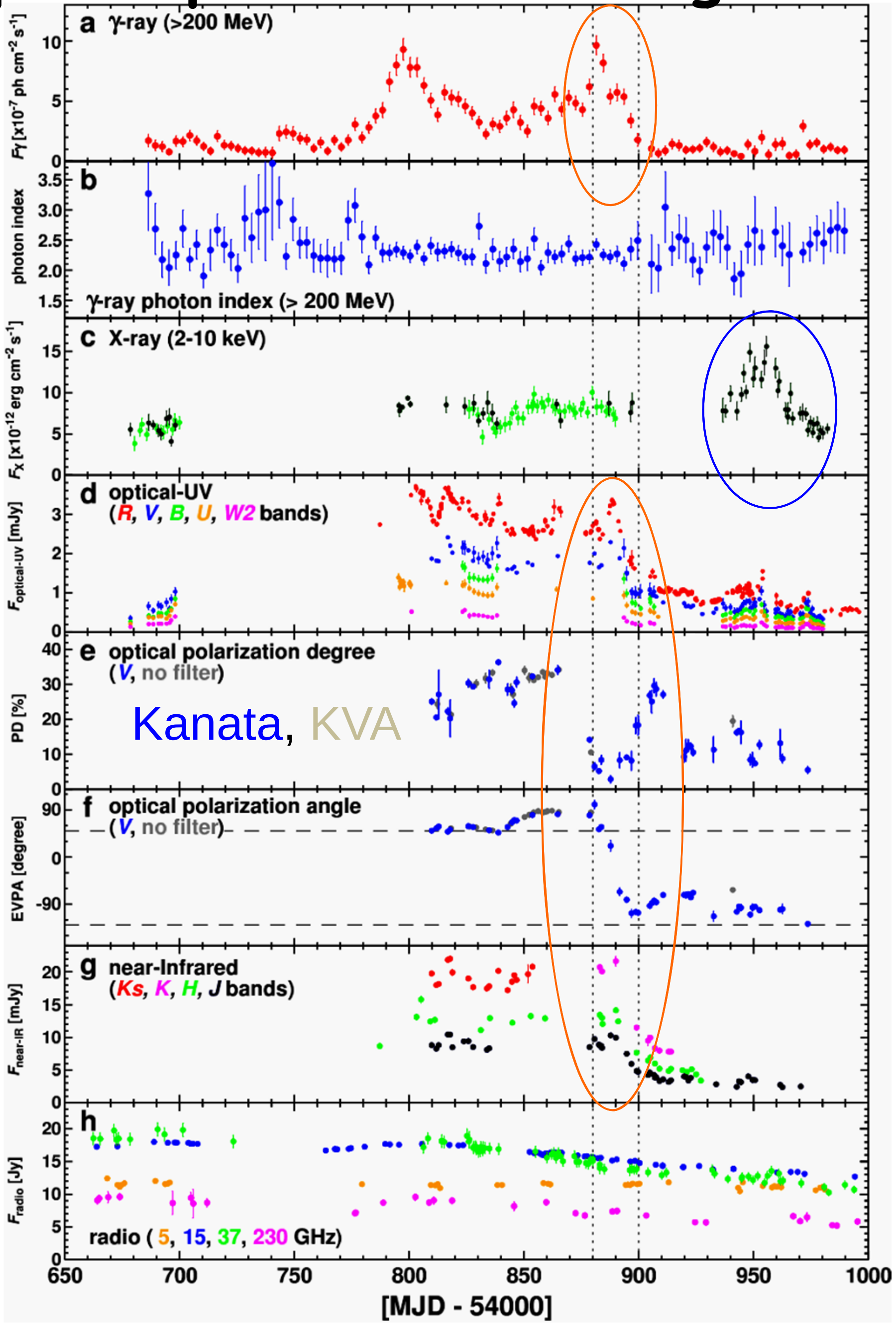


3C279 (Hayashida+14)



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

Optical polarization swing with gamma-ray flare



γ-ray (LAT)

γ-ray photon index (LAT)

X-ray

optical-UV

optical polarization degree (PD)

optical polarization angle (EVPA)

Near-Infrared

Radio

3C279 (Abdo+10)

20 days rotation

Outside BLR ?

TeV Blazars

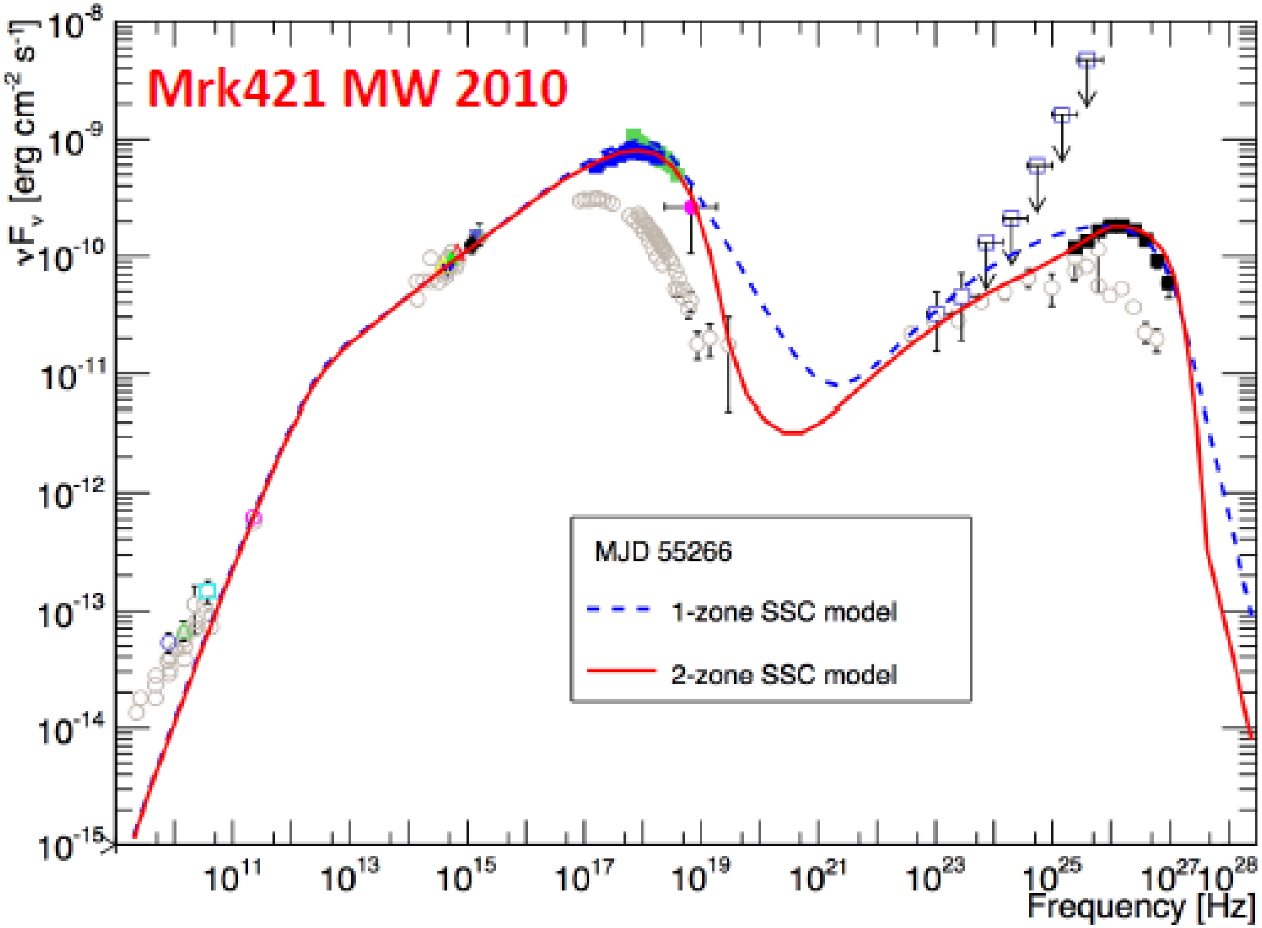
Typically, one-zone model fits SED.

One-zone vs two-zone SSC model

Paneque+14

→ Both of them provide reasonably good agreement

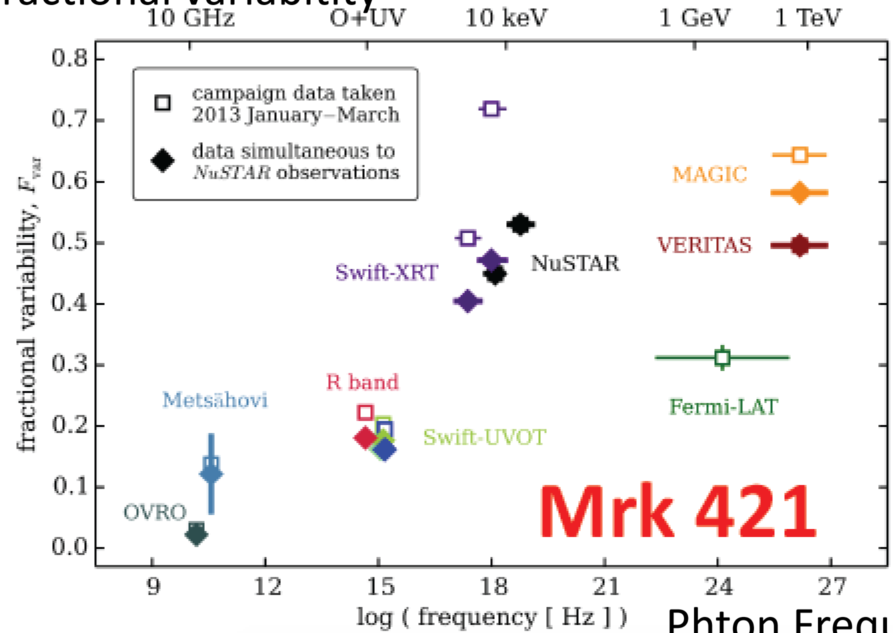
→ Two-zone SSC describes slightly better the narrow peaks



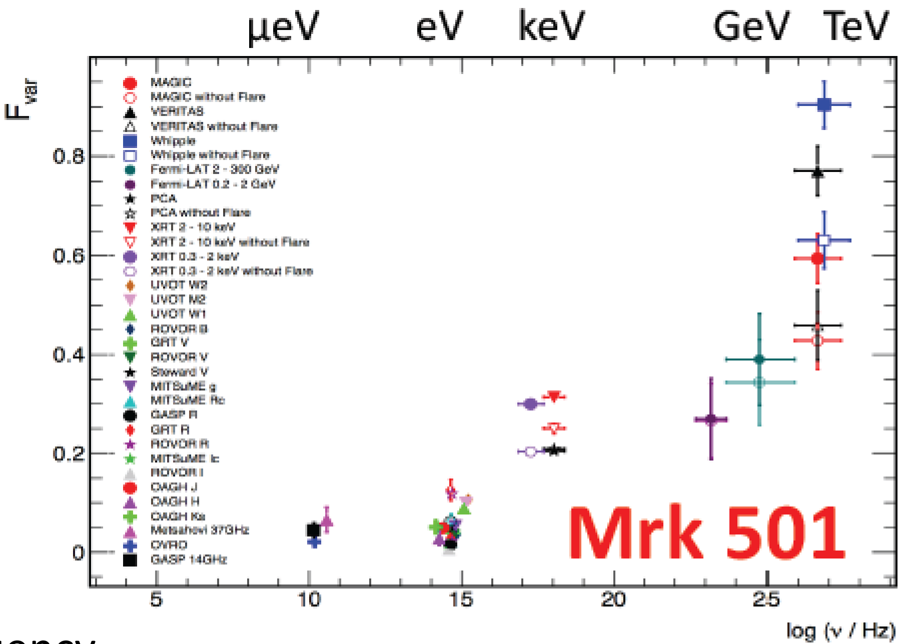
But. Multi-wavelength variability often indicates not simple one-zone ! CTA is important.

Balokovic et al., 2016 *ApJ* 819, 156

Fractional varibitity



Ahnen et al. Submitted to A&A



Phton Frequency

Typically, we measure that:

F_{var} (**Mkr421**): clear double-peaked structure, **Fvar (X-rays) ~ Fvar(VHE)**

F_{var} (**Mrk501**): monotonic increase with energy, **Fvar(X-rays) < Fvar(VHE)**

→ Note observational bias due to lack of complete energy coverage

→ **e.g.** *Fvar at Hard X-rays (>100 keV) expected to be larger*

From D.Panique's slides

Leptonic or Hadronic ?

Mrk421 SED described with a
Leptonic scenario

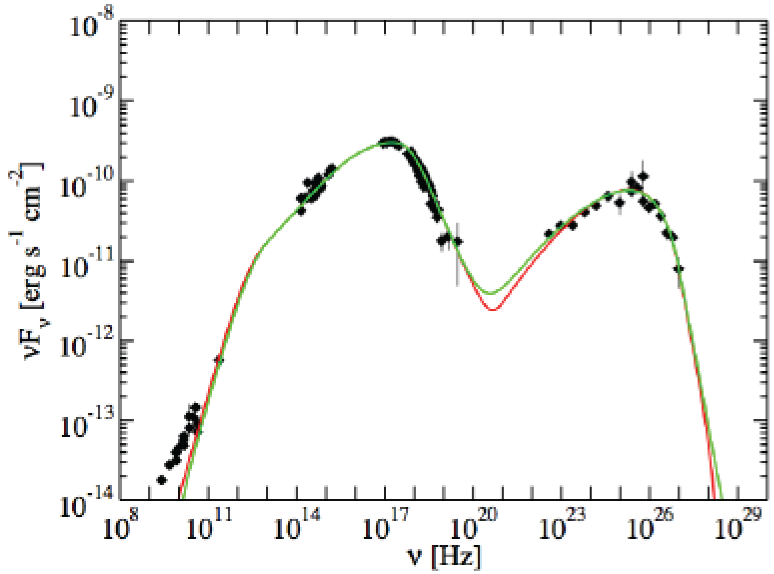


Figure 11. SED of Mrk 421 with two one-zone SSC model fits obtained with different minimum variability timescales: $t_{var} = 1$ day (red curve) and $t_{var} = 1$ hr (green curve). The parameter values are reported in Table 4. See the text for further details.

Mrk421 SED described with a
Hadronic scenario

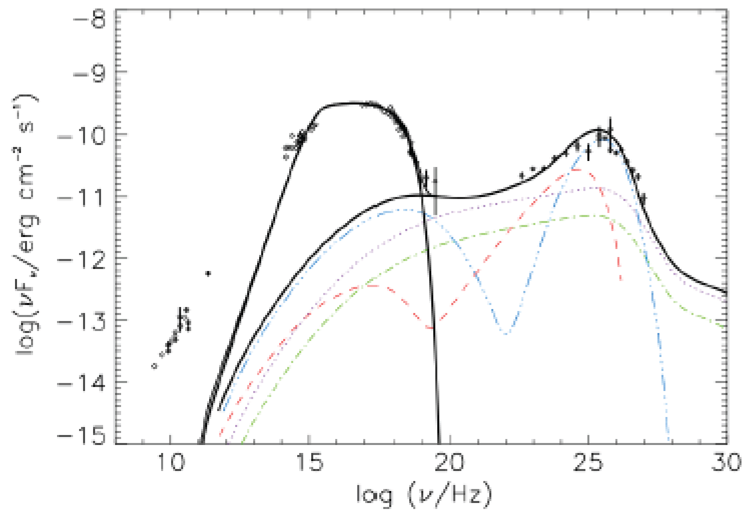


Figure 9. Hadronic model fit components: π^0-cascade (black dotted line), $\pi^{\pm}$ cascade (green dash-dotted line), μ-synchrotron and cascade (blue triple-dot-dashed line), and proton synchrotron and cascade (red dashed line). The black thick solid line is the sum of all emission components (which also includes the synchrotron emission of the primary electrons at optical/X-ray frequencies). The resulting model parameters are reported in Table 3.

Abdo et al., ApJ 736 (2011) 131

Multi-band variability is key to distinguish between models

CTA

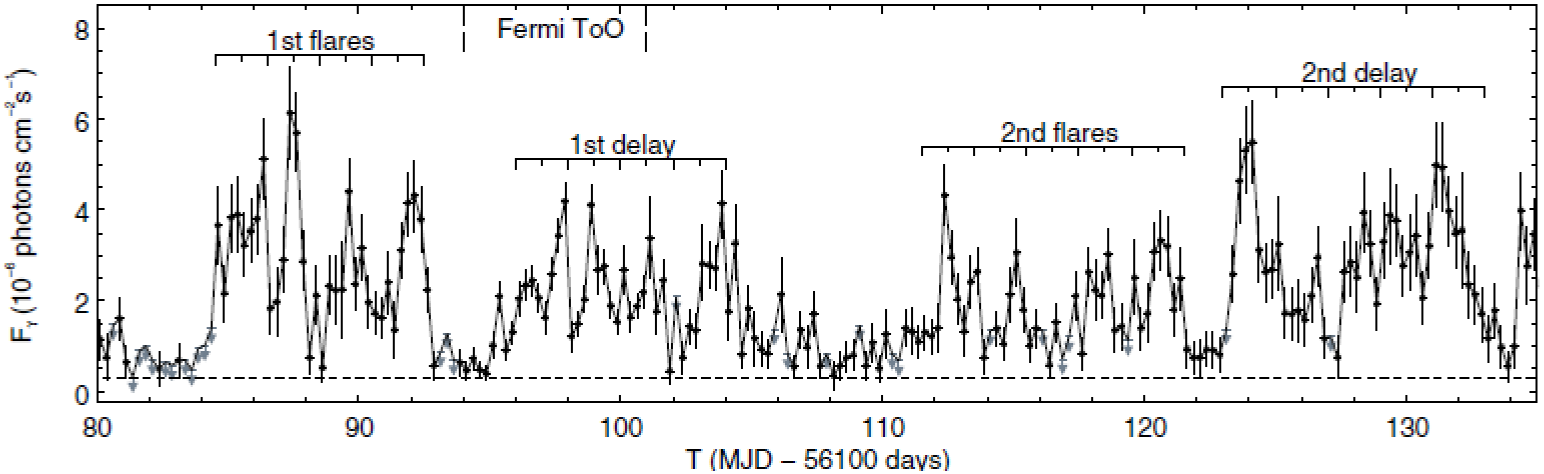
From D.Panique's slides

Gamma-ray from Gravitationally-lensed blazar

Provide one tool to probe the emission region

B0218+357 (z=0.944)

Cheung+14



Delay 11.46+/-0.16 days

Delayed gamma-ray was not detected unlike radio.

Different emission sites between radio and gamma-ray ?

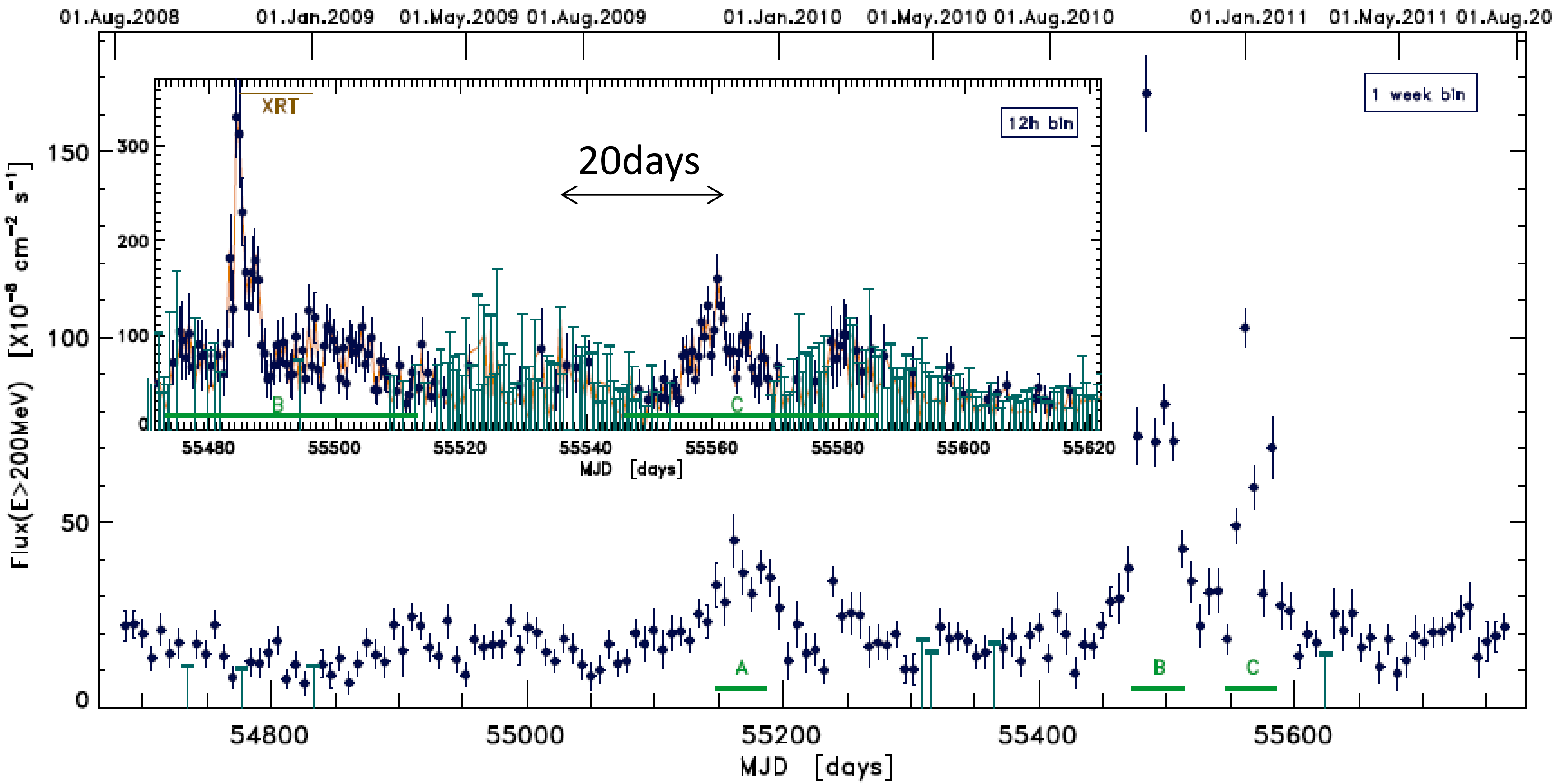
Gamma-ray variation due to microlensing was also suggested.

High-z TeV Blazars are interesting.

PKS1830-211 (z=2.507)

Expected delay : 25 days

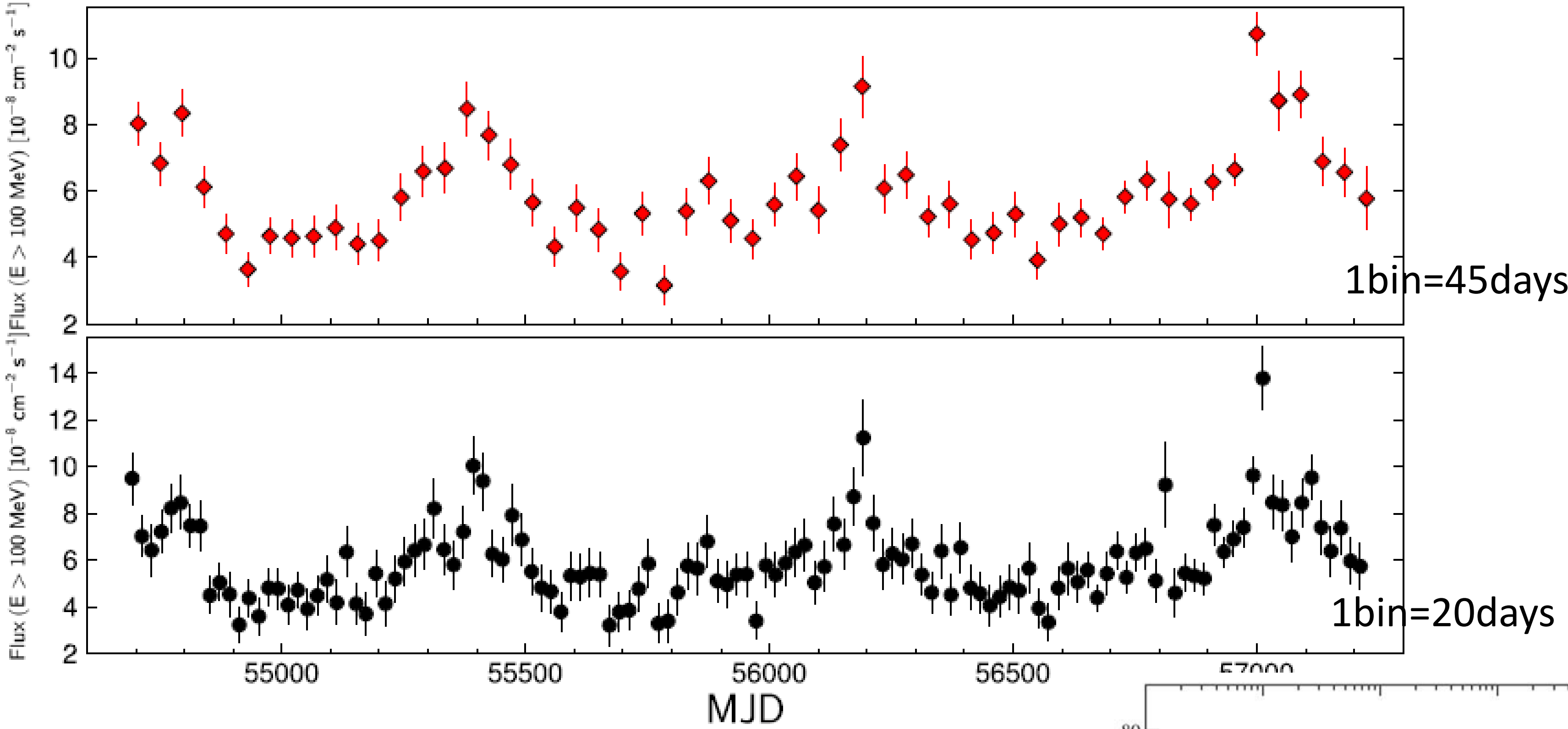
Abdo+15

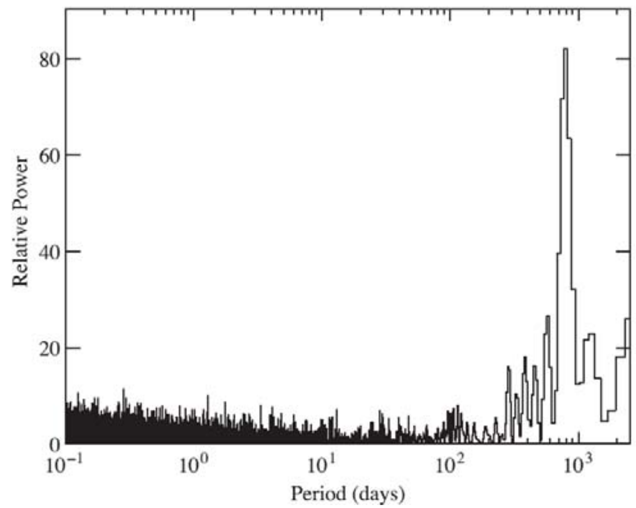


Quasi-periodic (2.18yr) gamma-rays from blazar

PG1553+113 (BL Lac)

Ackermann+15



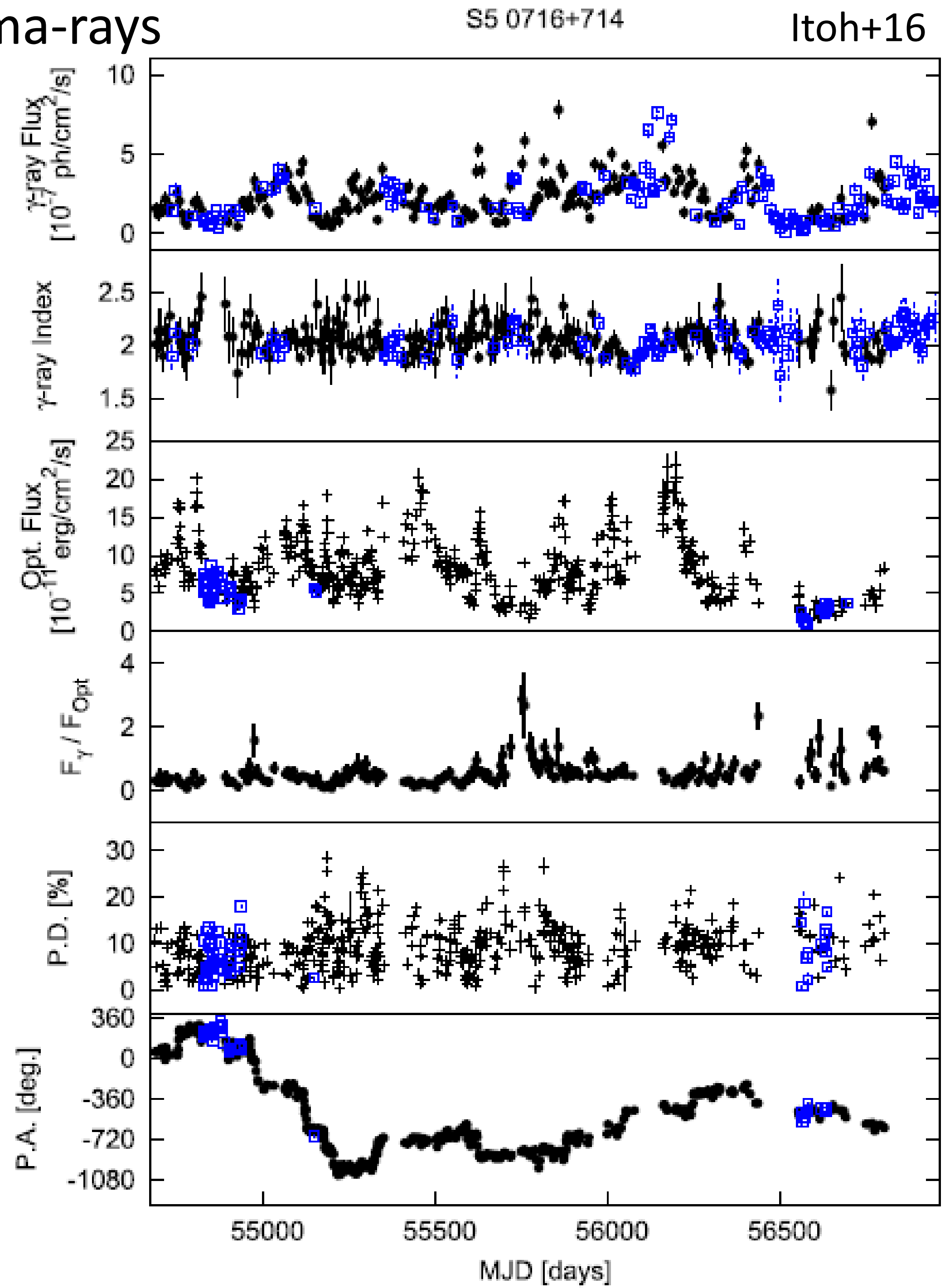


Periodic optical emission is also suggested.

Optical polarization and gamma-rays

KANATA telescope, RoboPol, and so on have provided a rich amount of optical polarization monitoring data for GeV blazars.

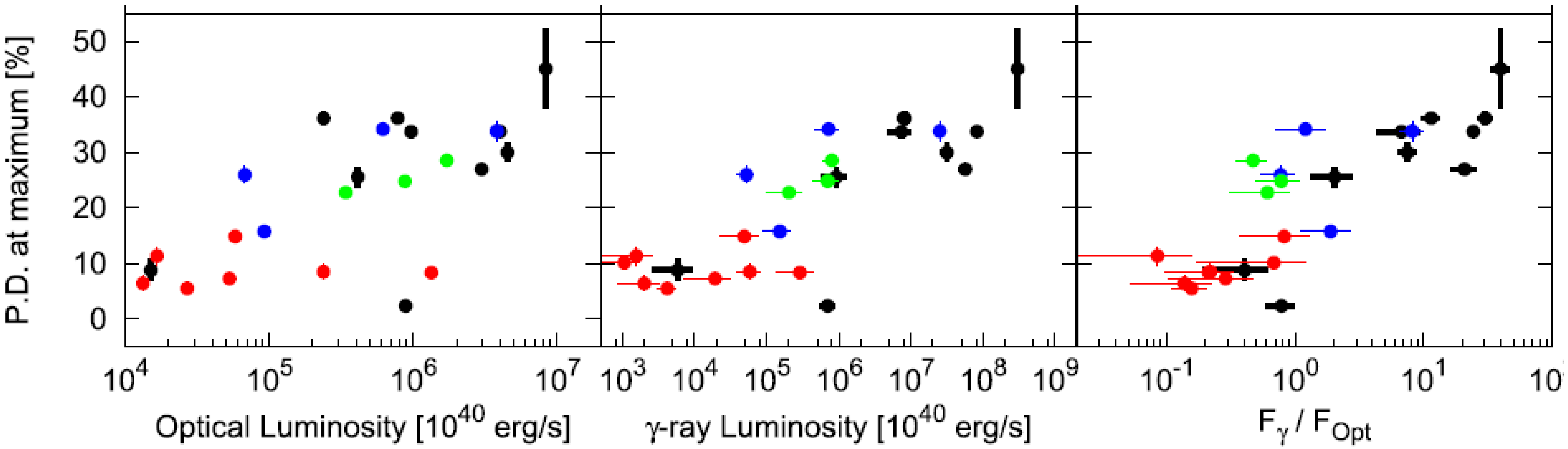
Important to understand the magnetic field structure in jets



Optical polarization degree in flares well correlates with gamma-ray luminosity or gamma-ray to optical flux ratio.

Different alignment in jets between FSRQ (FR-II) and BL Lac (FR-I) ?

Itoh+16

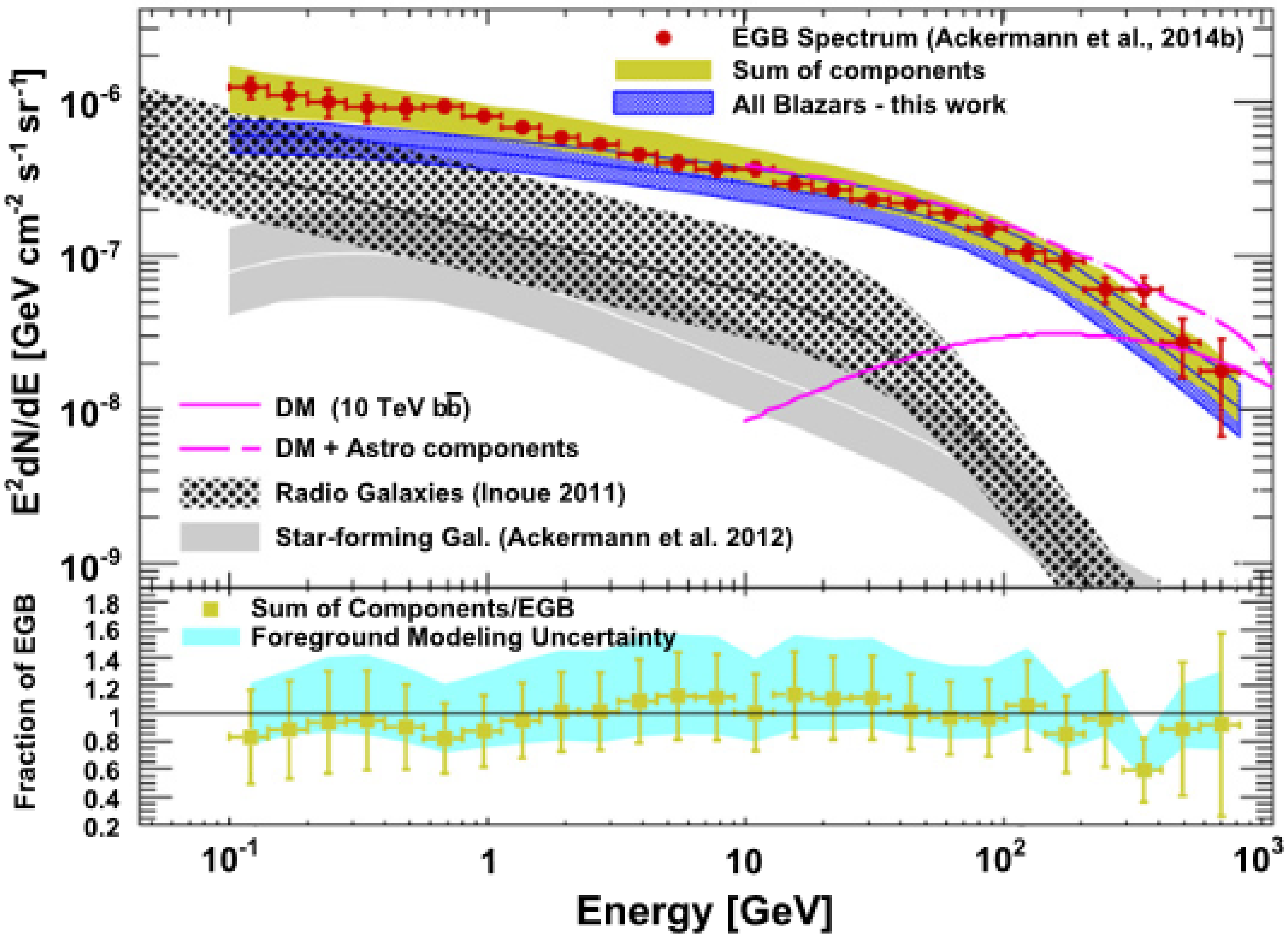


- Blazars-related topics

Extragalactic gamma-ray background update

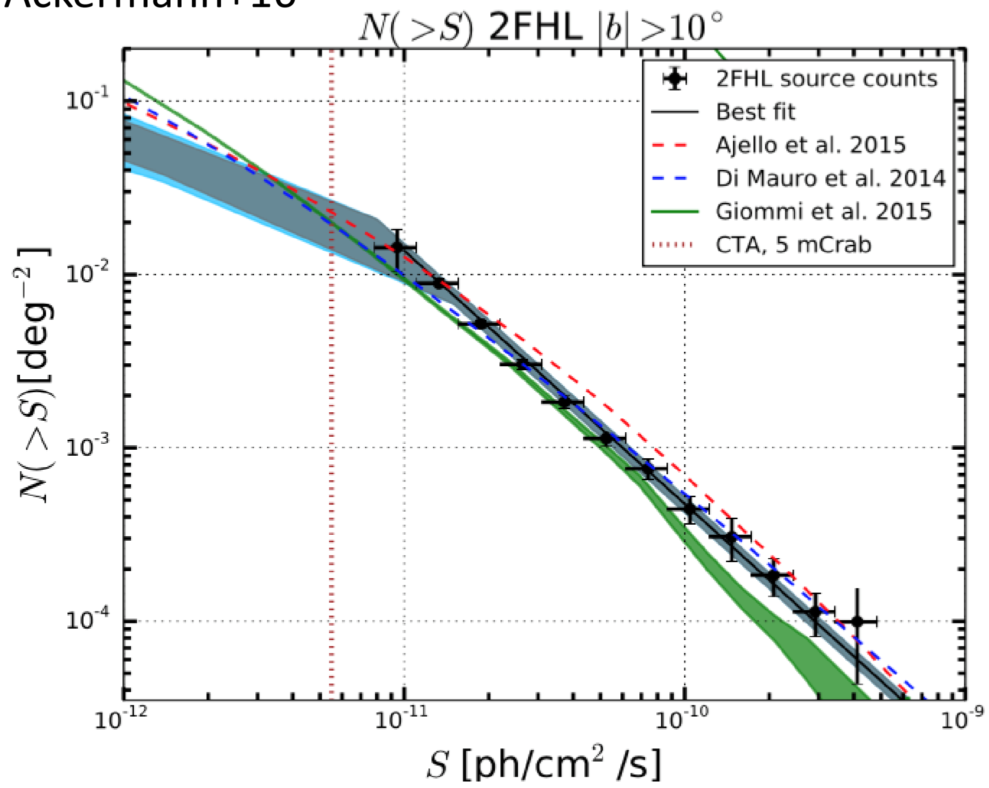
Approaching to 1 TeV.

Ackermann+15



Using 2FHL to Resolve the Extragalactic Background

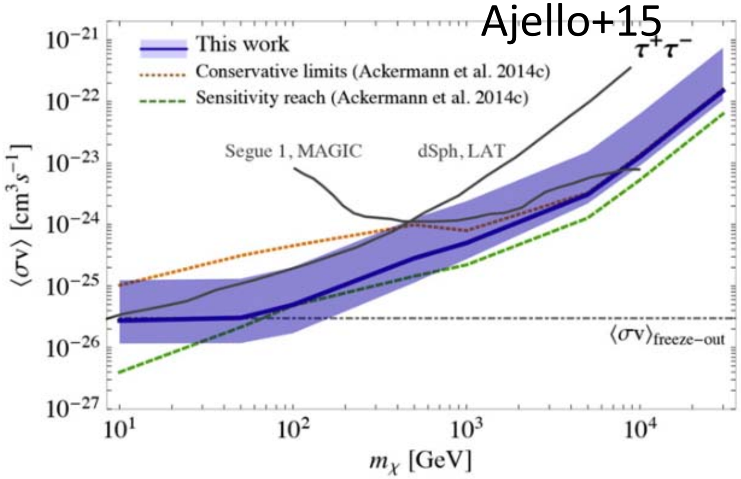
Ackermann+16



Point sources (blazars) explain 86 (+16 -14)% of the EGB above 50 GeV

Can constrain cosmological dark matter emission.

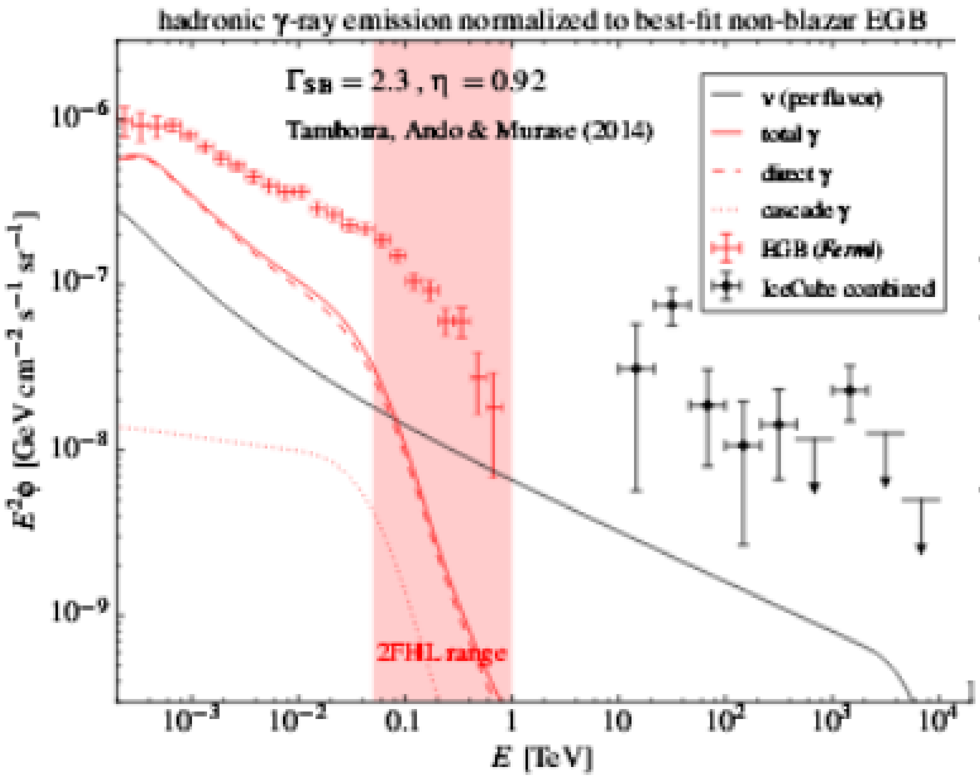
Ajello+15



Constraining high-E neutrino sources

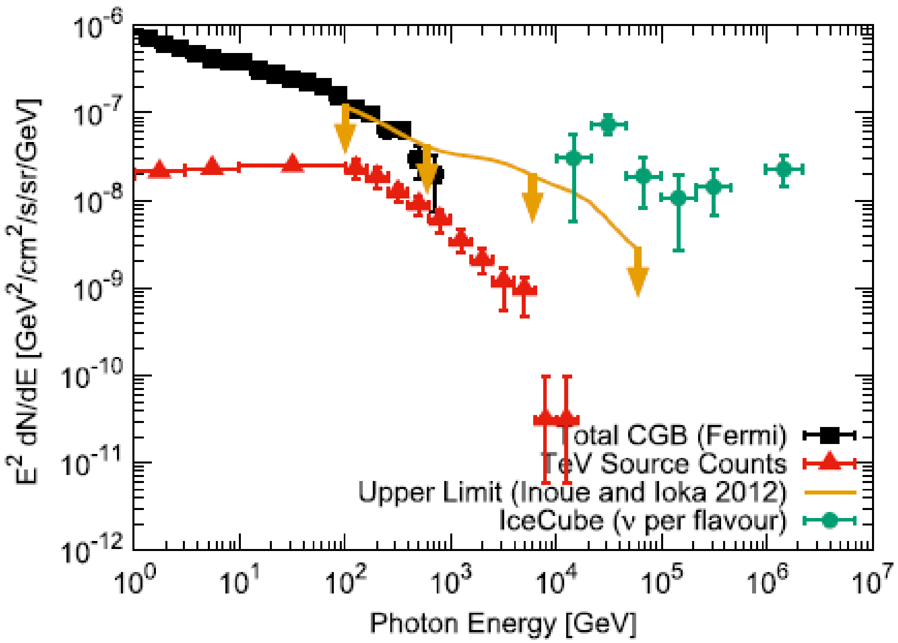
Starburst galaxies are not ??

Bechtol+15



TeV extragalactic gamma-ray background can give further constraints.

Inoue+16



Gamma-ray absorption by Extragalactic background light (Opt/UV)

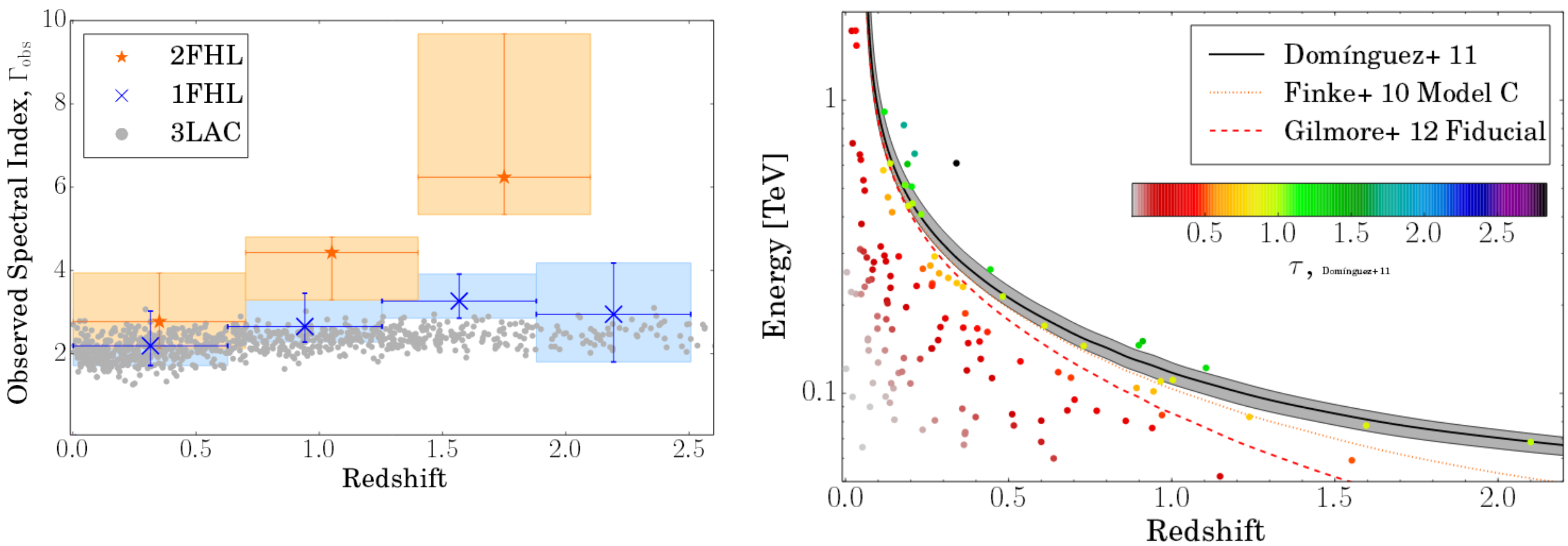
Fermi has obtained evidences of absorption

Ackermann+12, Dominguez+15

More constraint has been progressing with continuous survey.

Combined constraing with TeV is important.

Ackermann+16 (2FHL)



Constraint of intergalactic magnetic field

λ_B Correlation length og B

$$D_e = 10^{23}\left(\frac{E}{10TeV}\right)^{-1} cm$$ e+e-のmean free path

D: Halo extension size

$$\lambda_B >> D_e \qquad \delta_{ext} = D_e / R_L = 3\times10^{-4}\left(\frac{E}{10TeV}\right)^{-2}\left(\frac{B}{10^{-16}G}\right)$$

$$\lambda_B << D_e \qquad \delta_{ext} = \sqrt{D_e\lambda_B} / R_L = 5\times10^{-5}\left(\frac{E}{10TeV}\right)^{-3/2}\left(\frac{B}{10^{-16}G}\right)\left(\frac{\lambda_B}{1kpc}\right)^{1/2}$$

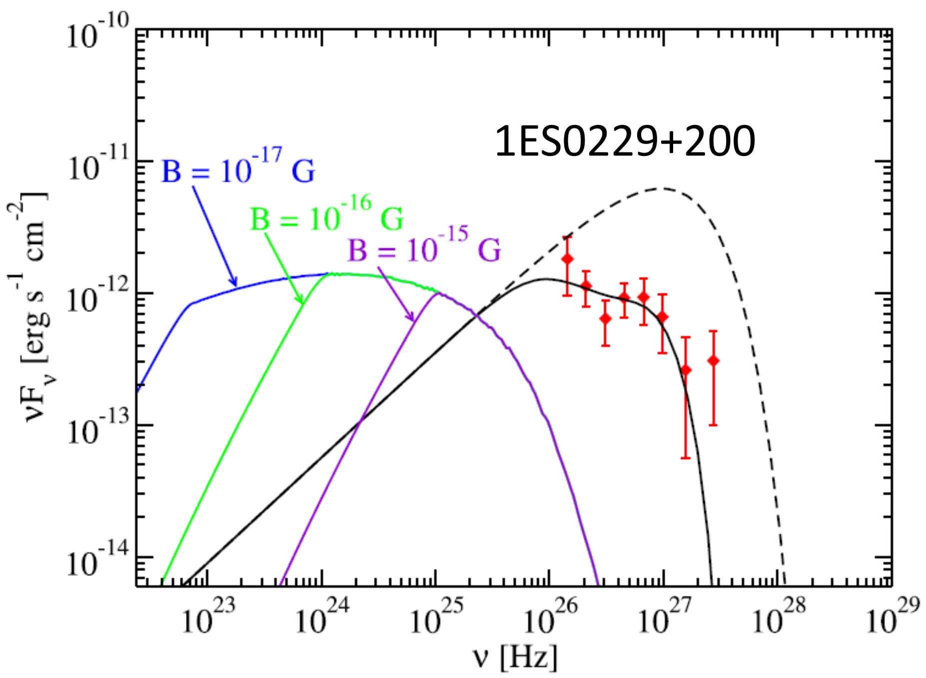
$\Rightarrow B_{IGMF} > 10^{-15}$ G

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

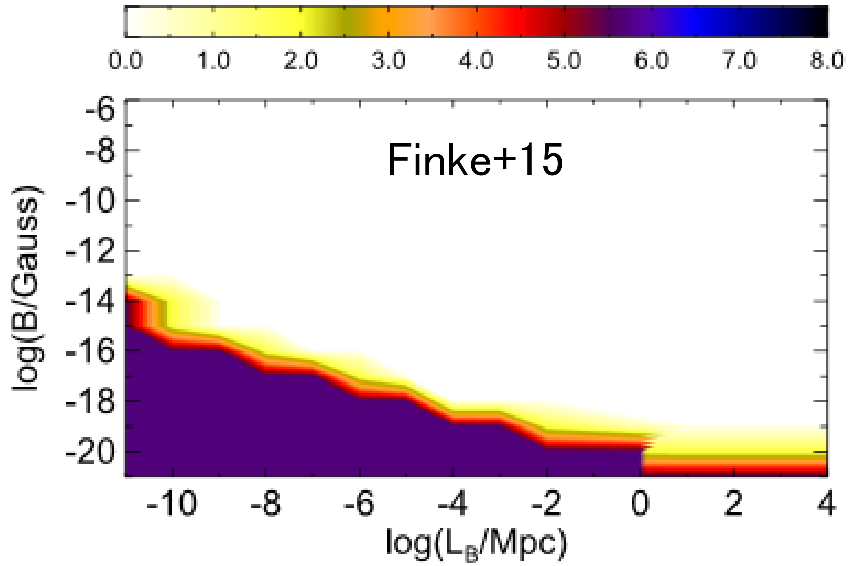
$\Rightarrow B_{IGMF} > 10^{-18}$ G

Considering time variability, various EBL models.

(Dermer 2011)



:011)



- Other AGNs

Non-blazar objects and Misaligned AGNs (Radio galaxies) @ 3LAC

Name	3FGL	2FGL	1FGL	Type	Photon Index
NGC 1218	J0308.6+0408[a]	···	J0308.3+0403[a]	FRI	2.07 ± 0.11
IC 310	J0316.6+4119[a]	J0316.6+4119	···	FRI/BLL	1.90 ± 0.14
NGC 1275	J0319.8+4130[a]	J0319.8+4130[a]	J0319.7+4130[a]	FRI	2.07 ± 0.01
1 H 0323+342	J0325.2+3410[a]	J0324.8+3408[a]	J0325.0+3403[a]	NLSy1	2.44 ± 0.12
4C+39.12	J0334.2+3915[a]	···	···	FRI/BLL?	2.11 ± 0.17
TXS 0348+013	J0351.1+0128[a]	···	···	SSRQ	2.43 ± 0.18
3C 111	J0418.5+3813	···	J0419.0+3811	FRII	2.79 ± 0.08
Pictor A	J0519.2–4542[a]	···	···	FRII	2.49 ± 0.18
PKS 0625–35	J0627.0–3529[a]	J0627.1–3528[a]	J0627.3–3530[a]	FRI/BLL	1.87 ± 0.06
4C+52.17	J0733.5+5153	···	···	AGN	1.74 ± 0.16
NGC 2484	J0758.7+3747[a]	···	···	FRI	2.16 ± 0.16
4C+39.23B	J0824.9+3916	···	···	CSS	2.44 ± 0.10
3C 207	J0840.8+1315[a]	J0840.7+1310	J0840.8+1310	SSRQ	2.47 ± 0.09
SBS 0846+513	J0849.9+5108[a]	···	···	NLSy1	2.28 ± 0.04
3C 221	J0934.1+3933	···	···	SSRQ	2.28 ± 0.12
PMN J0948+0022	J0948.8+0021[a]	J0948.8+0020[a]	J0949.0+0021[a]	NLSy1	2.32 ± 0.05
PMN J1118–0413	J1118.2–0411[a]	···	···	AGN	2.56 ± 0.08
B2 1126+37	J1129.0+3705	[illegible]	[illegible]	AGN	2.08 ± 0.13
3C 264	J1145.1+1935[a]	···	···	FRI	1.98 ± 0.20
PKS 1203+04	J1205.4+0412	···	···	SSRQ	2.64 ± 0.16
M 87	J1230.9+1224[a]	J1230.8+1224[a]	J1230.8+1223[a]	FRI	2.04 ± 0.07
3C 275.1	J1244.1+1615	···	···	SSRQ	2.43 ± 0.17
GB 1310+487	J1312.7+4828[a]	J1312.8+4828[a]	J1312.4+4827[a]	AGN	2.04 ± 0.03
Cen A Core	J1325.4–4301[a]	J1325.6–4300	J1325.6–4300	FRI	2.70 ± 0.03
Cen A Lobes	J1324.0–4330e	J1324.0–4330e	J1322.0–4515	FRI	2.53 ± 0.05
3C 286	J1330.5+3023[a]	···	···	SSRQ/CSS	2.60 ± 0.16
Cen B	J1346.6–6027	J1346.6–6027	···	FRI	2.32 ± 0.01
Circinus	J1413.2–6518	···	···	Seyfert	2.43 ± 0.10
3C 303	J1442.6+5156[a]	···	···	FRII	1.92 ± 0.18
PKS 1502+036	J1505.1+0326[a]	J1505.1+0324[a]	J1505.0+0328[a]	NLSy1	2.61 ± 0.05
TXS 1613–251	J1617.3–2519	J1617.6–2526c	···	AGN	2.59 ± 0.10
PKS 1617–235	J1621.1–2331[a]	J1620.5–2320c	···	AGN	2.50 ± 0.23
NGC 6251	J1630.6+8232[a]	J1629.4+8236	J1635.4+8228[a]	FRI	2.22 ± 0.08
3C 380	J1829.6+4844[a]	J1829.7+4846[a]	J1829.8+4845[a]	SSRQ/CSS	2.37 ± 0.04
PKS 2004–447	J2007.8–4429[a]	J2007.9–4430[a]	J2007.9–4430[a]	NLSy1	2.47 ± 0.09

Several types of AGNs
Some are hard.

Narrow-Line Radio-loud Seyfert galaxy (NLSy1)

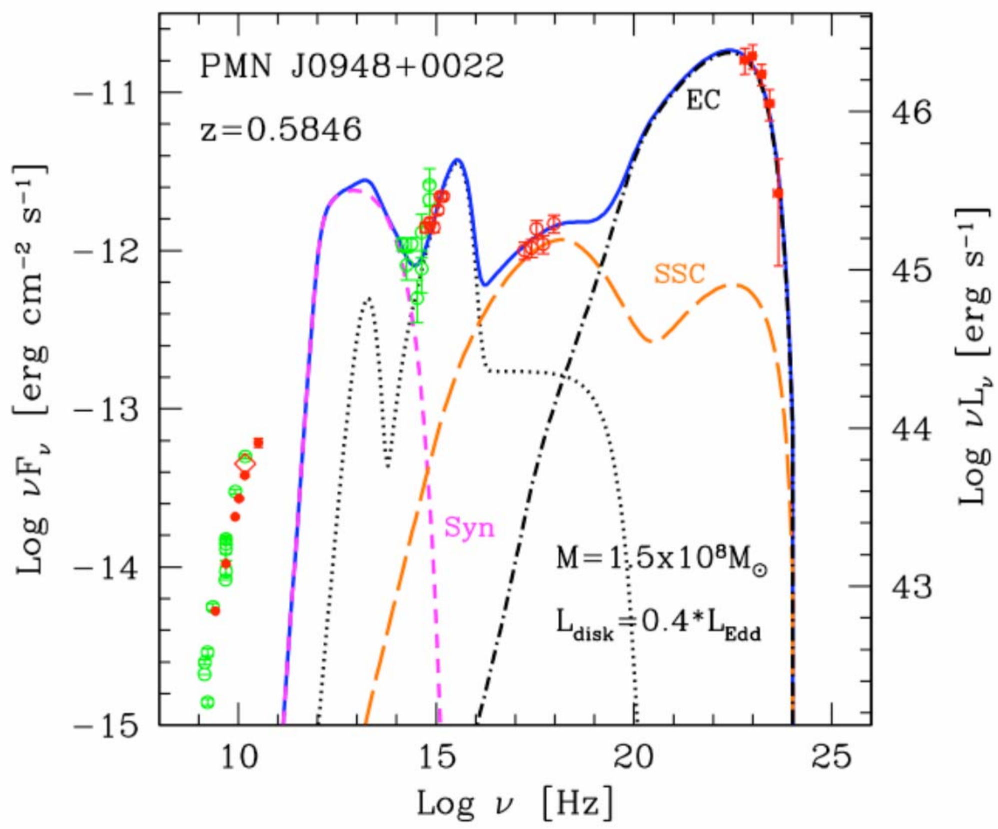
New-type of gamma-ray AGNs

PMN J0948+0022   Gamma-ray L ~10^{48} erg s^{-1}

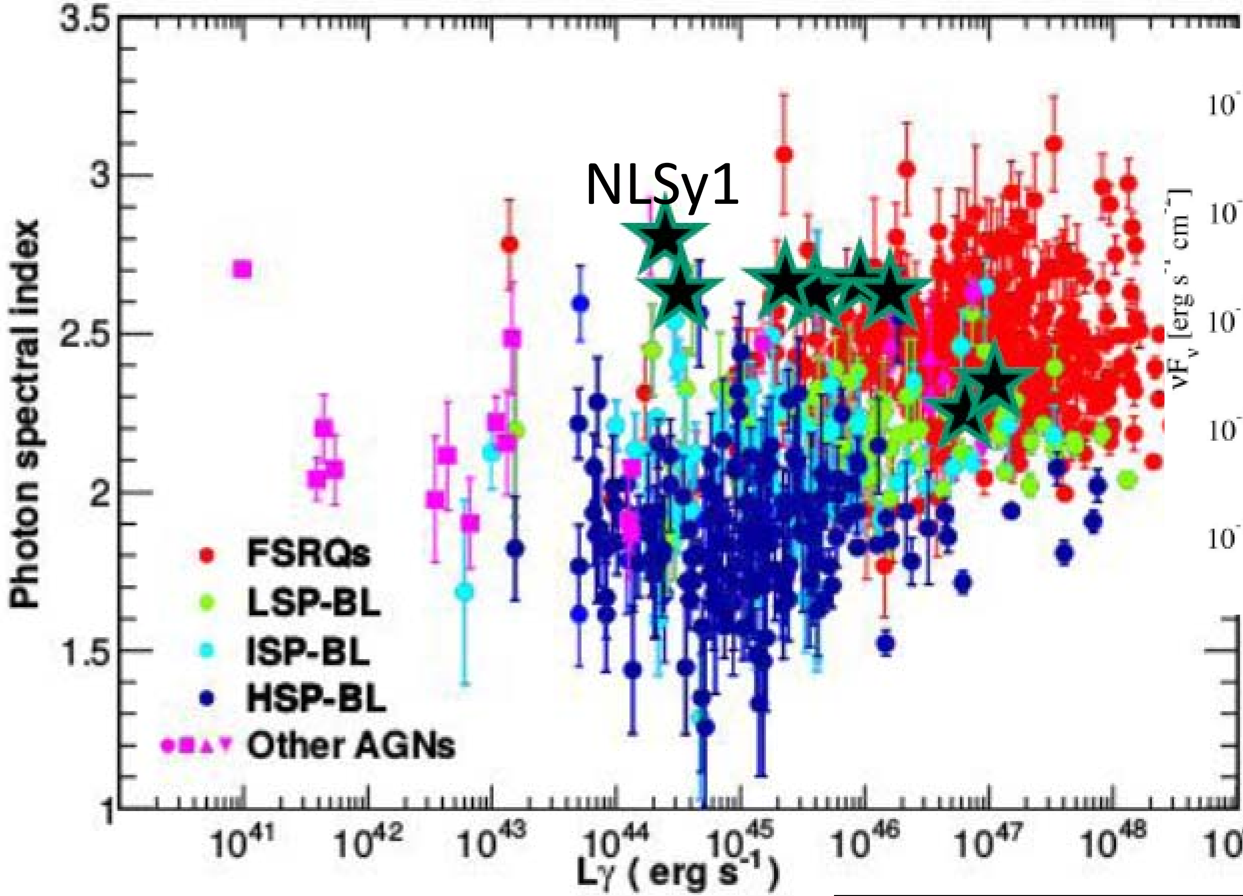
- small-mass BH ($10^{6.7}$-$10^{8.2}$ $M_{\odot}$) with high accretion rate (~90% Eddington
  (Blazar, radio galaxies: 10^{7}-$10^{10}M_{\odot}$)
- Found in spiral galaxies, unlike blazars and radio galaxies.
- Very compact radio core.

SED: SSC+EC
Jet power: middle between FSRQ and BL Lac

Important to probe jet and accretion

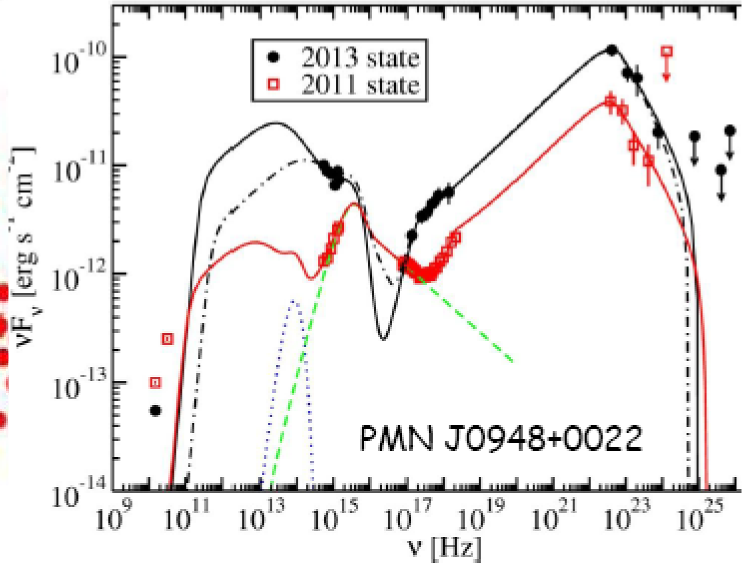


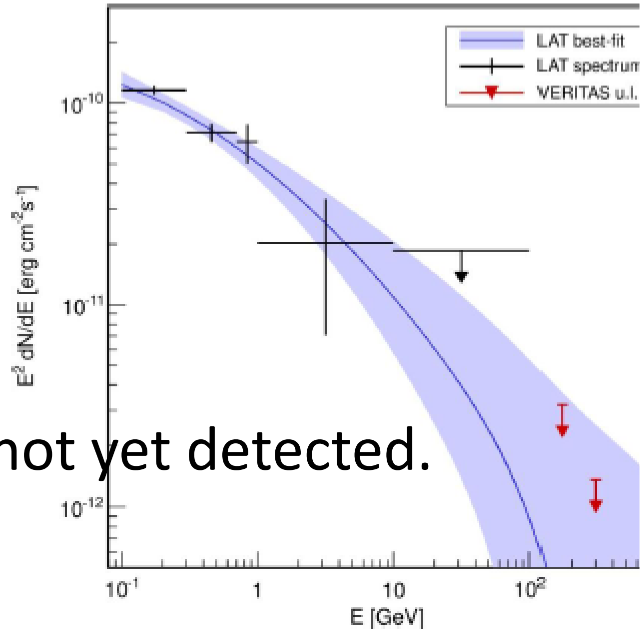
D’Ammando+16



Adapted from Ackermann

D’Ammando+15

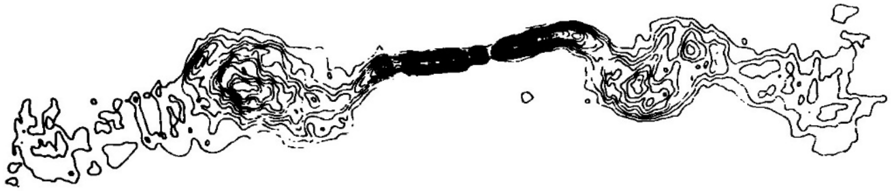




TeV: not yet detected.

Radio galaxies

Parent population of Blazars
Misaligned jet → weak beaming



EGRET: Cen A and some radio galaxies were detected.
3EG catalog: Hartman et al. (1999)
see also Sreekumar et al. (1999)

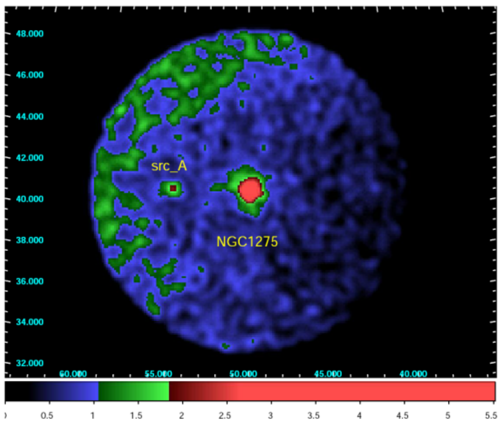
他に、3C111 and NGC6251?

TeV gamma-ray was first detected from M87 in 2000s.

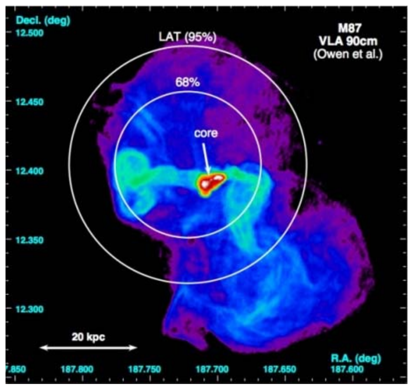
Probe the jet structure with a various viewing angle

Fermi detected three famous radio galaxies in 3 months.

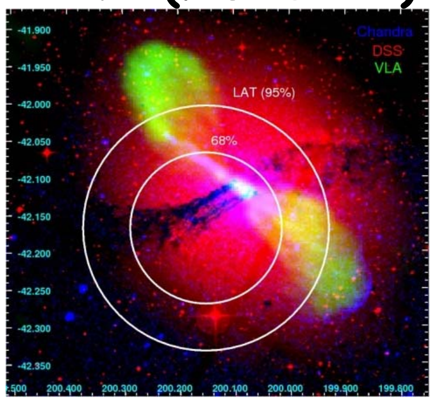
NGC1275(Per A)

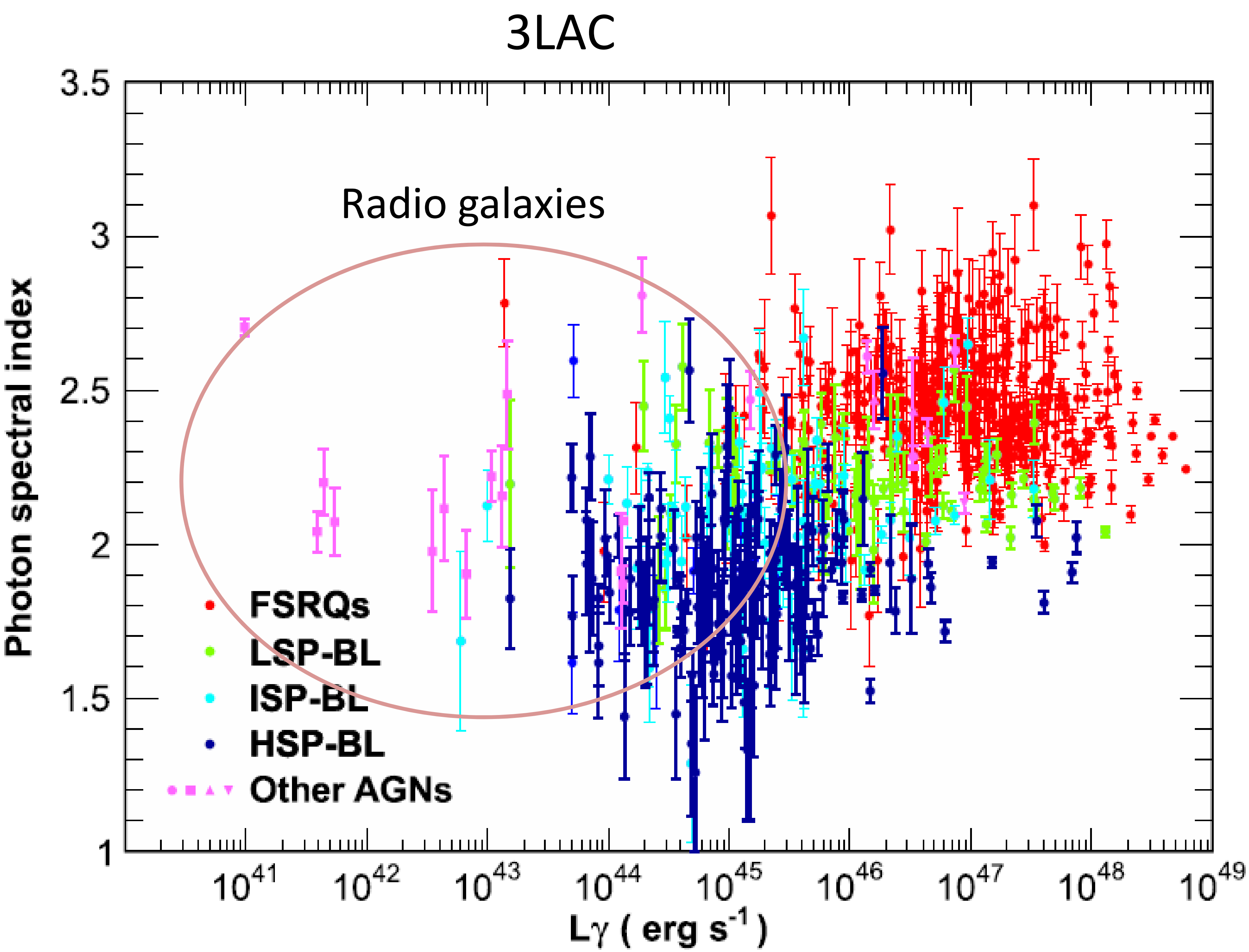


M87(Vir A)



Cen A(NGC5128)




3LAC
Radio galaxies
Photon spectral index
Lγ (erg s-1)
FSRQs
LSP-BL
ISP-BL
HSP-BL
Other AGNs
3.5
3
2.5
2
1.5
1
10^41
10^42
10^43
10^44
10^45
10^46
10^47
10^48
10^49

SED fitting parameters ; Comparison with other radio galaxies

All the fittings were done by the one-zone SSC model (Finke+08)

Lower bulk Lorentz factors compared to those of typical blazars

Fukazawa+15

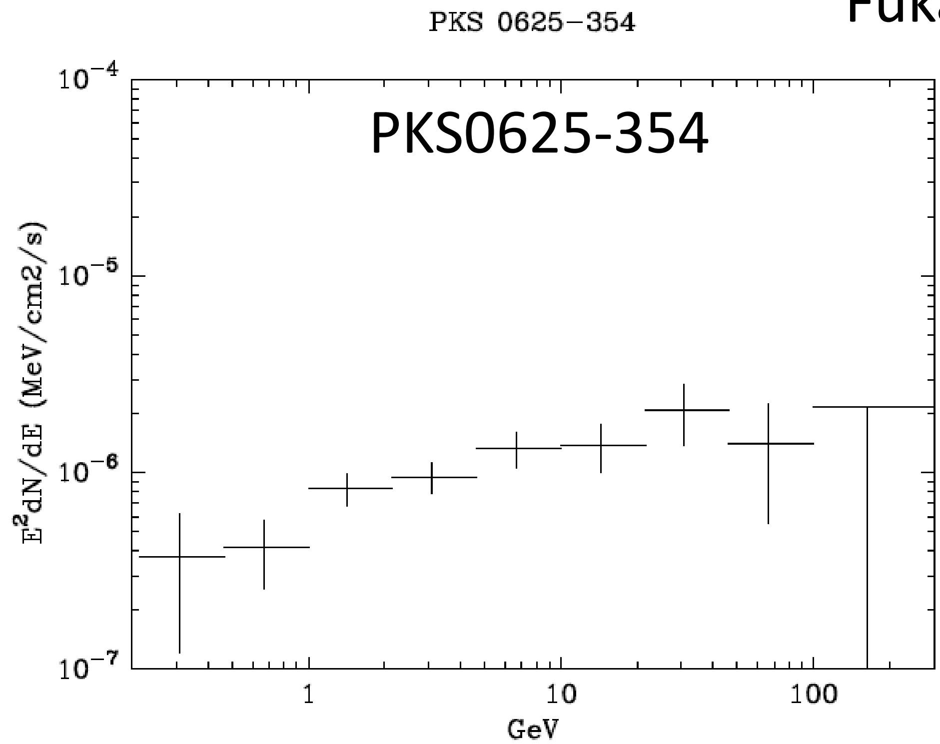
	PKS 0625−354		3C 78		Cen A	M 87	NGC 1275	NGC 6251
Γ	5.8	5.7	2.93	5.75	7.0	2.3	1.8	2.4
δ	5.8	5.8	2.92	5.75	1.0	3.9	2.5	2.4
θ [deg]	10	19	20	20	30	10	25	25
B [G]	0.82	0.11	0.77	0.02	6.2	0.055	0.05	0.04
t_v [Ms]	0.1	1	0.1	1	0.1	1.2	30	1.7
R_b [10^{16} cm]	1.6	16	0.85	17	0.3	1.4	200	12
p_1	2.5	2.5	2.7	2.7	1.8	1.6	2.1	2.75
p_2	3.5	3.5	3.7	3.7	4.3	3.6	3.1	4.0
γ_{min}	6×10^3	6×10^3	1×10^3	1×10^4	3×10^2	1	8×10^2	250
γ_{max}	2×10^6	6×10^6	2×10^7	2×10^7	1×10^8	1×10^7	4×10^5	4.4×10^5
γ_{brk}	2.9×10^4	4.6×10^4	7.3×10^4	1.4×10^5	8×10^2	4×10^3	9.6×10^2	2.0×10^4
$P_{j,B}$ [10^{42} erg s^{-1}]	43	740	0.3	2.5	65	0.02	230	0.4
$P_{j,e}$ [10^{42} erg s^{-1}]	2	10	0.6	13	31	7	120	160

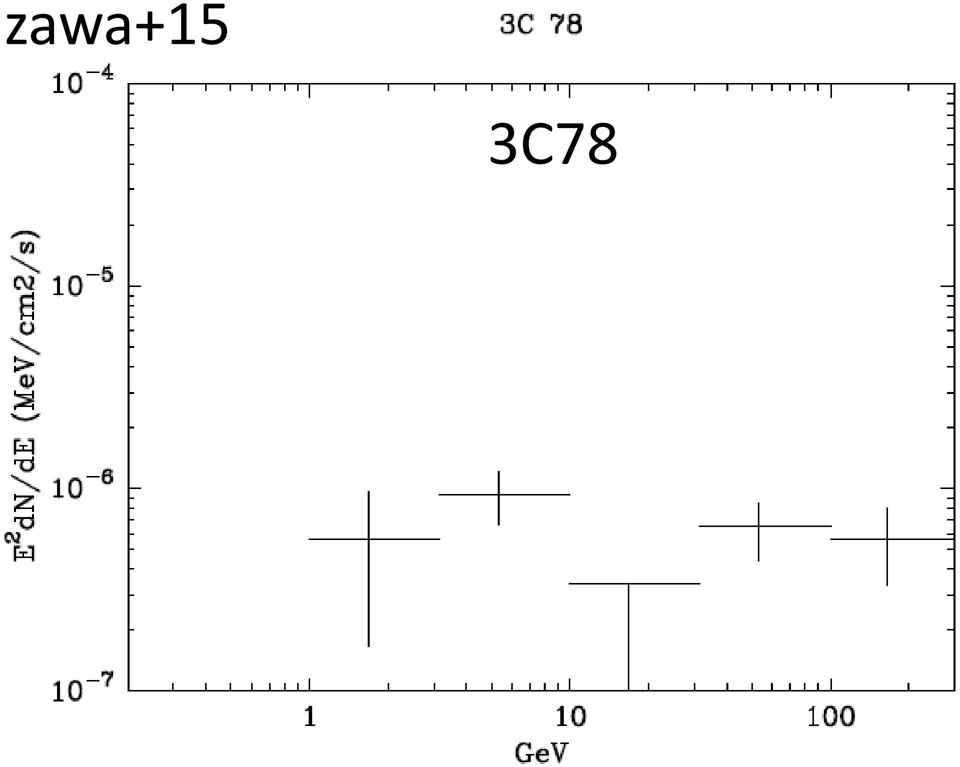
Radio Galaxies (FR-I)
Possible TeV AGNs

TeV-detected …. NGC1275/M87/Cen A

Some radio galaxies have a hard GeV spectrum.

Fukazawa+15



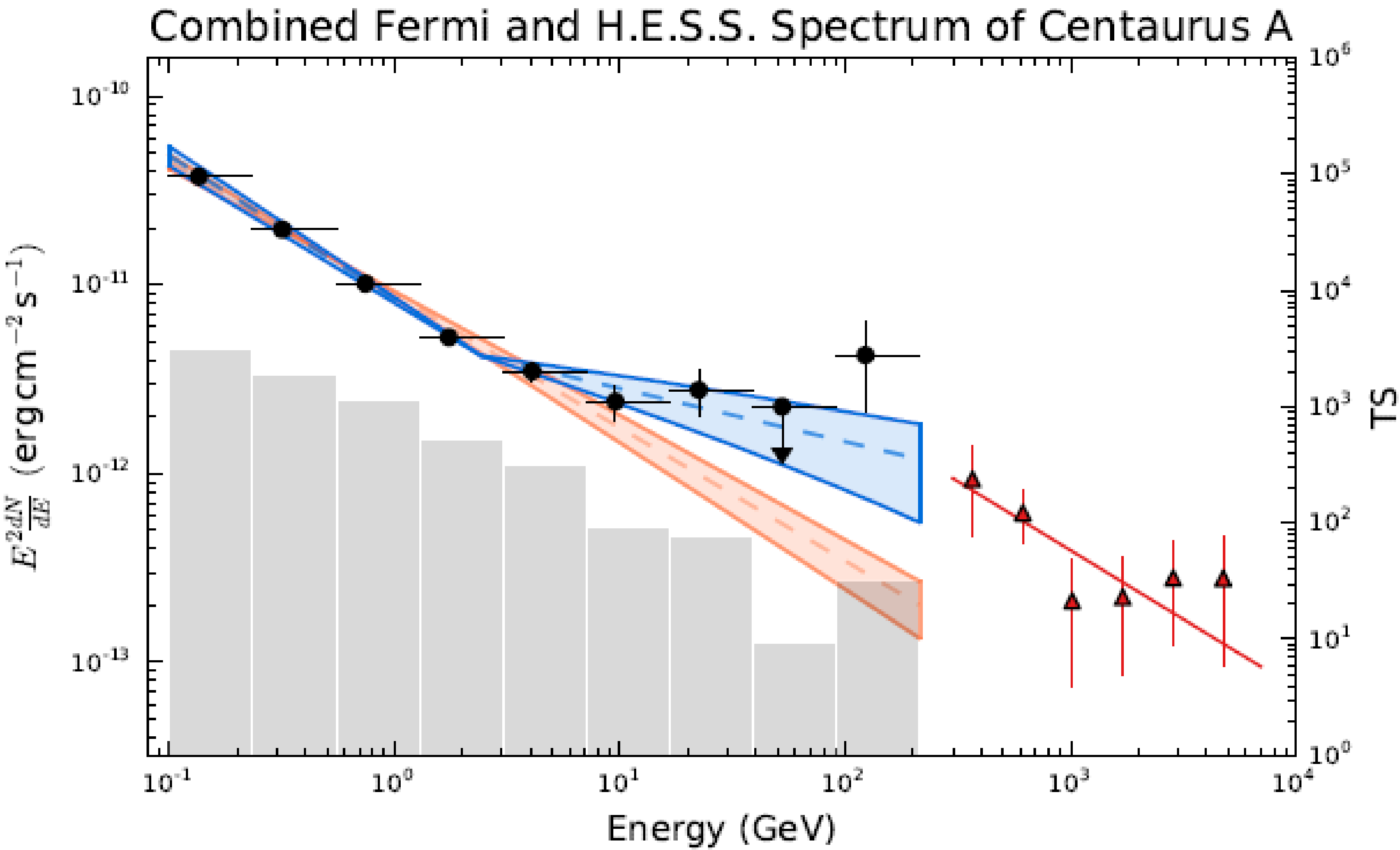


Cen A excess hard TeV tail

2nd SSC ?, Decelerating jet ?

DM ?, others ?

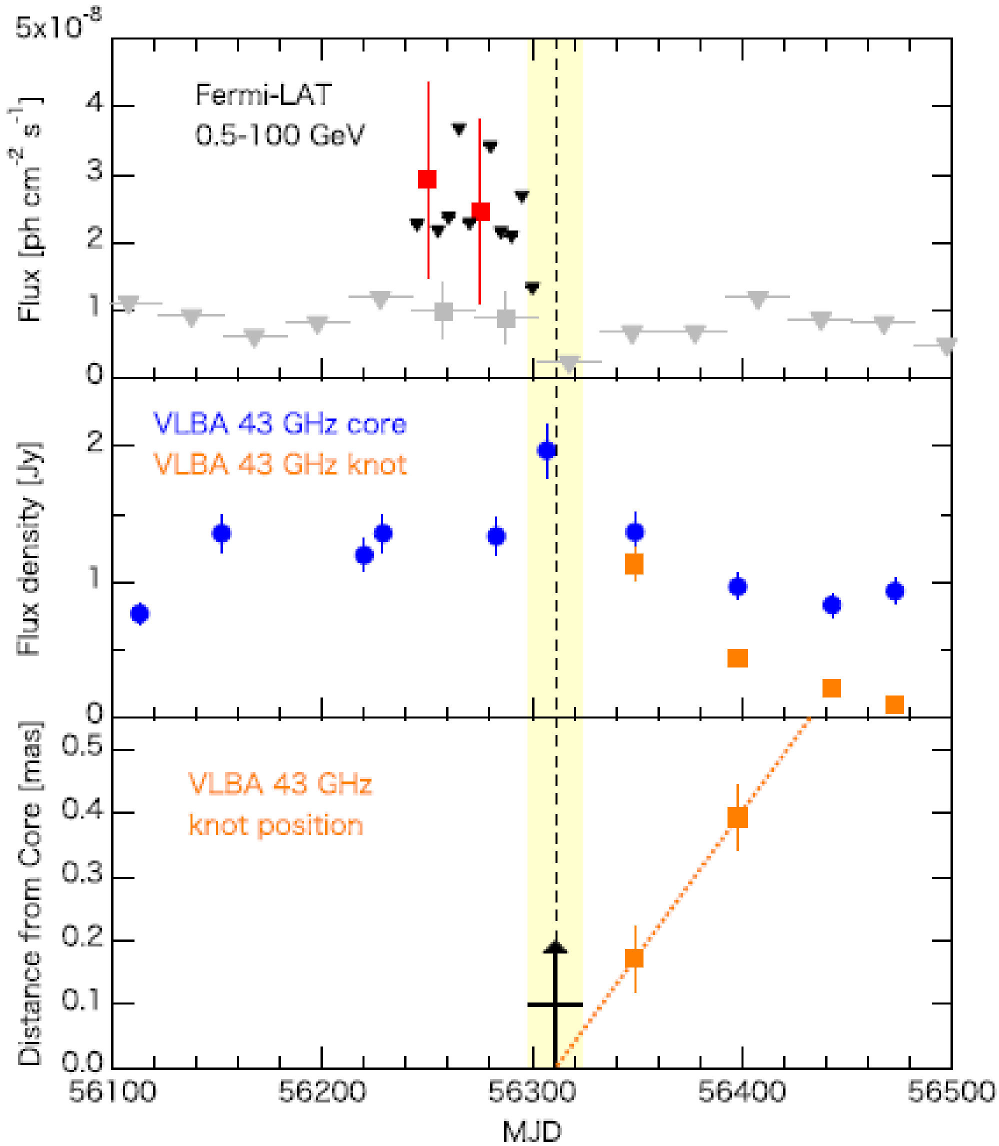
Sahakyan+13
Brown+16



3C120 GeV Flaring associated with radio knot ejection

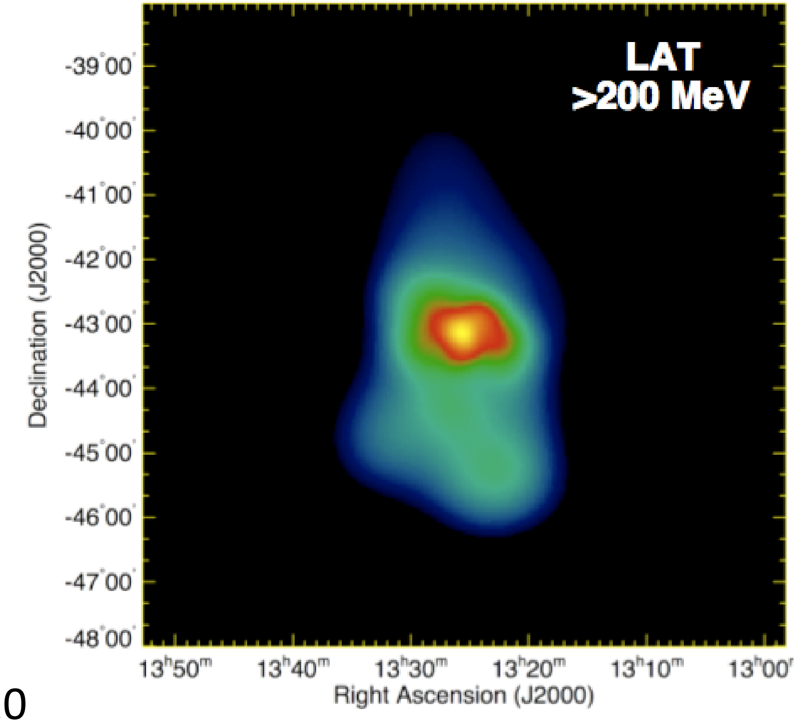
Tanaka+15

GeV emission region is inside the 43GHz unresolved core (<0.5 pc from BH), 0.1-0.3 pc outside the BLR.

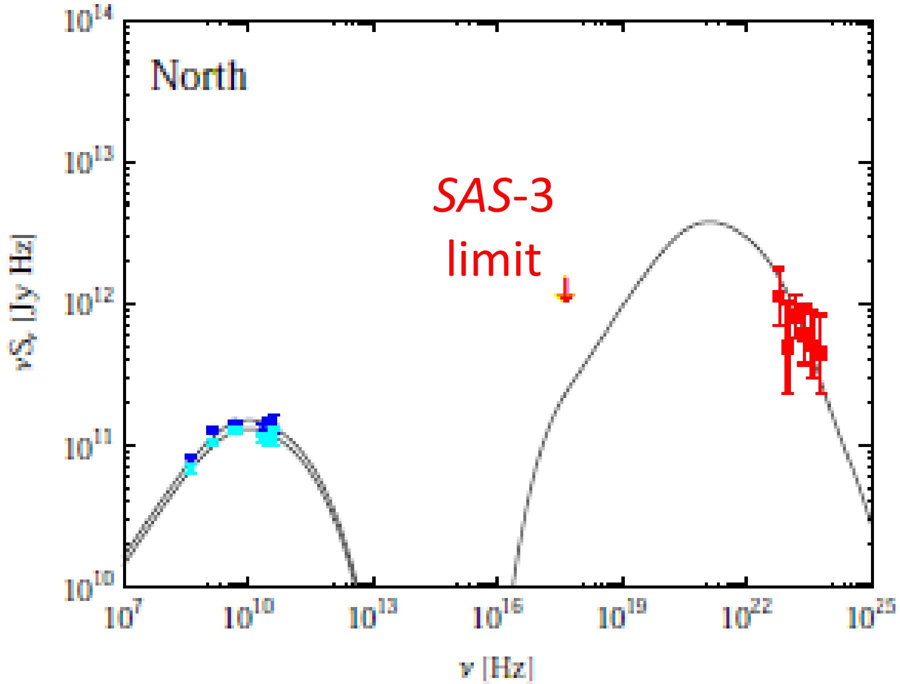


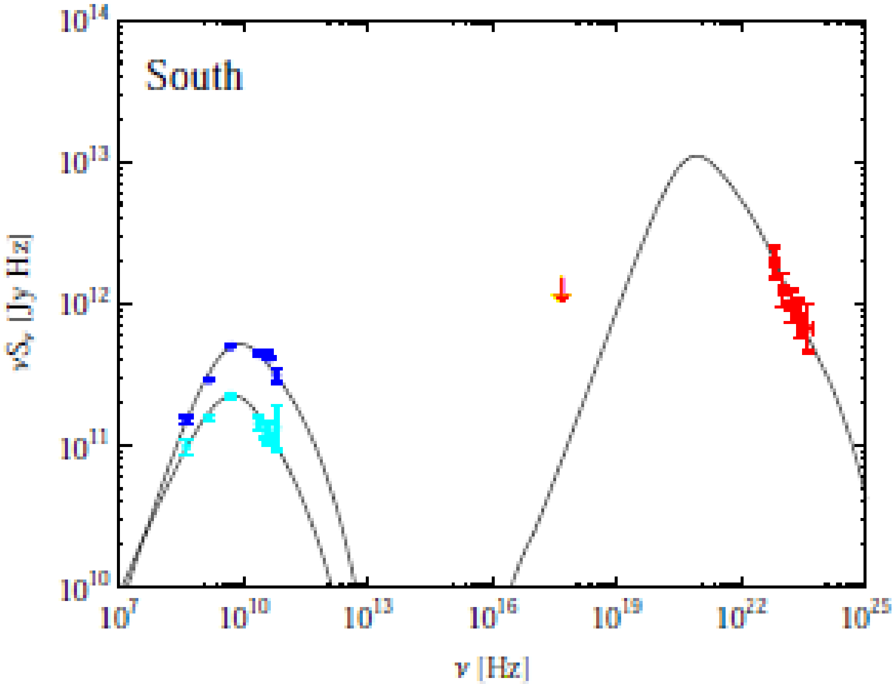
Cen A gamma-ray lobe

In-situ acceleration ?

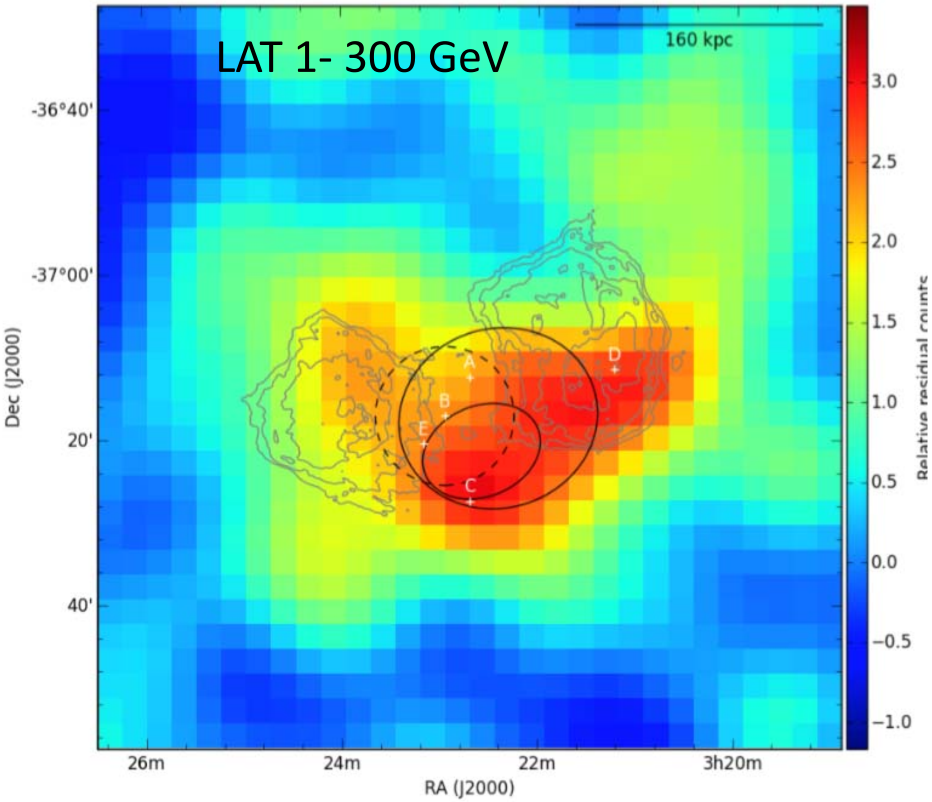


Abdo+10



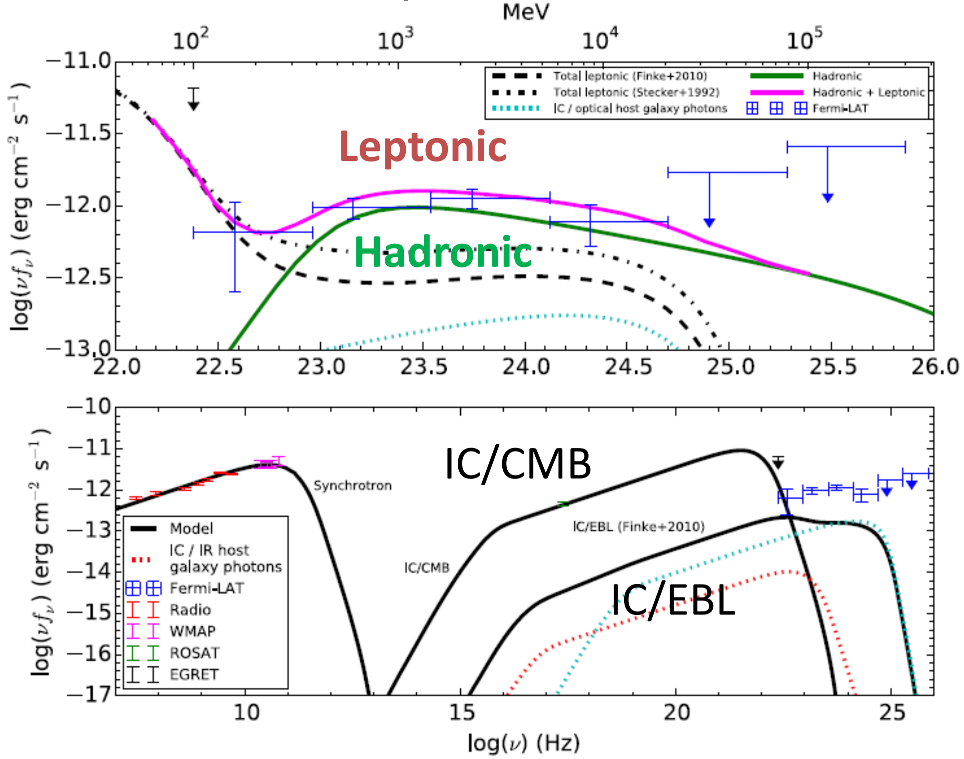


2nd example of gamma-ray lobe : Fornax A



Ackermann et al. 2016

Broadband spectral model for lobes



Hadronic emission could explain excess, but requires unexpectedly high total cosmic-ray energy for Fornax A lobes

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.

MAGIC : TeV min-scale variability from radio galaxy IC 310

Low beaming factor

Black hole lightning at subhorizon scales

Aleksic+14