Recent highlights of gamma-ray and multiwavelength observations of AGNs

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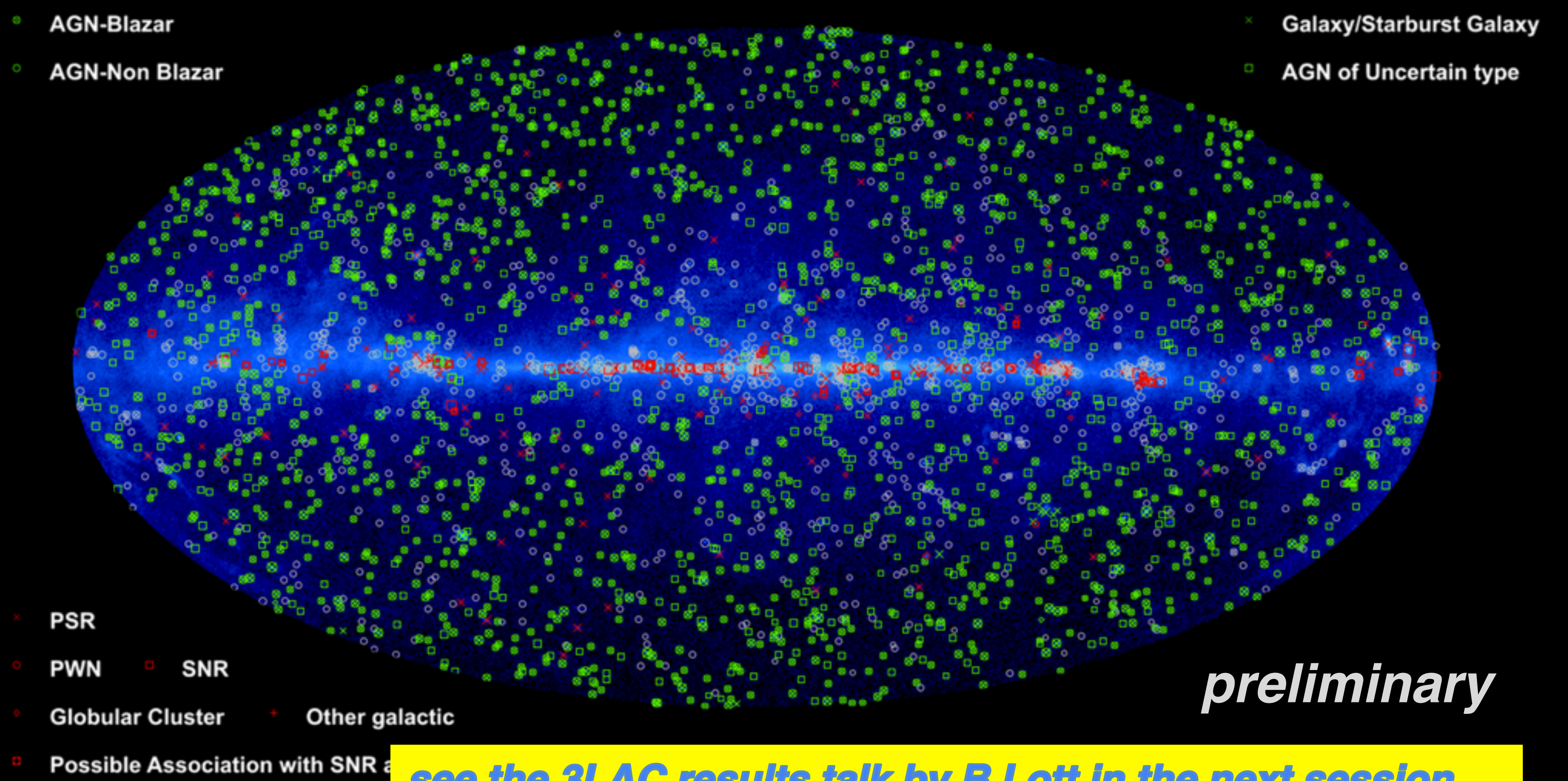
for the Fermi-LAT collaboration

Fermi Gamma-ray Space Telescope

ICRR Institute for Cosmic Ray Research University of Tokyo

Fermi Large Area Telescope 3FGL catalog



see the 3LAC results talk by B.Lott in the next session

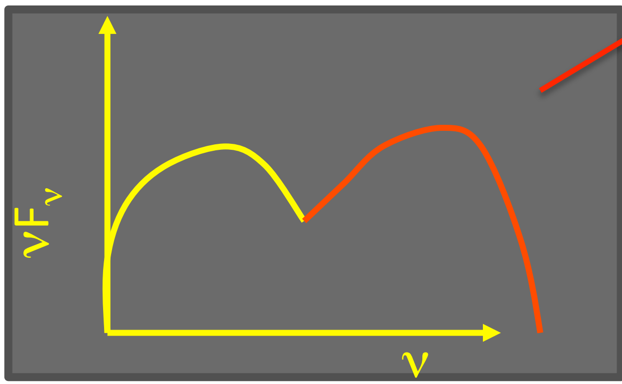
Credit: Fermi Large Area Telescope Collaboration

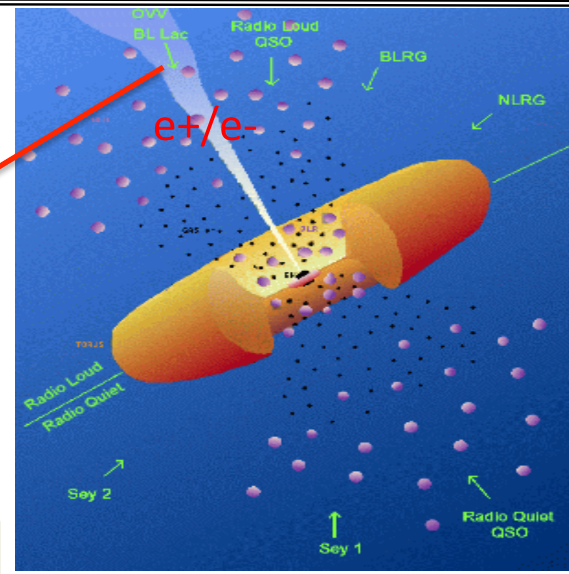
AGN is the most dominant gamma-ray source

Gamma-ray emission from AGNs

AGNs with relativistic jet

Inverse-Compton scattering
by electrons in the jets





	Blazar	Radio Galaxies
• low power	BL Lac	FR I
• high power	FSRQ	FR II
	small viewing angle -> relativistic beaming	mis-aligned blazar ?

- extended lobe
  (e,g, Cen A: Abdo+10, *Science*)

no relativistic jet

(Seyferts, starbrust, galaxies)

p + (n) -> π^0 -> 2γ

see NGC253 model talk
by T.Venter in the next session

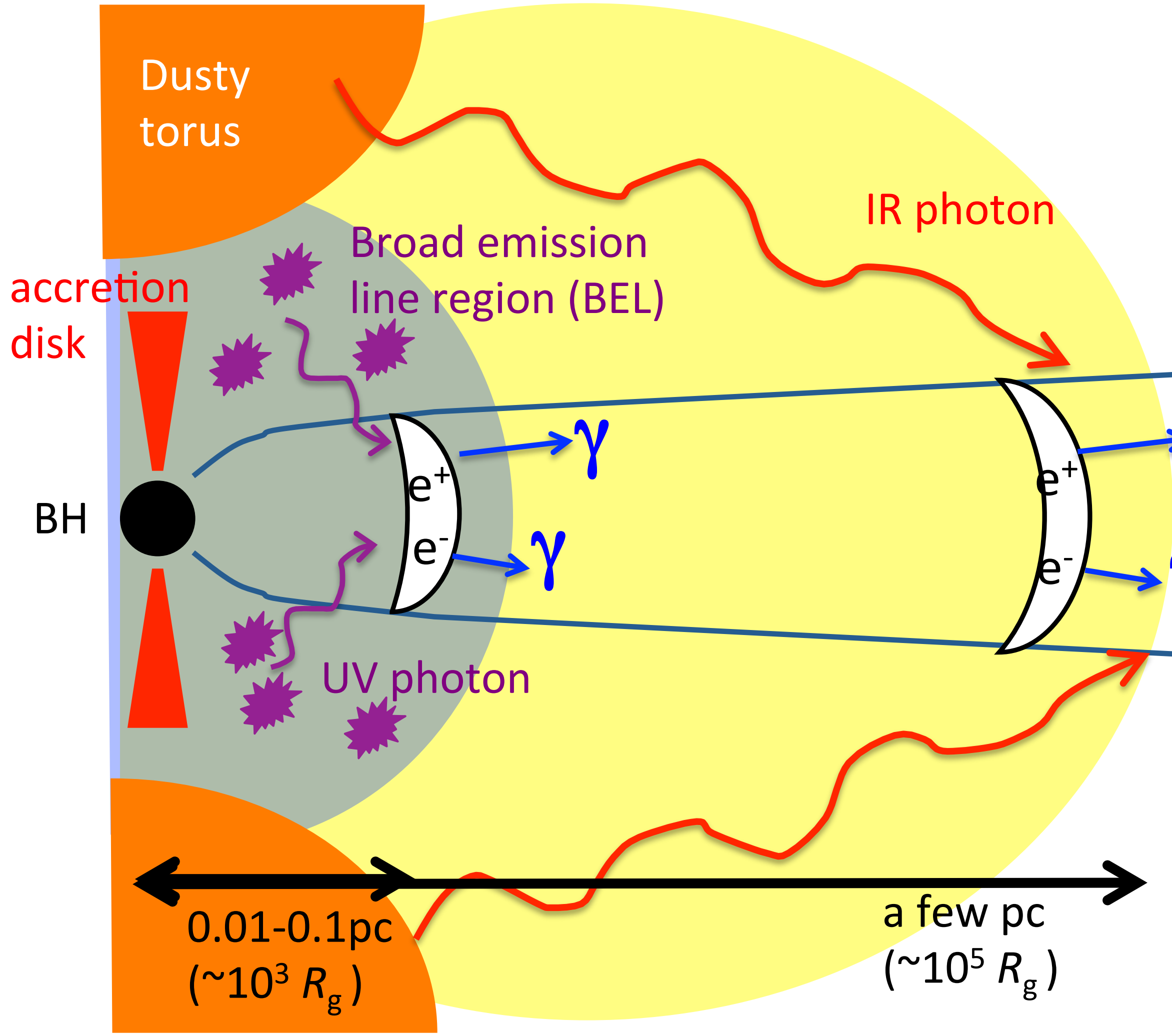
see also Circinus galaxy
(Hayashida+13, *ApJ*,)

Outline

- where is the gamma-ray emission site?
- what is the acceleration mechanism?
- what is the dominant component in jet?
- do the GeV and TeV emissions originate from the same site/component?
  - new 3C 279 results (as example)
- future gamma-ray observations
  - Cherenkov Telescope Array

“blazar zone”

where does γ-ray emission arise in relativistic jets?



(fast variability in BL Lacs)

Near side?* *(10^{15-16} cm)

or

Far side?* *(10^{18-19} cm)

(TeV detection from FSRQs)

Far side ? (optical polarization)

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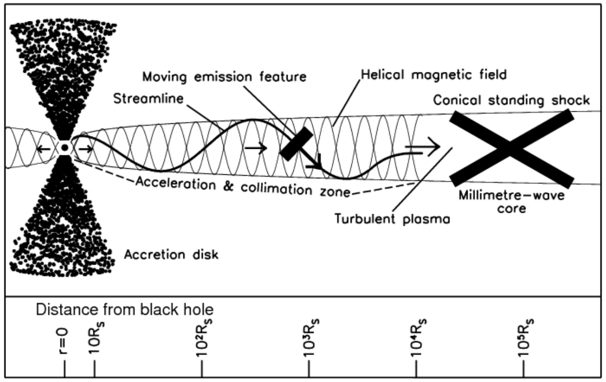
Helical magnetic field ?

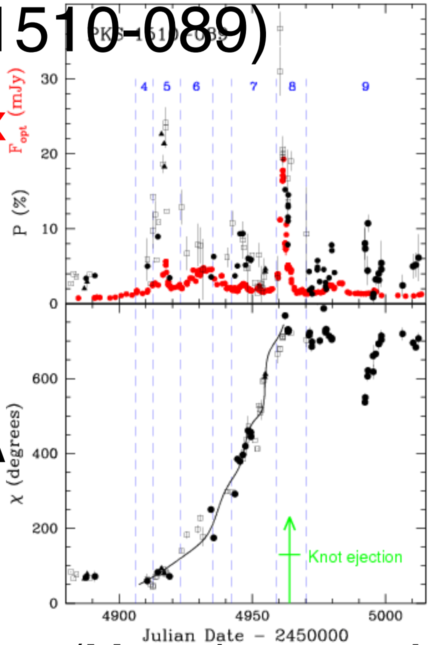


(PKS1510-089)

flux

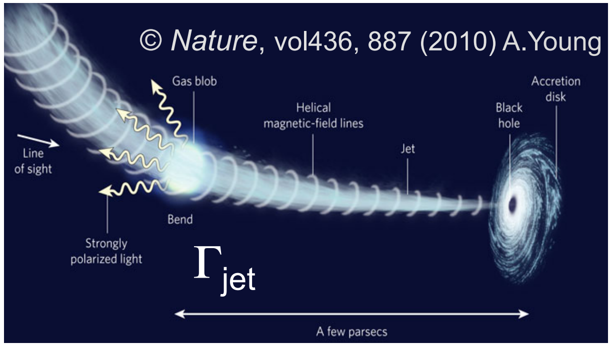
PD

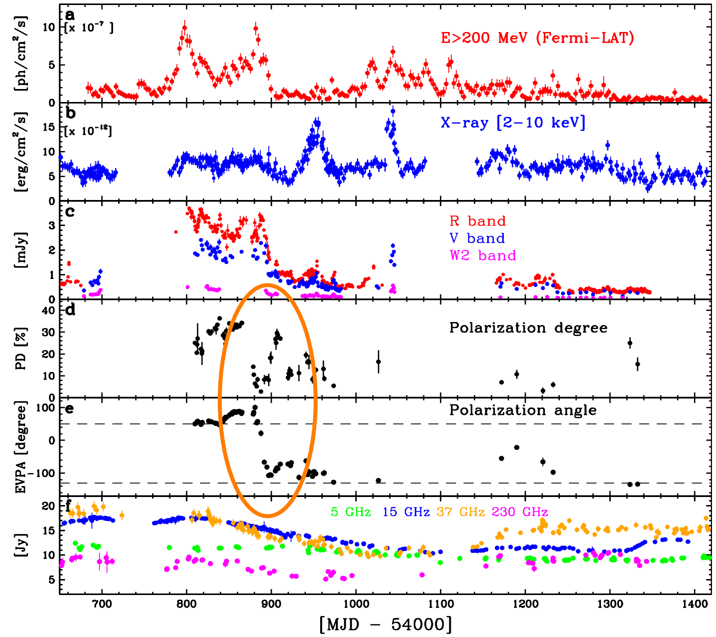
EVPA



(Marscher+10, *ApJ*)

bent jet ? (3C 279)





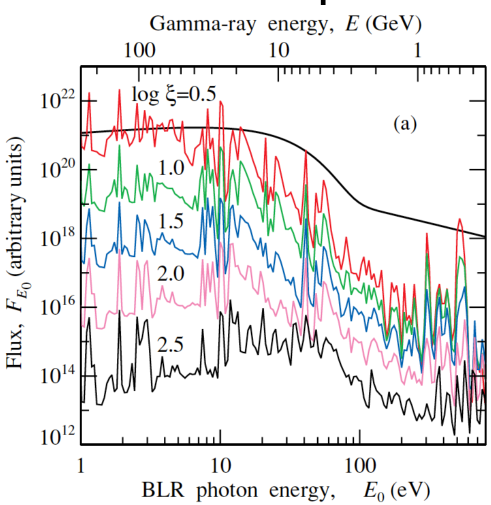
EVPA rotation
for a few ten days:
→ pc scale

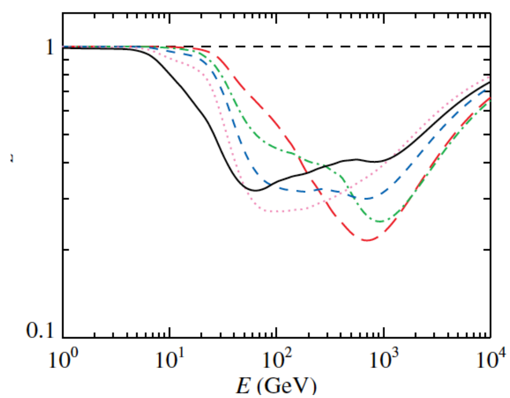
(Abdo+ 2010, Nature; Hayashida+ 2012, ApJ)

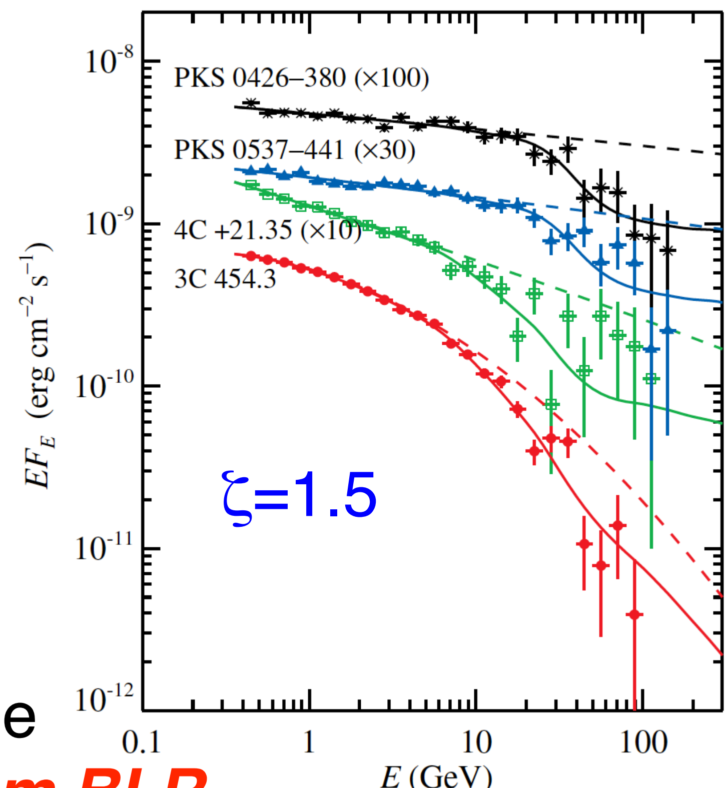
near side? (absorption feature)

(Putanen&Stern10, *ApJ*) (Stern&Poutanen14, *ApJ*)

Broad line spectrum







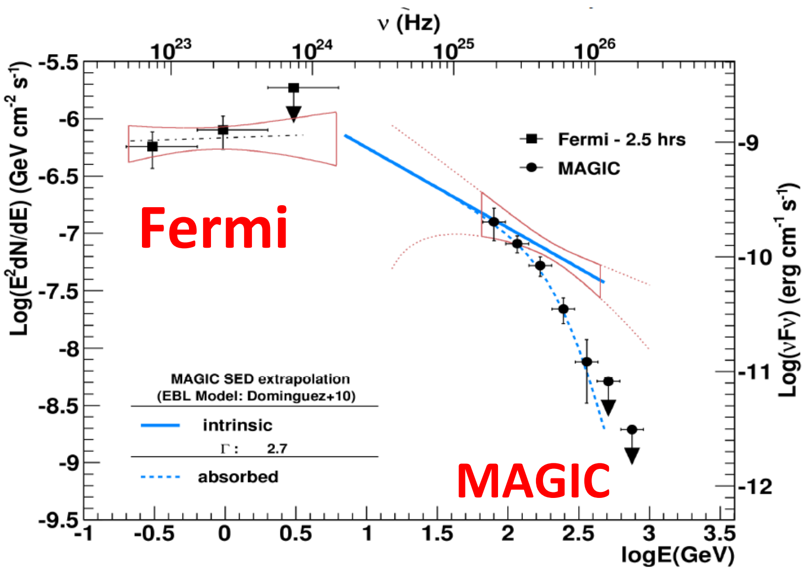
they claim presences of absorption feature in spectral shape

→ ***emission should originate from BLR***

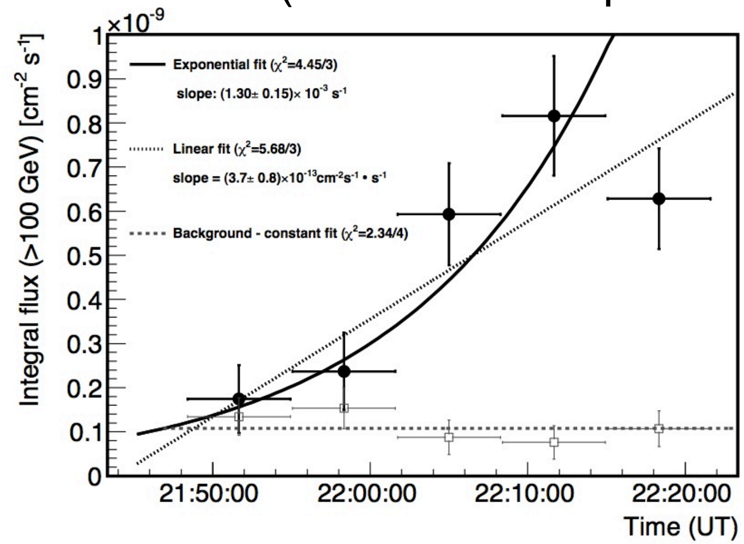
but see also poster Pass 8 FSRQ spectral studies by R.Britto (8.03)

but,,, contradiction! (PKS 1222+21)

- PKS 1222+21 (z =0.432), 2nd TeV FSRQ
- One night detection (June 17th 2010) by MAGIC



(MAGIC Coll. ApJL 2011)



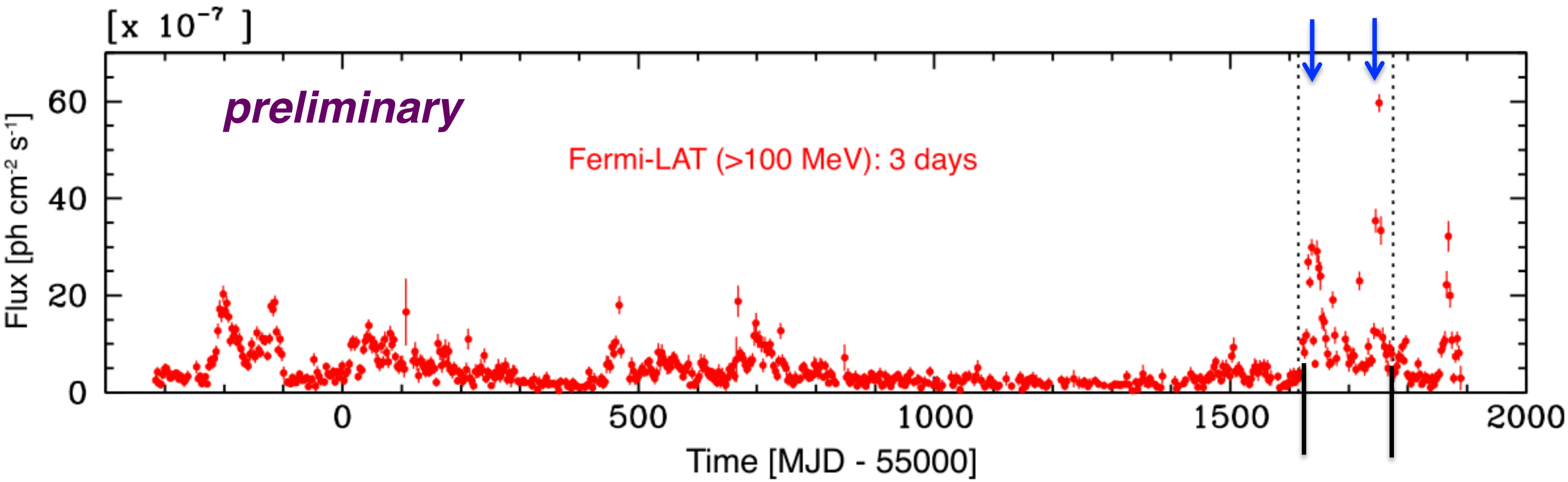
Good conjunction between Fermi and MAGIC spectra
-> should be outside of BLR

Very fast (~ 10 min scale) variability
-> should come from a small region

not compatible in the simple (conical) jet model!!

3C 279 activity for 6 years

- 2008 August – 2014 August measured by Fermi-LAT



Note: Sun occultation (on October 8)

- pair halo search, axion-like particle

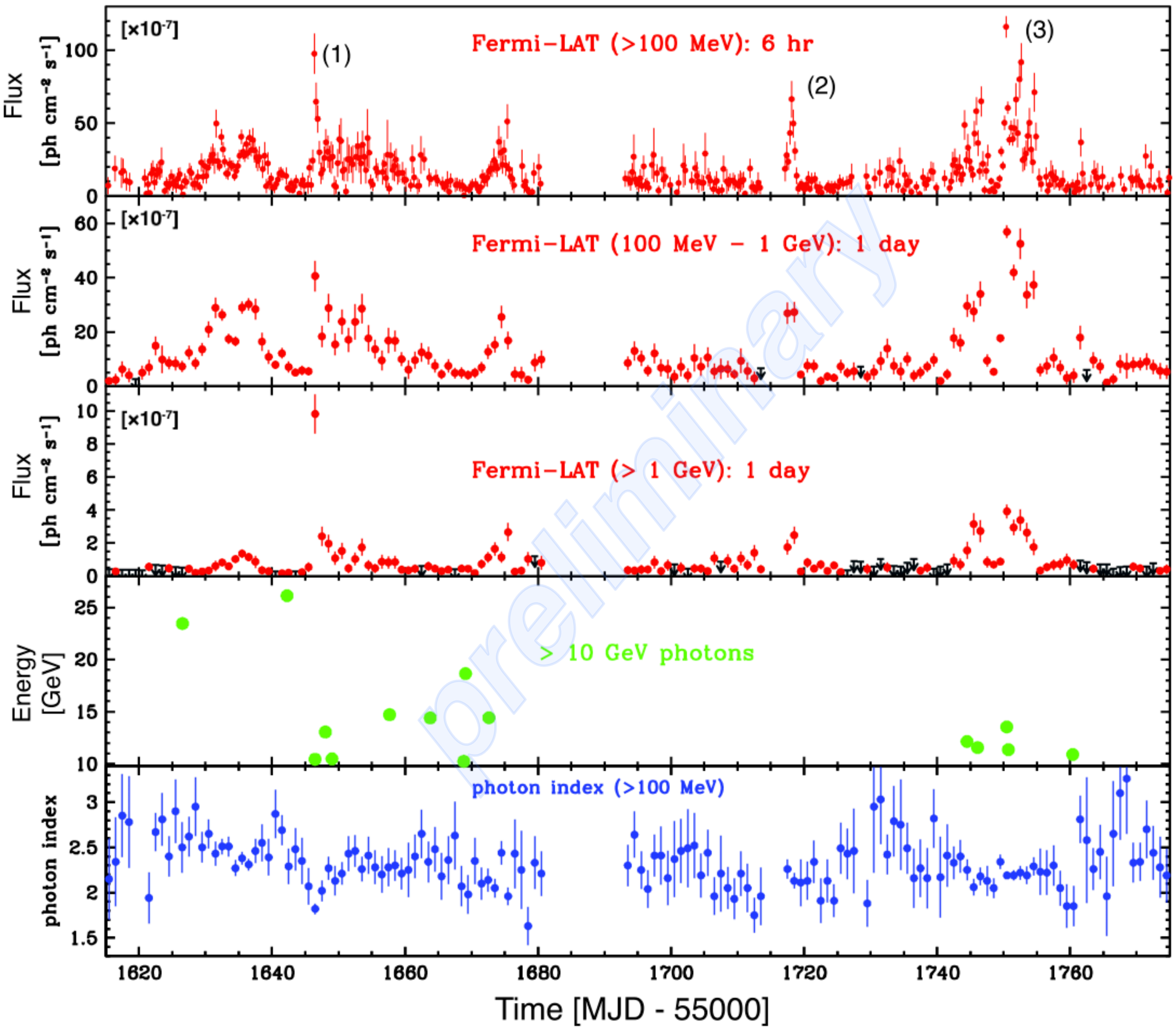
(Fermi coll. (Barbiellini+)14, ApJ, 784, 118)

2013/11/19 – 2014/04/28
(MJD 56615 – 56775)

Gamma-ray flare activity reported in Atel

- 2013/12/21: #5680 Fermi LAT detection of a GeV flare from the FSRQ 3C 279
- 2014/04/01: #6036 Fermi LAT detection of renewed GeV activity from blazar 3C 279

Fermi-LAT light curve

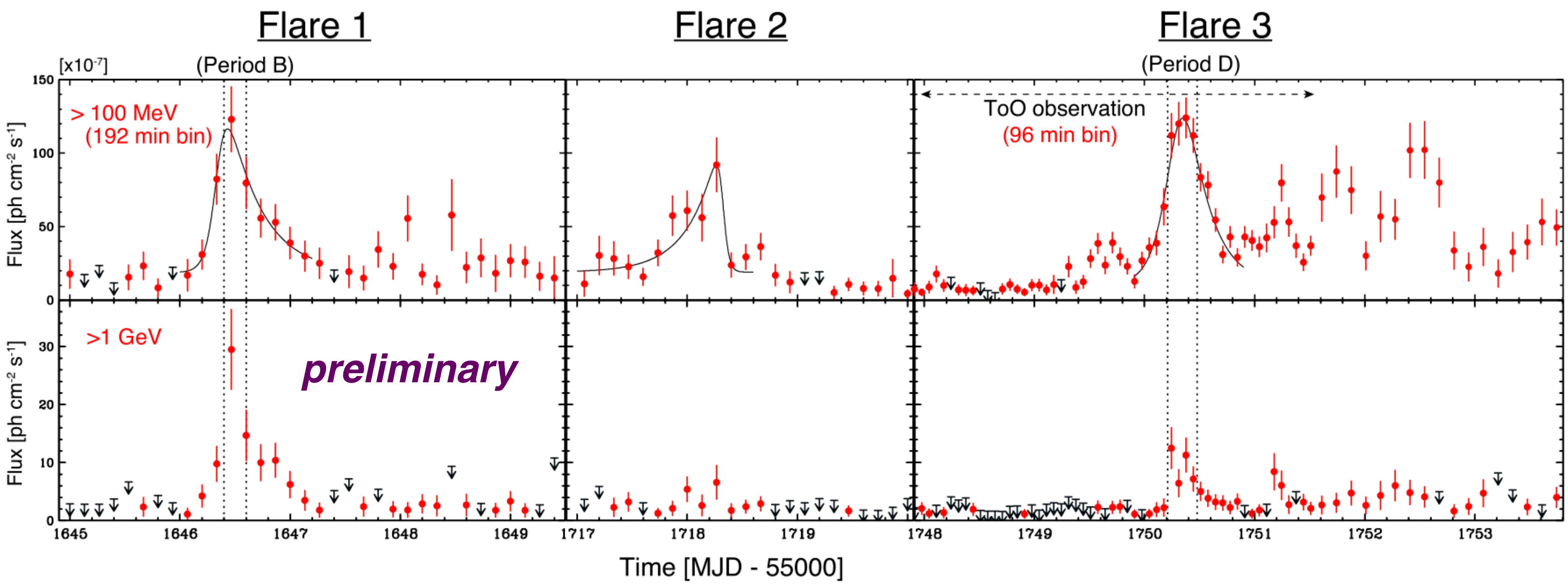


reached 10^{-5} ph/cm^2/s level in flux (> 100 MeV)

only a several FSRQs show such a high flux

c.f. Crab: 2.5×10^{-6} ph/cm^2/s

Flare profile



$$F(t) = F_0 + \frac{b}{e^{-(t-t_0)/\tau_{\rm rise}} + e^{(t-t_0)/\tau_{\rm fall}}}$$

Flare number	$\tau_{\rm rise}$ [hrs]	$\tau_{\rm fall}$ [hrs]	b ($\times 10^{-7}$) photons cm^{-2} s^{-1}	F_0 ($\times 10^{-7}$) photons cm^{-2} s^{-1}
Flare 1	1.4 ± 0.8	7.4 ± 3.2	150 ± 36	19 ± 12
Flare 2	6.4 ± 2.4	0.68 ± 0.59	100 ± 26	19 ± 5
Flare 3 (ToO)	2.6 ± 0.6	5.0 ± 0.8	216 ± 19	10.5 ± 6.6

a small emission region (1hr ~ $2 \times 10^{15} (\Gamma/20)$ cm)

short time variability in FSRQs

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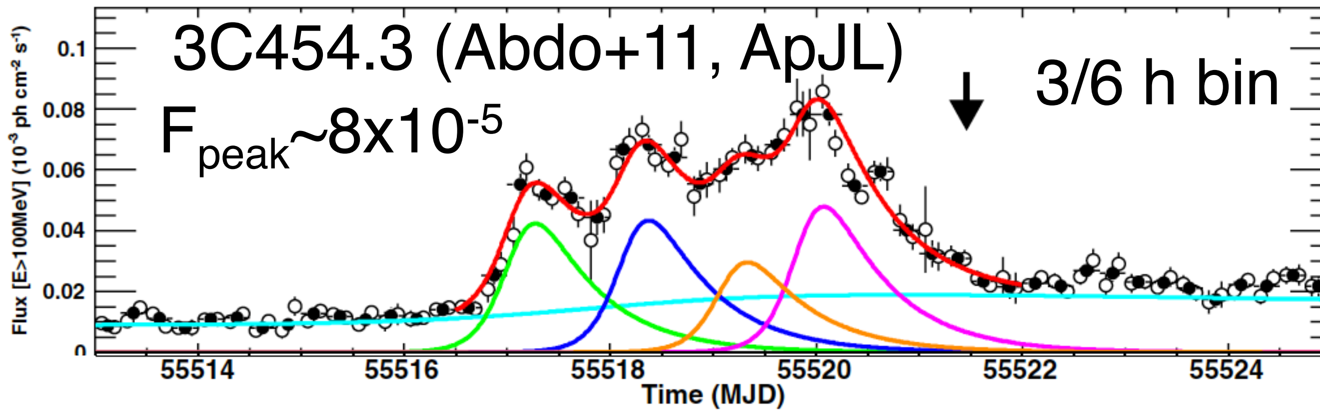
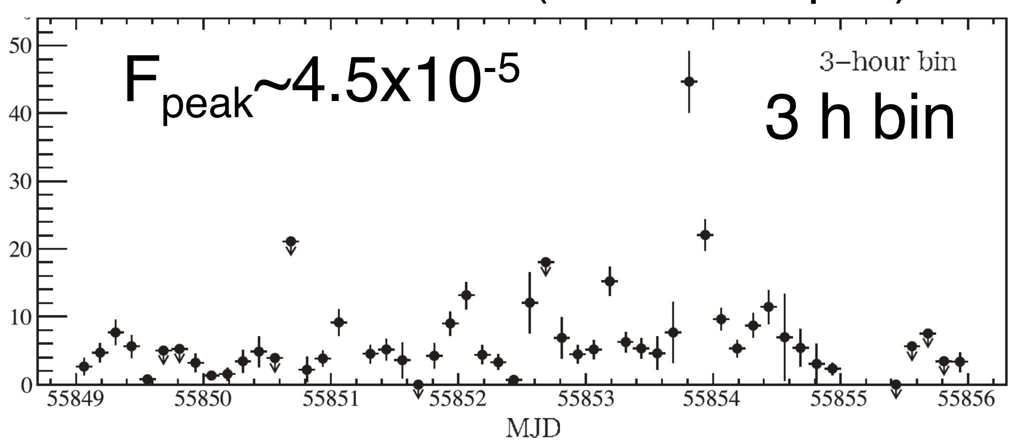
Fermi-LAT
(>100 MeV)



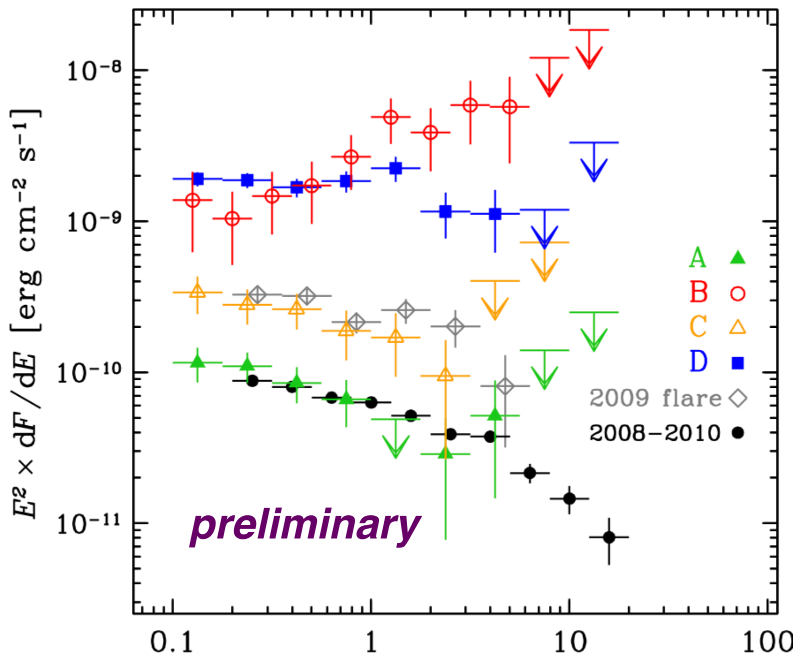
see the talk by M. Barkov in this session

PKS1510-089 (Saito+13 ApJL)



see the talk by S.Saito in this session

LAT Spectrum



- **Very hard index (1.71±0.10)**
- **peaked at a few GeV**

Period (MJD - 56000)	fitting model[a]	$\Gamma/\alpha/\Gamma_1$	β/Γ_2	E_{brk} (GeV)	TS	$-2\Delta L$[b]	Flux (> 0.1 GeV) (10^{-7} ph cm^{-2} s^{-1})	# of photons > 10 GeV
Period A (3 days)	PL	2.36 ± 0.13	···	···	174	···	5.9 ± 0.9	1
Dec 16,0h – 19,0h	LogP	2.32 ± 0.17	0.03 ± 0.07	···	174	< 0.1	5.7 ± 0.9	(26.1 GeV)
(642.0 — 645.0)								
Period B (0.2 days)	PL	1.71 ± 0.10	···	···	407	···	117.6 ± 19.7	1
Dec 20,9h36 – 14h24	LogP	1.12 ± 0.31	0.19 ± 0.09	···	413	6.0	94.5 ± 18.1	(10.4 GeV)
(646.4 — 646.6)	BPL	1.41 ± 0.17	3.01 ± 0.91	3.6 ± 1.6	415	7.6	100.6 ± 18.4	
Period C (3 days)	PL	2.29 ± 0.13	···	···	219	···	17.1 ± 2.8	1
Dec 31,0h – Jan 02,0h	LogP	2.29 ± 0.16	0.00 ± 0.06	···	219	< 0.1	17.1 ± 2.9	(GeV)
(657.0 — 660.0)	BPL	2.22 ± 0.42	2.32 ± 0.20	0.34 ± 0.27	219	< 0.1	16.9 ± 3.1	
Period D (0.267 days)	PL	2.16 ± 0.06	···	···	1839	···	117.9 ± 7.1	1
Apr 03,5h03 – 11h27	LogP	2.02 ± 0.08	0.10 ± 0.05	···	1840	5.3	114.9 ± 7.1	(13.5 GeV)
(750.210 — 750.477)	BPL	2.02 ± 0.09	2.89 ± 0.45	1.6 ± 0.6	1843	8.0	115.1 ± 7.7	

Hard spectra in FSRQs

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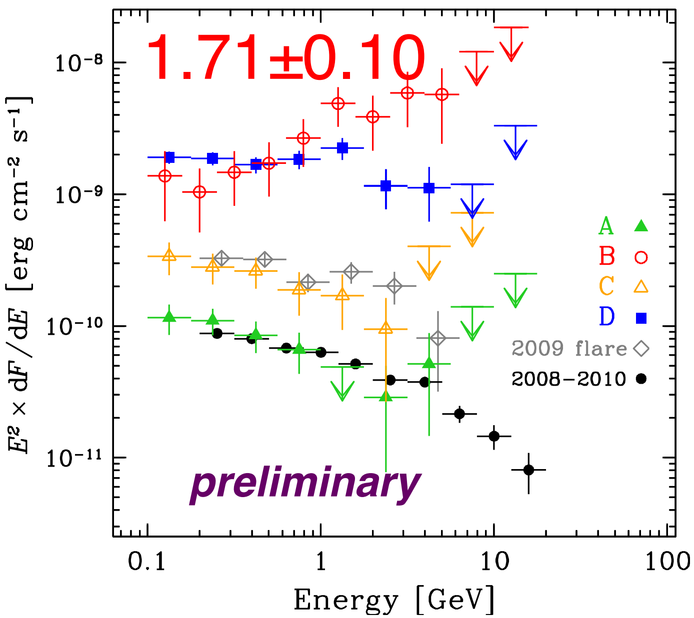
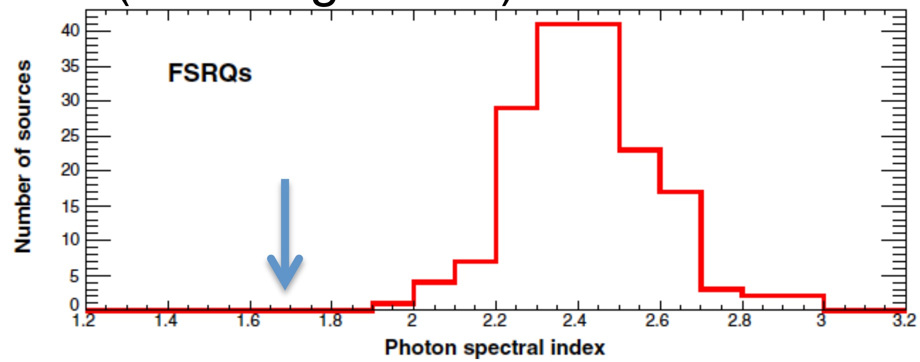
3C 279 (this work)



Fermi 2nd AGN catalog (2LAC)
(= average state)

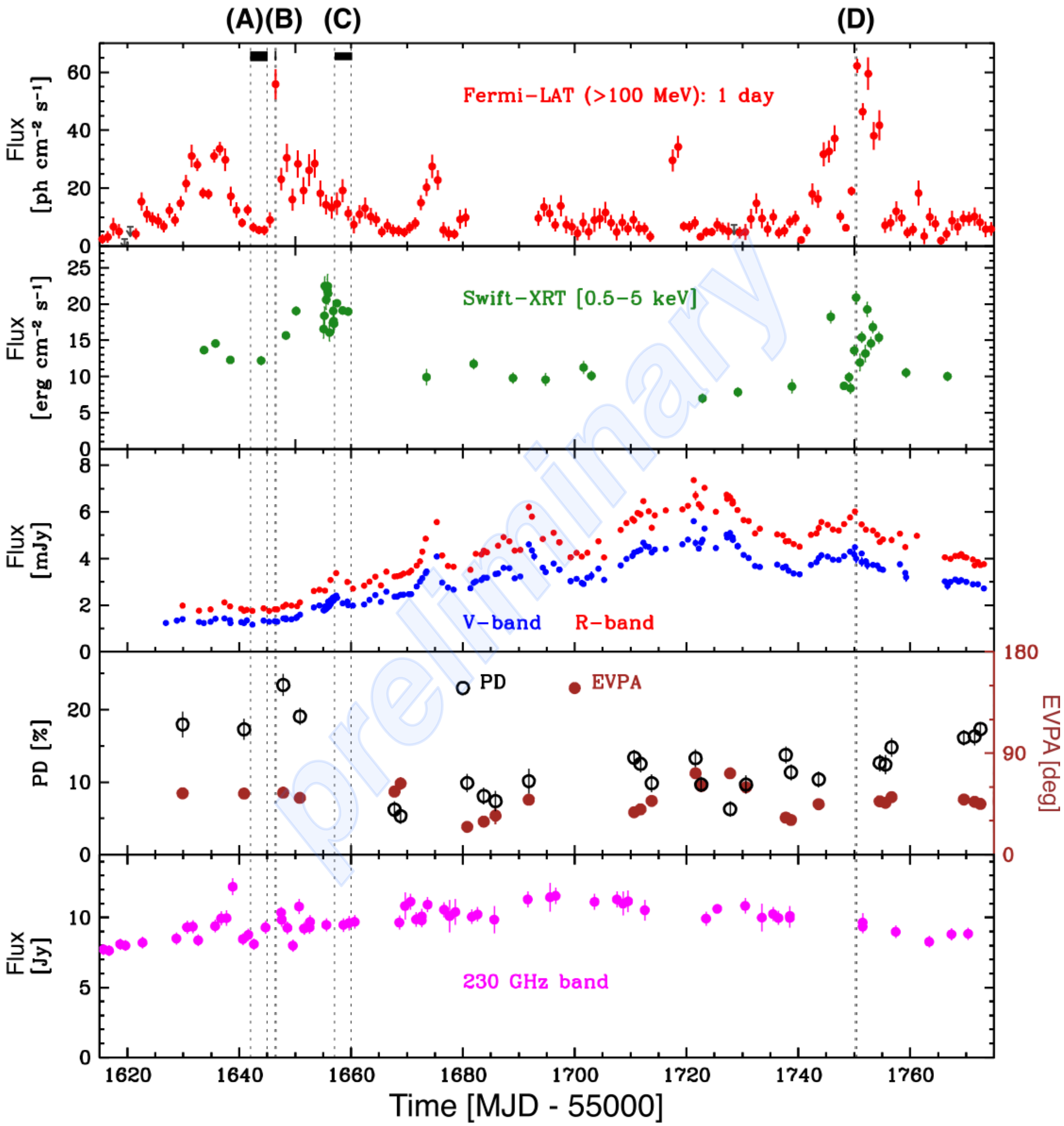


see the 3LAC results talk by B.Lott in the next session

(Pacciani+14, ApJ, flaring FSRQs)

Source	Period A	Δ_t (days)	No. of HE Photons	Chance Prob. (%)****	Γ_{ph} (0.2–10 GeV)	Δ_t (days) for Period B	C	D	Prob shape$_A$ = shape$_B$ (%)
PKS 1502+106	2009 May 6 05:20–2009 May 6 13:11	0.326 (0.38)*	2	0.27/32.3	1.99 ± 0.31	4	8		<3.4
CTA 102	2012 Sep 22 18:12–2012 Sep 22 21:55	0.155	4	0.16/2.3****	1.73 ± 0.14	3	4***	4	0.36
3C 454.3	2013 Sep 24 15:00–2013 Sep 25 04:12	0.55	5	4.1/15.3	1.77 ± 0.17 (1.84 ± 0.08)**	3	3	3	<0.053
PKS 0805−07	2009 May 15 00:21–2009 May 15 08:26	0.337 (0.38)*	4	0.028/0.82	1.51 ± 0.34 (1.77 ± 0.10)**	8	8		0.97
4C +38.41	2011 Jul 3 15:39–2011 Jul 3 18:56	0.136 (0.30)*	2	0.038/4.1	1.85 ± 0.23	4	8		<1.4

Multi-band light curve



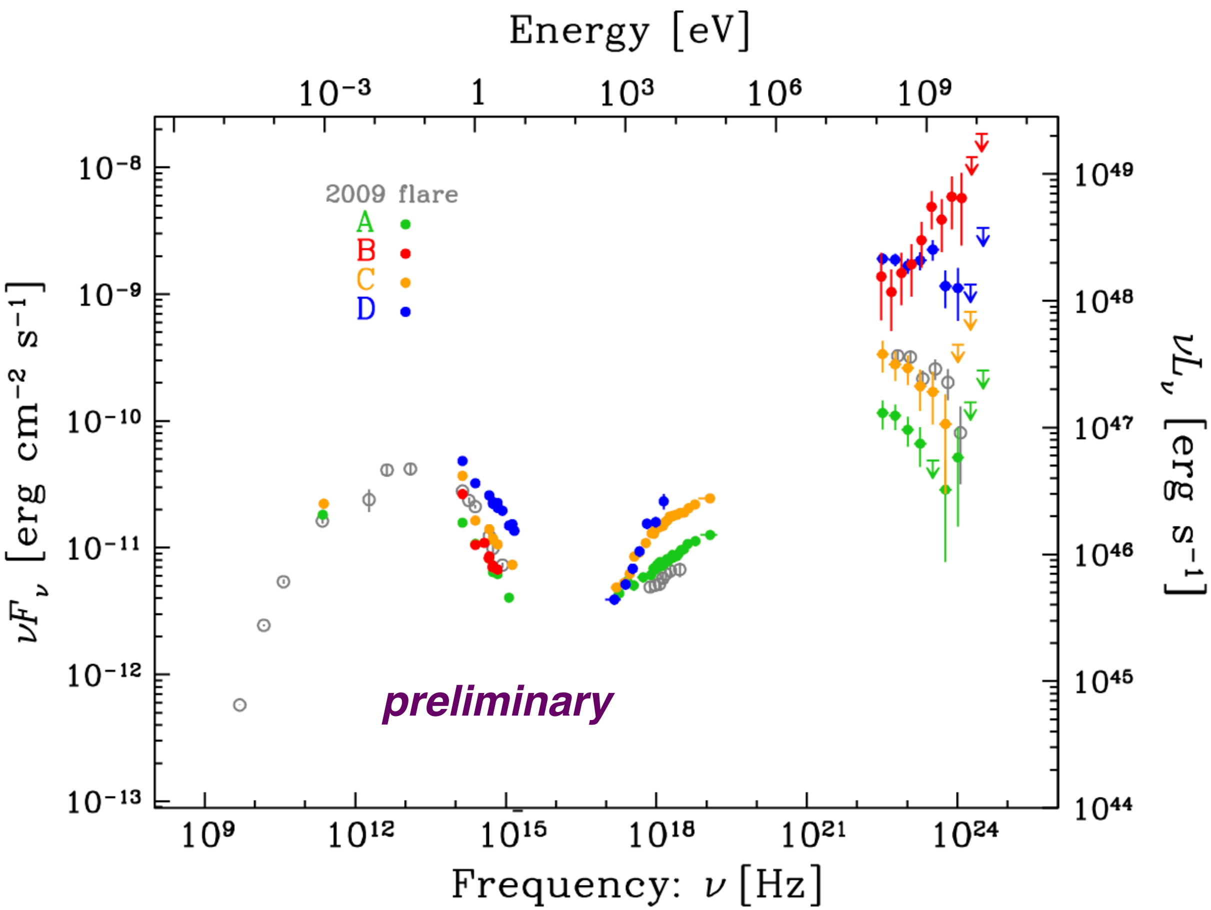
Period (B):
no flare
in other bands

Kanata,
SMART

Kanata,

SMA

Broad band SED



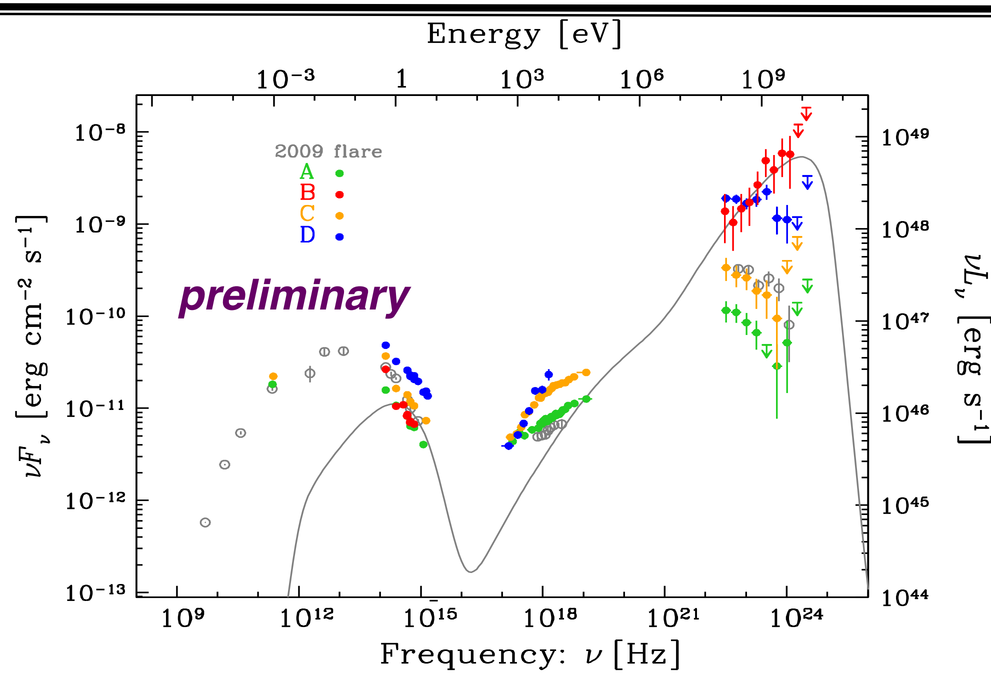
leptonic model
conical jet
(Moderski et al. 2003)

Model parameters constrained based on Nalewajko+14, ApJ

fast variability: (tvar=2h)

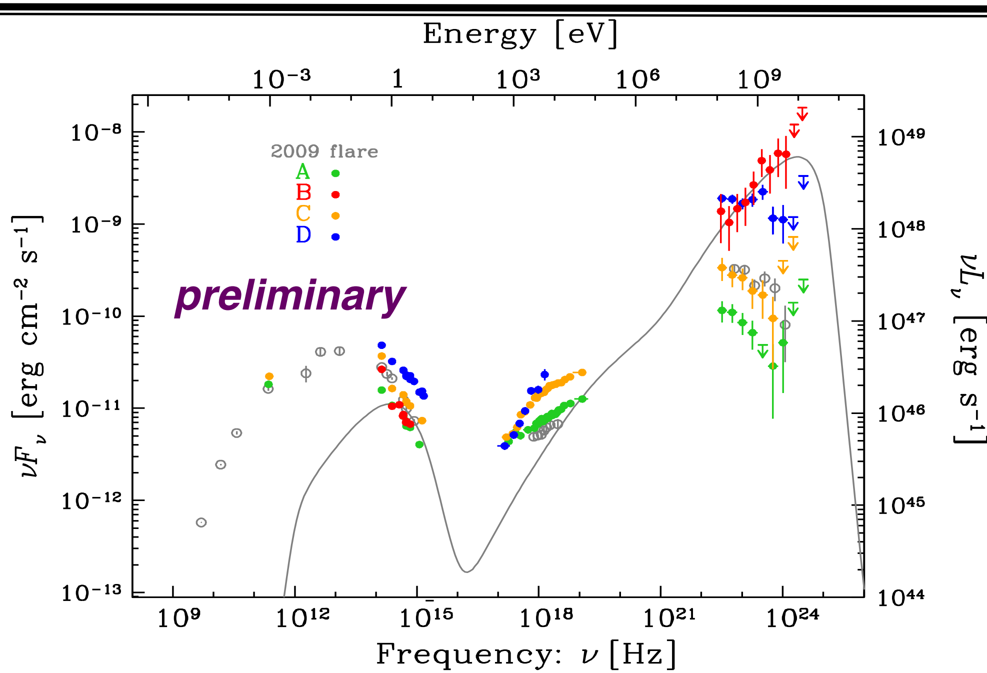
- small emission region, *R*(size)=4.5x10^{15} cm
- efficient cooling *r*(location) = 9x10^{16}cm **(inside BLR)**,
- G=20

emission model for Period B



1. hard index (γ-ray band) in the fast cooling regime
   - required very hard index for electron injection spectrum: **q=1**
2. Gamma-ray emission site should be inside BLR (< 0.1 pc)
3. very matter dominated jet: $L_B/L_{jet} \sim 10^{-4}$
4. no optical counter flare: γ_{max} = 3700: GeV-TeV origin?

emission model for Period B



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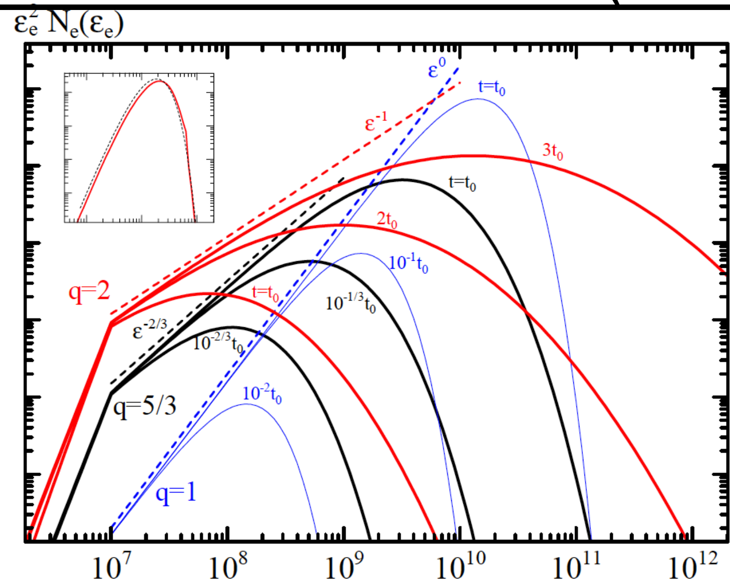
hard (q<2) electron index

q : injected electron index

q ≥ 2: standard shock (Fermi-I) acceleration: ***too soft!!***

<possible solutions>

Stochastic Acceleration (Fermi-II)



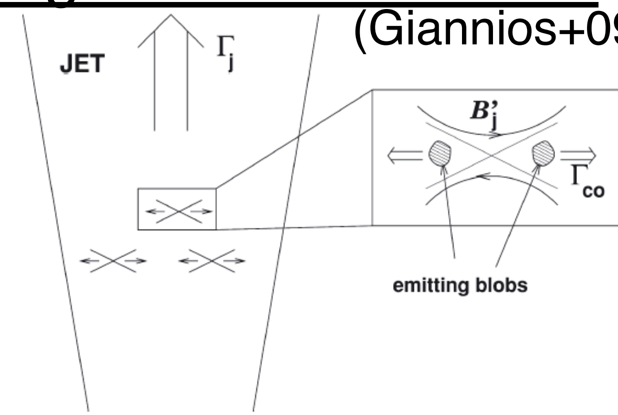
(Asano+14, ApJ)

see also Asono's talk on Monday

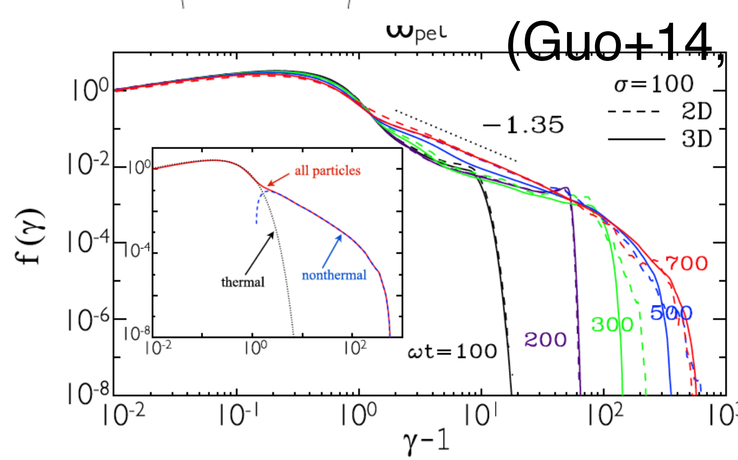
do they work for FSRQ jets?

magnetic reconnection

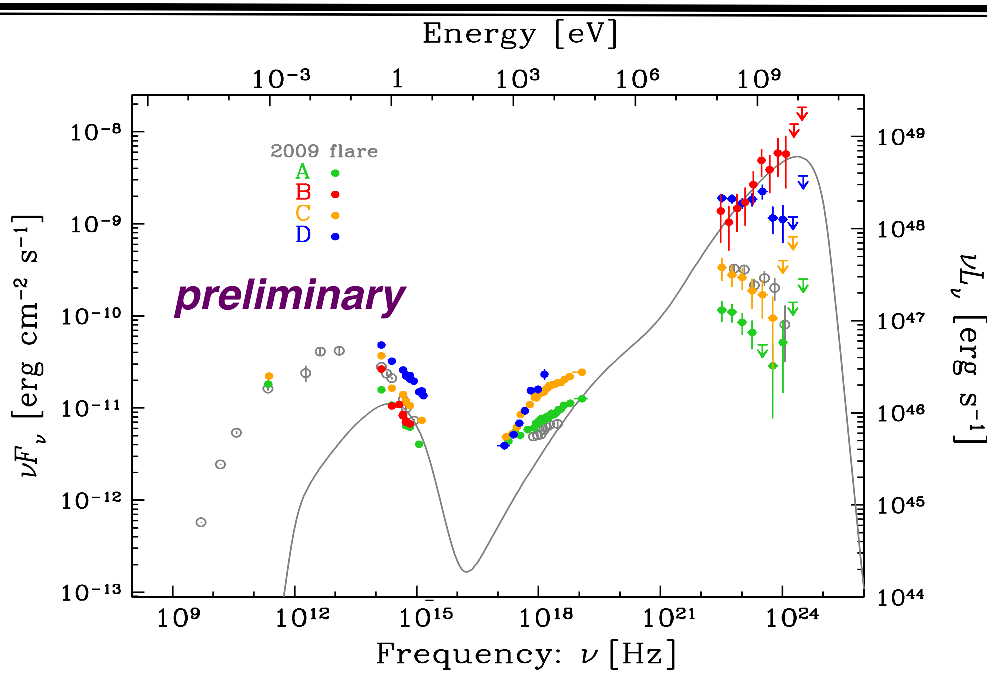
(Giannios+09)



(Guo+14, PRL)



emission model for Period B



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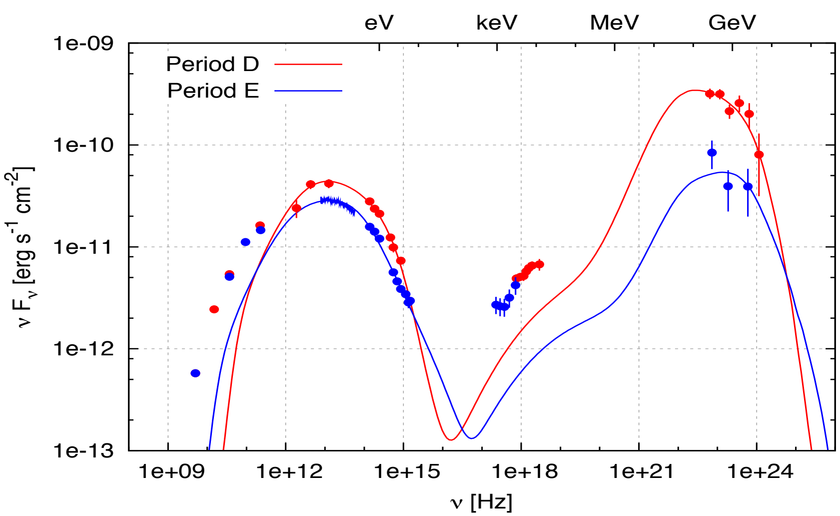
where is the emission region?

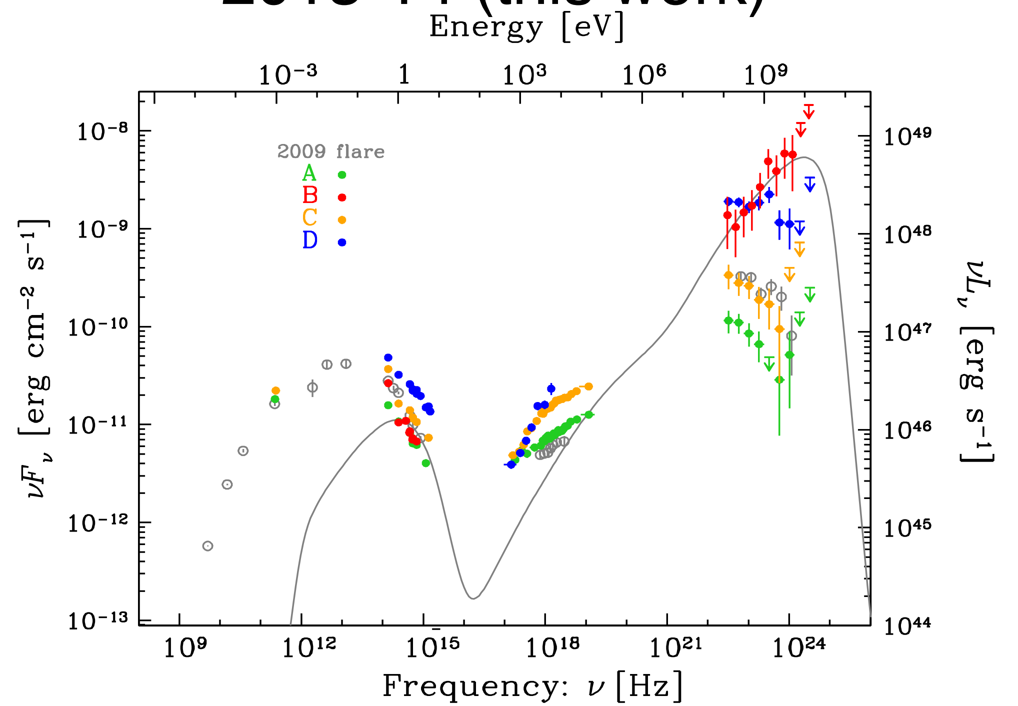
3C 279

2009 (Hayashida+12)



a few pc (outside BLR)

2013-14 (this work)



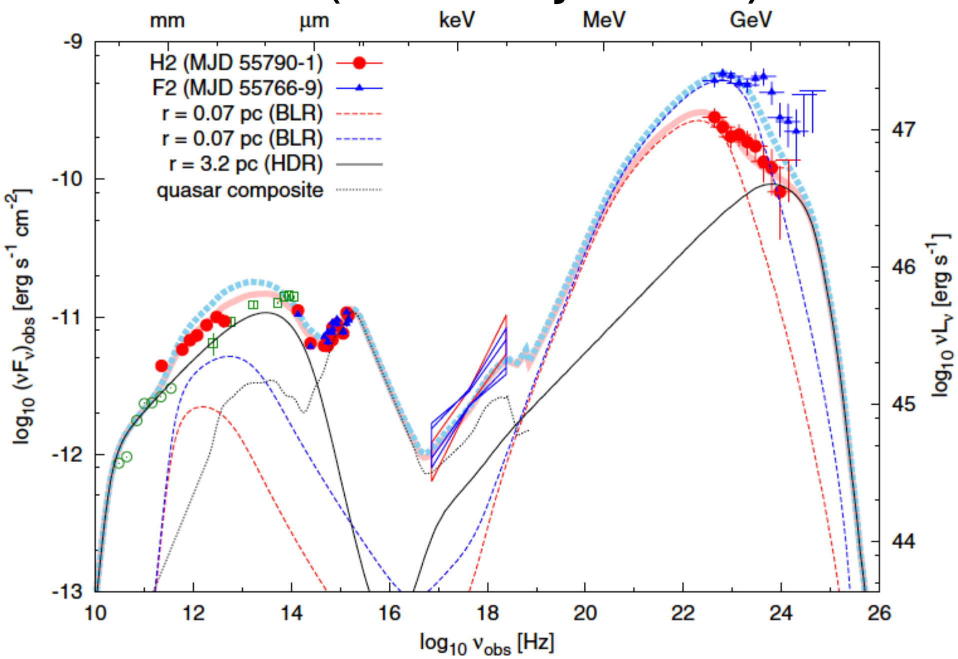
0.03 pc (inside BLR)

emission site is not unique!

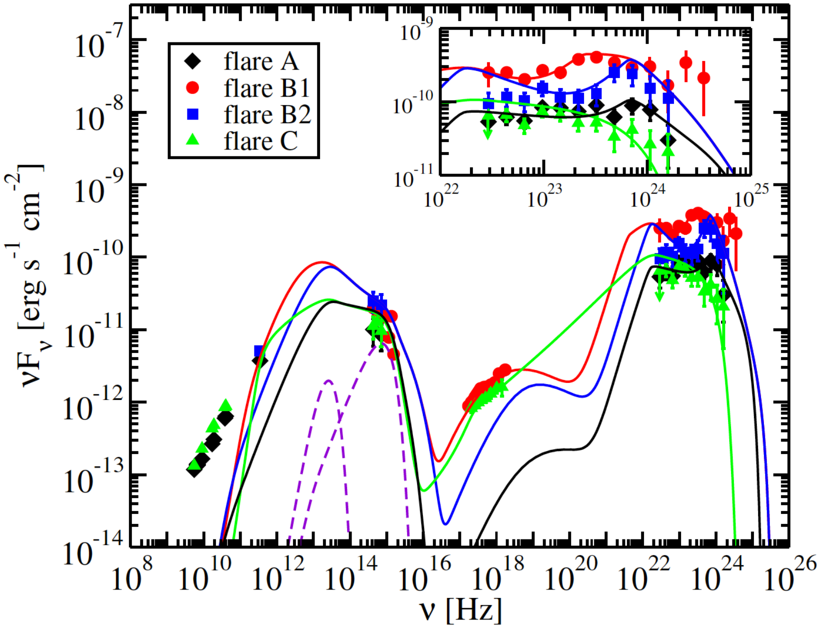
Multi-components for gamma-ray emission

Just examples

PKS1510-089 (z=0.31)
2011 (Nalewajko+12)

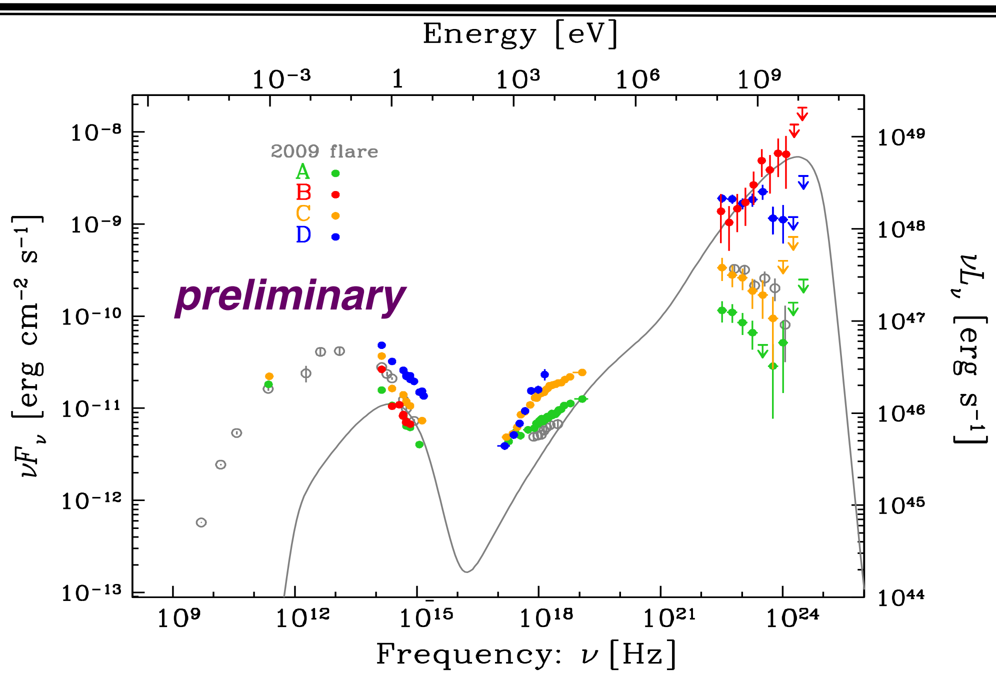


PKS1424-418 (z=1.522)
2008-2011 (Buson+14)



See also Fink&Demer+10 for 3C454.3
and many other works

emission model for Period B



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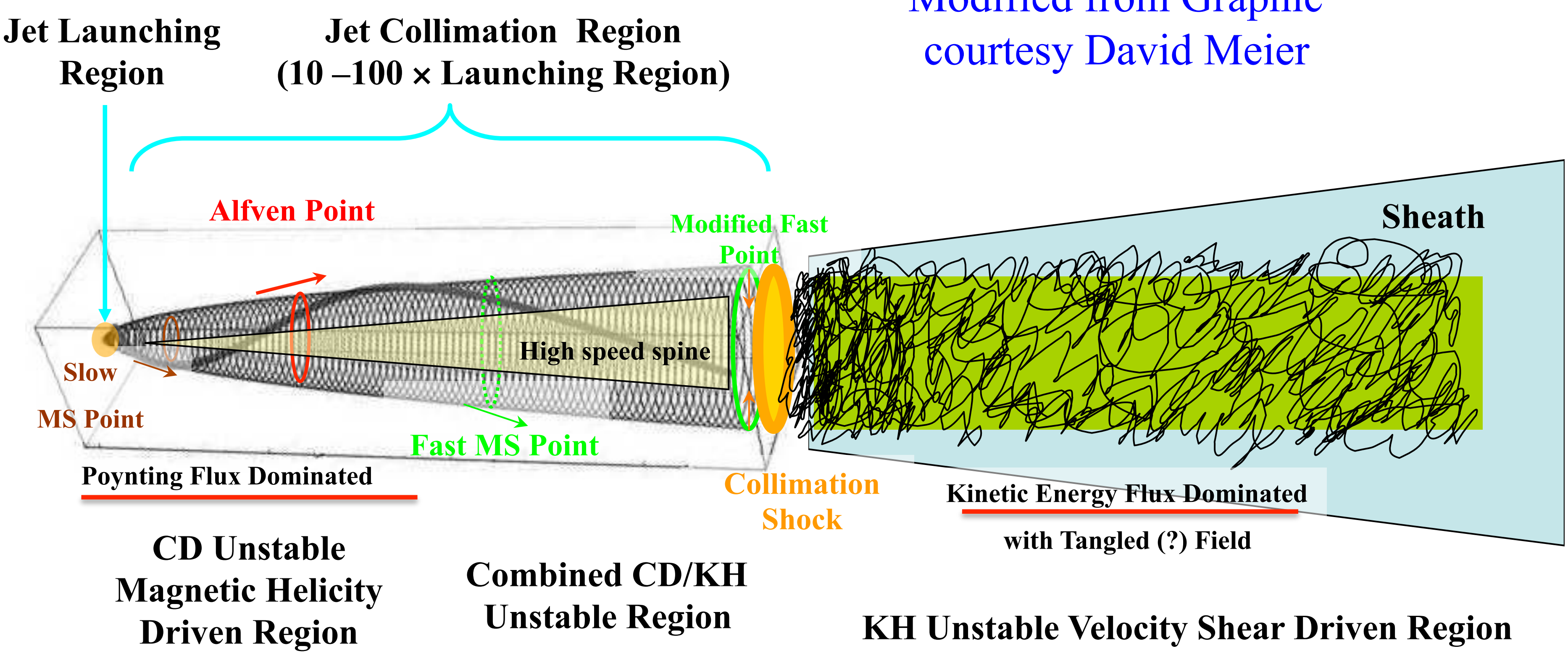
Regions of AGN Jet Propagation



slide by Y.Mizuno

Poynting flux dominated? particle-dominated?

- if jet is derived by the magnetic field (Blandford-Znajek process) ,,,,
  - → jet should be Poynting-flux dominated jet < 10^3 r_g (= inside BRL)
- Leptonic models can explain well broad band SEDs both cases for inside and outside BLR
  - the results (always?) suggest matter-dominated jets (or some models with equipartition see e.g., Dermer+14, *ApJ, 782* for 3C279)
- Hadronic models require stronger magnetic fields (10-100 G) than the Leptonic models (0.01-1 G), but also requires high power of relativistic protons ($10^{47\text{-}49}$ erg/s: Boettcher, Rimer+13, *ApJ,*)

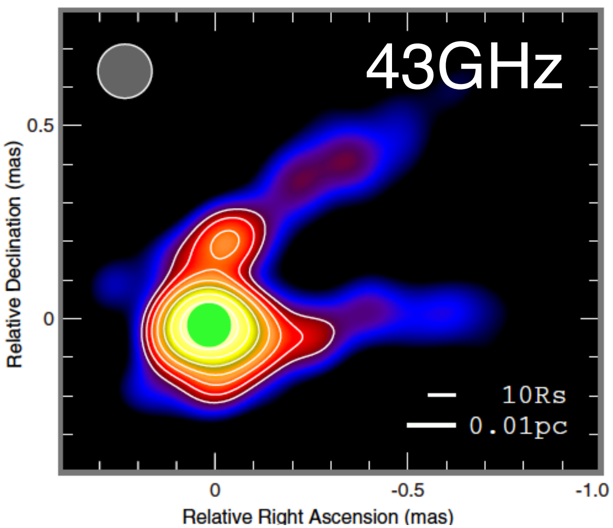
any other approaches to estimate U_{kin}/U_B?

U_e/U_B at the jet base of M87

(Kino+14, *ApJ*,786,5)

$$\frac{U_e}{U_B} = \frac{8\pi}{3b^2(p)} \frac{k(p)E_{e,\min}^{-p+2}}{(p-2)} \left(\frac{D_A}{1\,\mathrm{Gpc}}\right)^{-1} \left(\frac{\nu_{\mathrm{ssa,obs}}}{1\,\mathrm{GHz}}\right)^{-2p-13} \times \left(\frac{\theta_{\mathrm{obs}}}{1\,\mathrm{mas}}\right)^{-2p-13} \left(\frac{S_{\nu_{\mathrm{ssa}},\mathrm{obs}}}{1\,\mathrm{Jy}}\right)^{p+6} \left(\frac{\delta}{1+z}\right)^{-p-5}$$

(for $p > 2$). (14



core detection:

ν_obs = ν_ssa

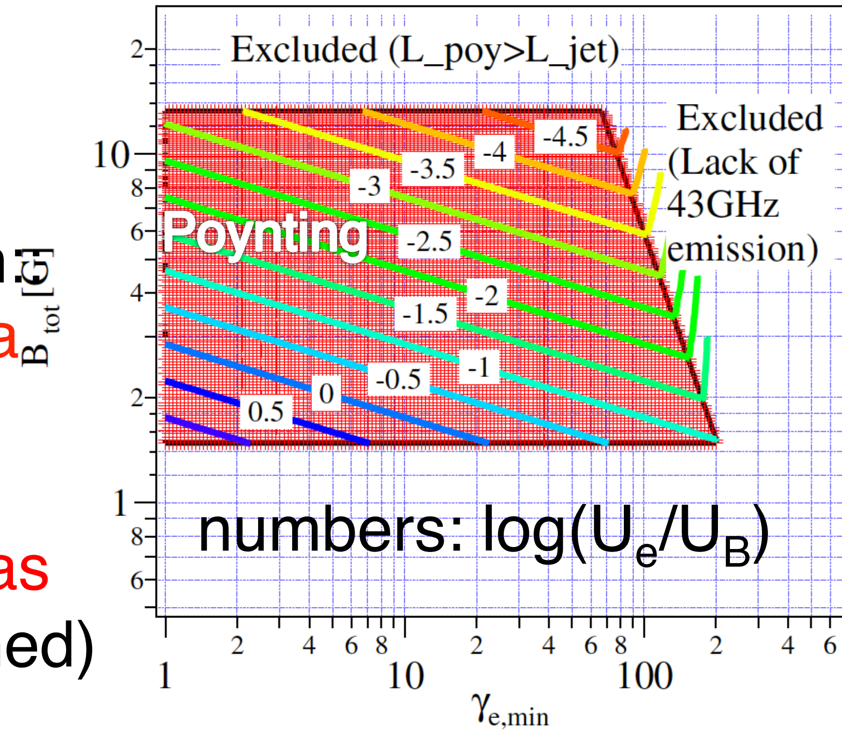
(at τ_{saa}=1)

θ_{FWHM}~0.11mas

(well determined)

Allowed B, γ_{min} region

(L_j=5x10^{44} erg/s, p=3)



numbers: $\log(U_e/U_B)$

see more details of the M87 observation talk by K.Hada in AGN III

emission model for Period B

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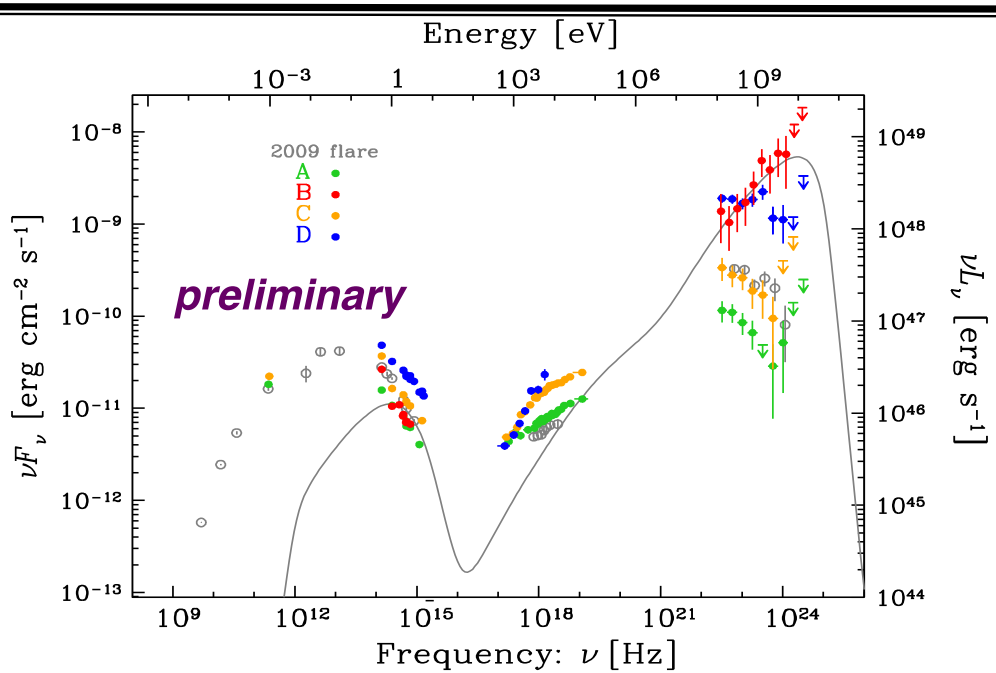

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GeV-TeV : the same origin (FSRQ)?

3 (4) TeV FSRQs:

- 3C 279 (z=0.536)
  (TeV detection after Fermi launch)

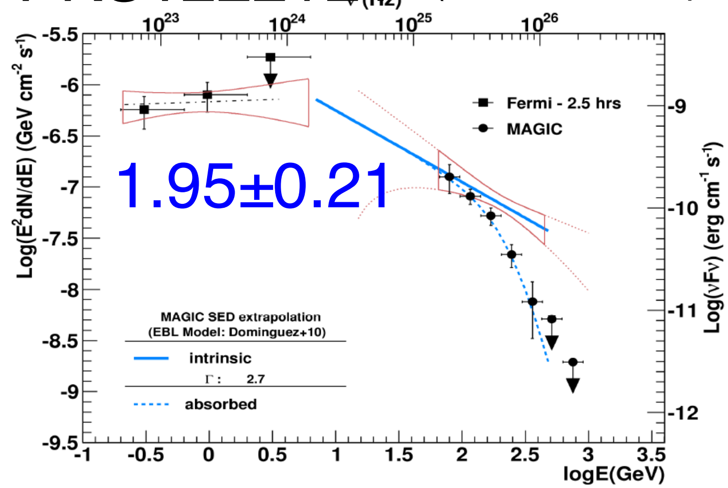
- PKS 1222+21 (z=0.432)
- PKS 1510-089 (z=0.36)

smooth conjunction
between GeV and TeV emission
→ ***one component***

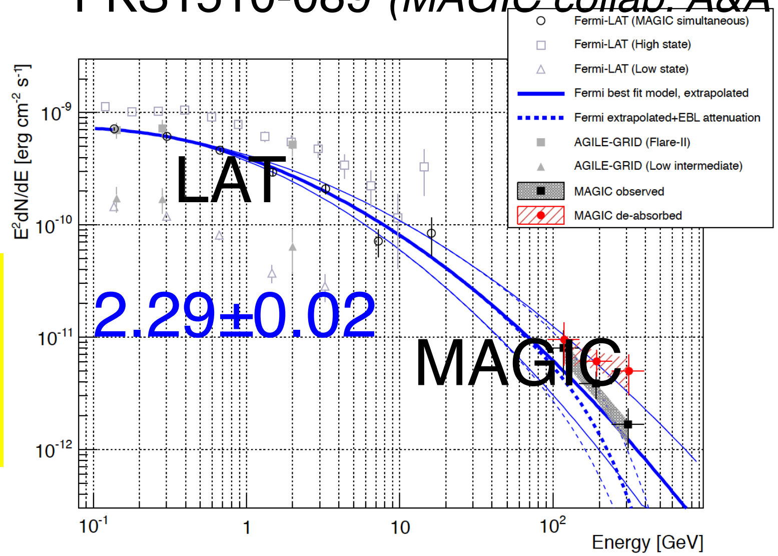
- *S3 0218+357 (z=0.944)*: ***new***

see the case for S3 0218+35,
the most distant new VHE blazar
talks by D.Mazin in the next session

PKS1222+21 (MAGIC Coll. ApJL 2011)

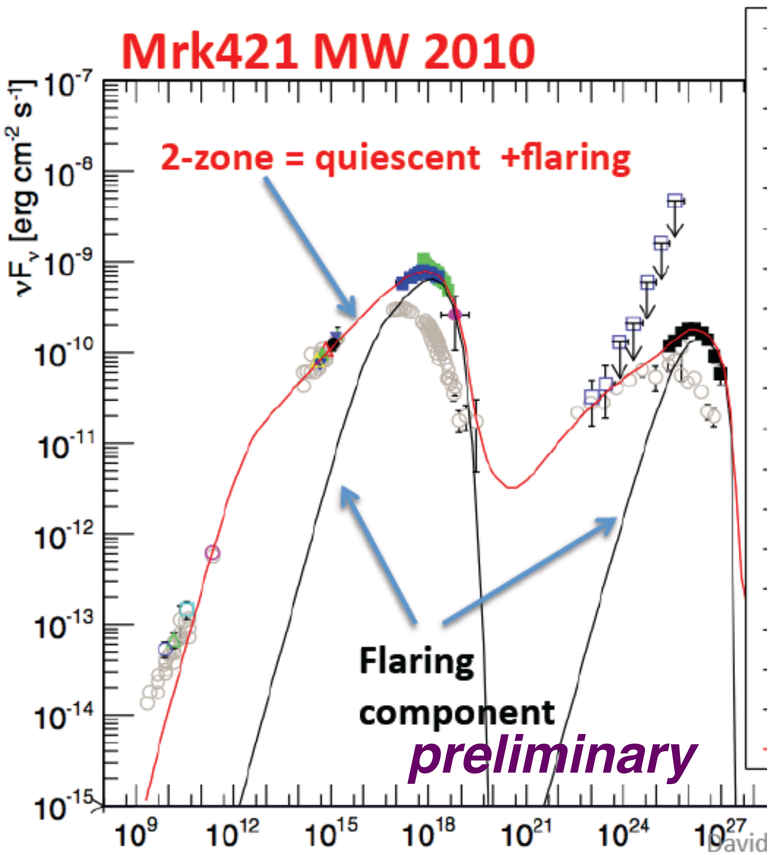


PKS1510-089 *(MAGIC collab. A&A)*



in classical HBL?

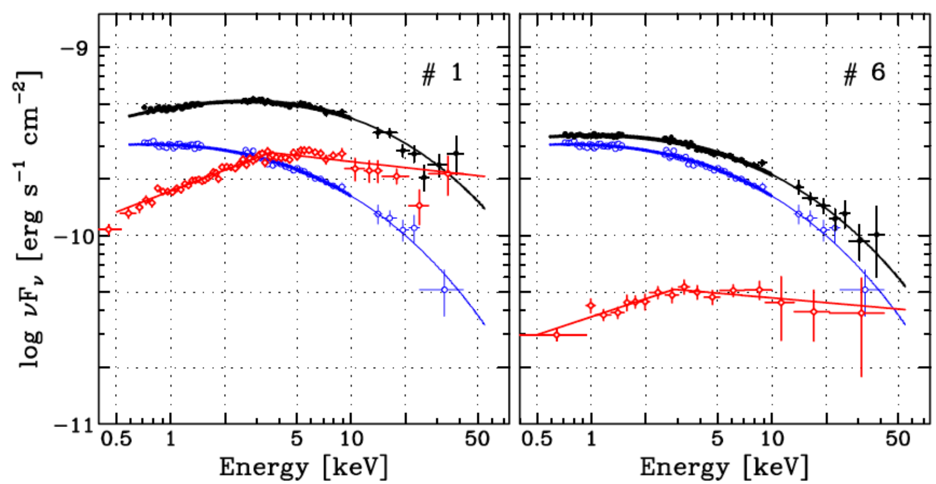
quiescent (broad) + flaring (narrow) components



see talk by D.Paneque in the AGN III session

X-ray by Suzaku in 2006

(Ushio,,,MH+09)



total

quiescent

flaring

extra-high energy component?

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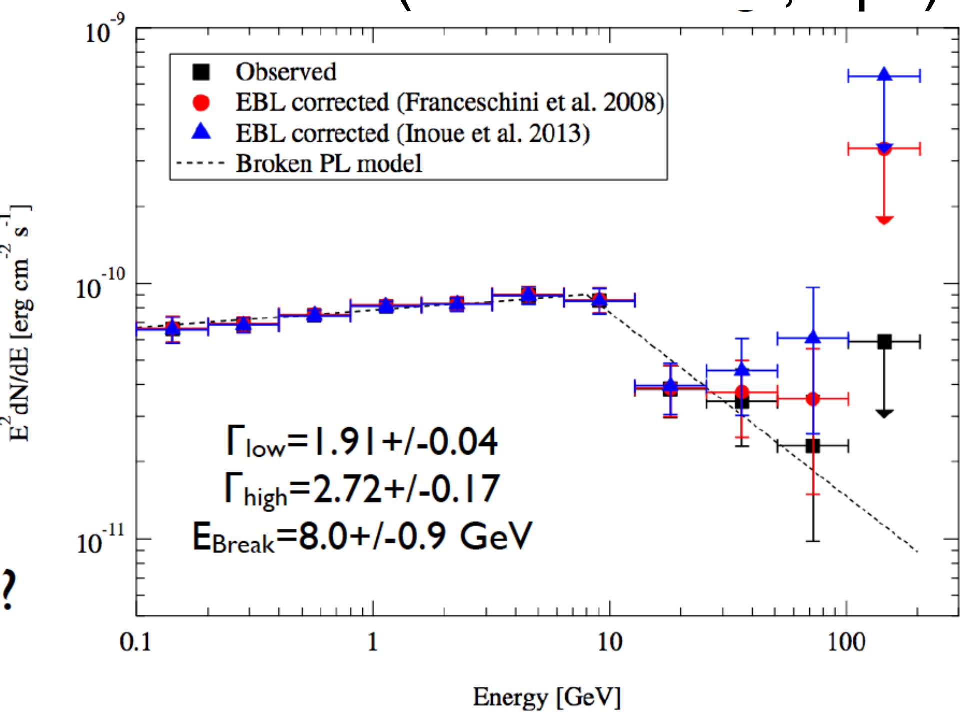
PKS0426-380 (*z*=1.1)

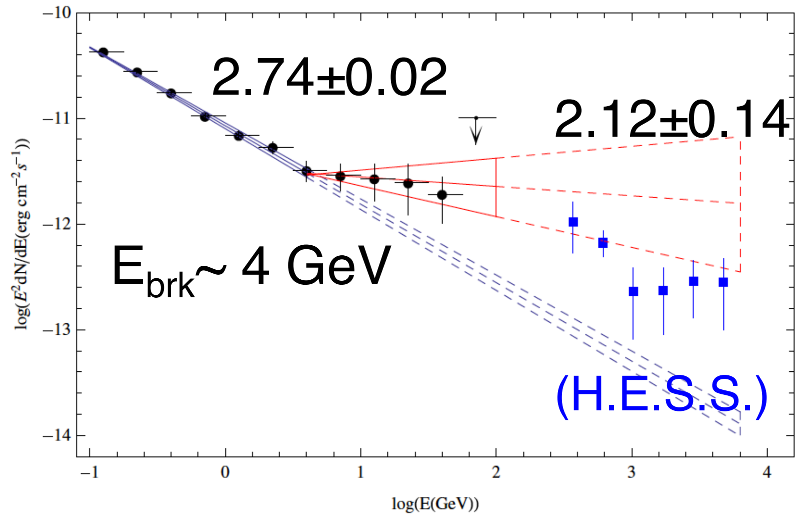
2 VHE (>100GeV) events detected

(Y.Tanaka+13, ApJ)



Cen A core

(Sahakyan+13, ApJ)



for more radio galaxies see talks by Y.Fukazawa and by I.Edahiro in the AGN III session

Answers:

- where is the gamma-ray emission site?
  - *both inside and outside BLR (near and far)*
- what is the acceleration mechanism?
  - *not only shock acceleration (Fermi-I)*
- what is the dominant component in jet?
  - *jet simulation: Poynting-flux dominated (< 10^3 r_g)*
  - *emission model : matter dominated,*
  - *VLBI observations (core detected) can be also used*
- do the GeV and TeV emissions originate from the same component?
  - *seems not always (not established, yet,,,)*
  - *quiescent + flaring, extra-high energy component,,,,,,*

For more details studies of blazars

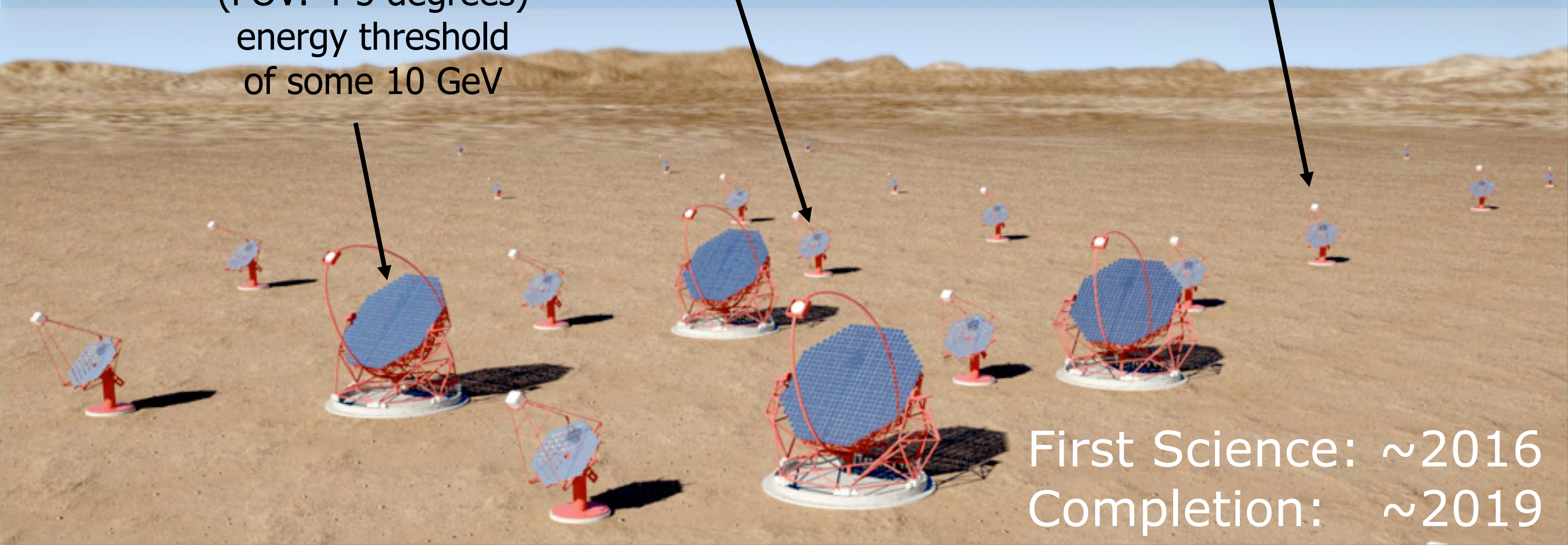
- Cherenkov Telescope Array

The Cherenkov Telescope Array

Core-energy array:
23 x 12 m tel. (MST)(SCT)
FOV: 7-8 degrees
mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section:
30-70 x 4-6 m tel. (SST)
- FOV: ~10 degrees
10 km^2 area at
multi-TeV energies

Low-energy section:
4 x 23 m tel. (LST)
(FOV: 4-5 degrees)
energy threshold
of some 10 GeV



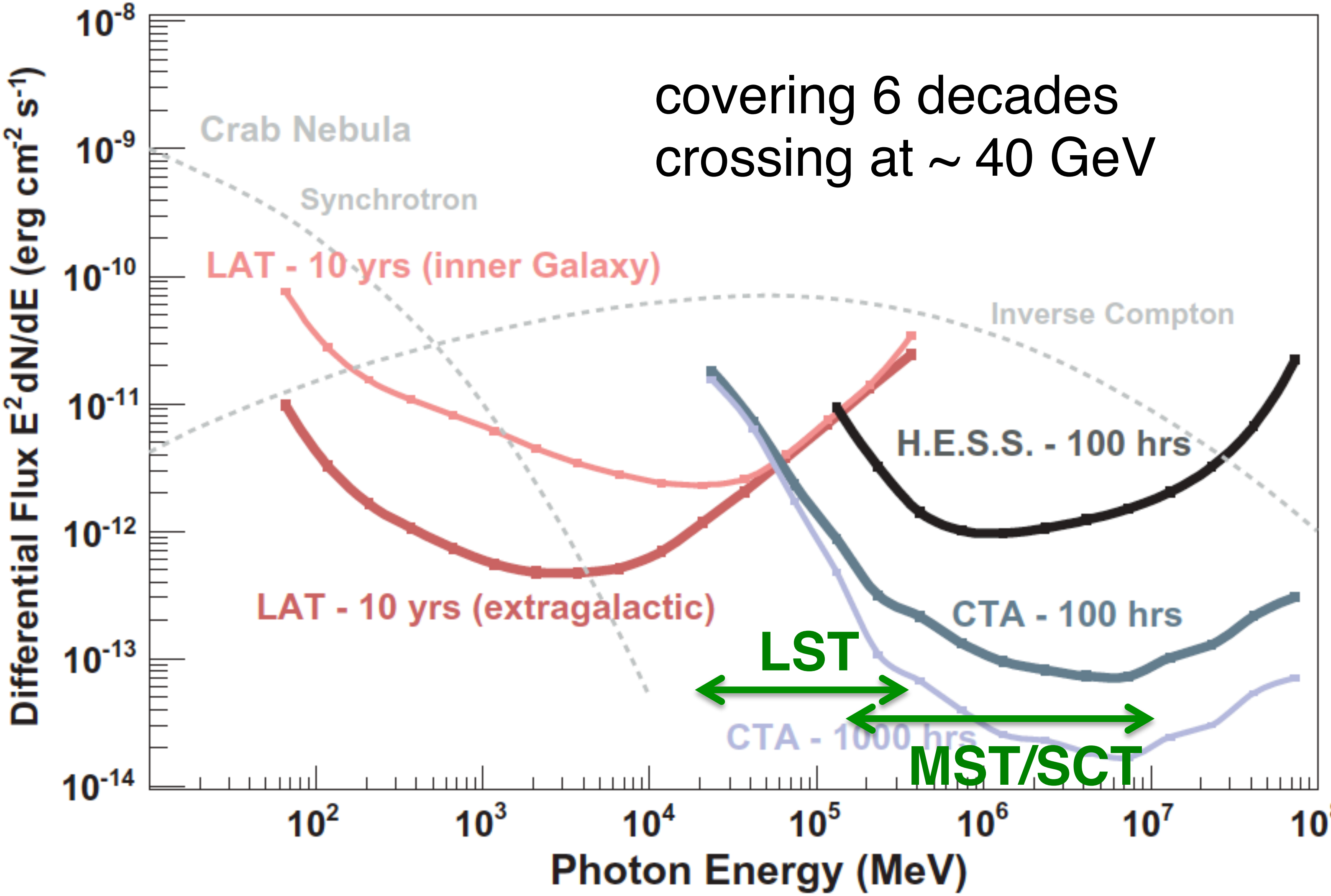
First Science: ~2016
Completion: ~2019

Performances: Fermi-LAT and CTA

sensitivity

Funk & Hinton (2013)

covering 6 decades
crossing at ~ 40 GeV



Japanese contributions : LST

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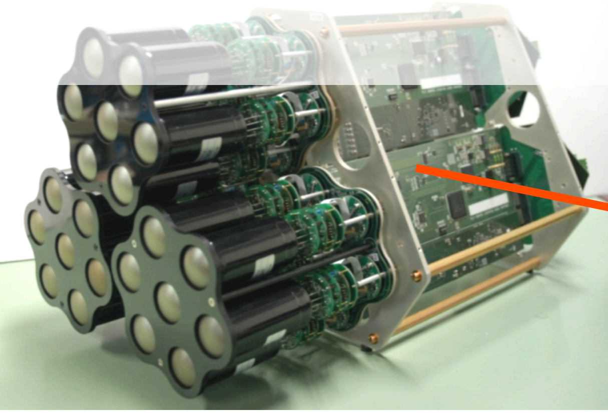
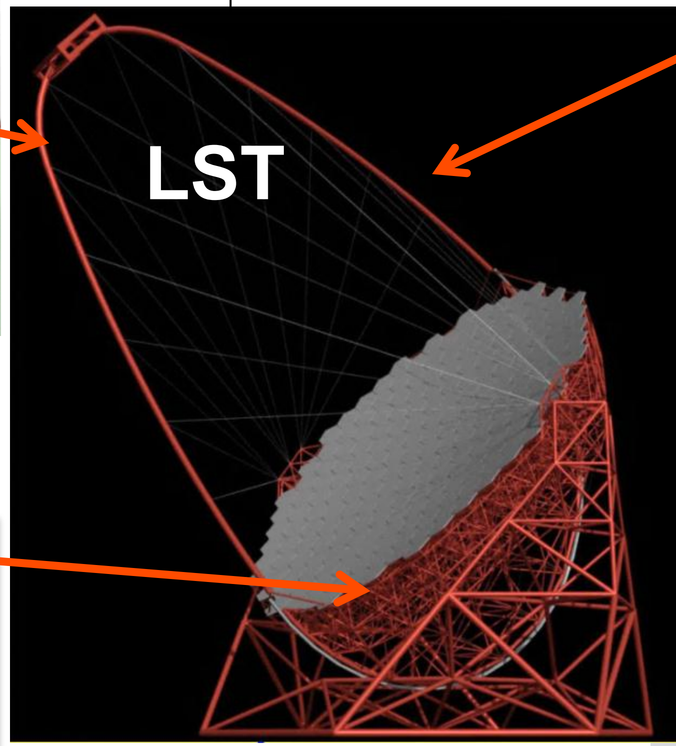
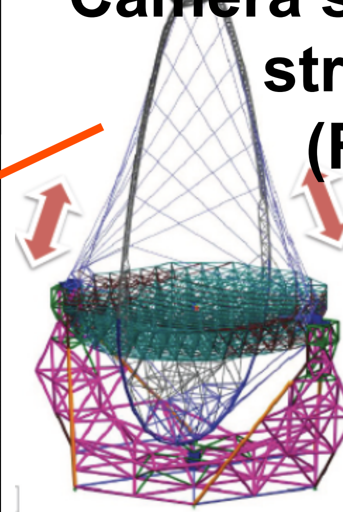
Camera(Japan, Spain)



International collaboration!!



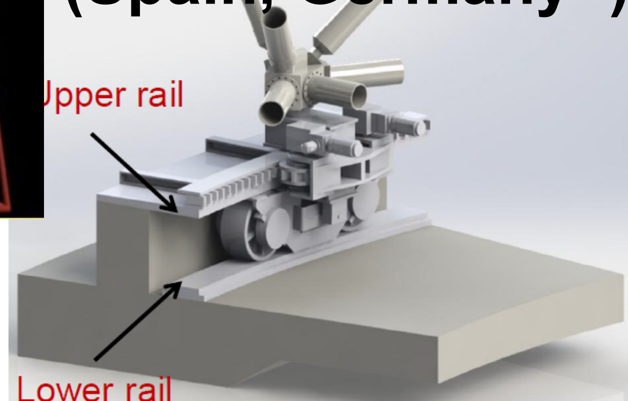
Camera support structure, (France)



Mirror(Japan)

Structure (Germany)

Drive (Spain, Germany+)



Japanese contributions : LST

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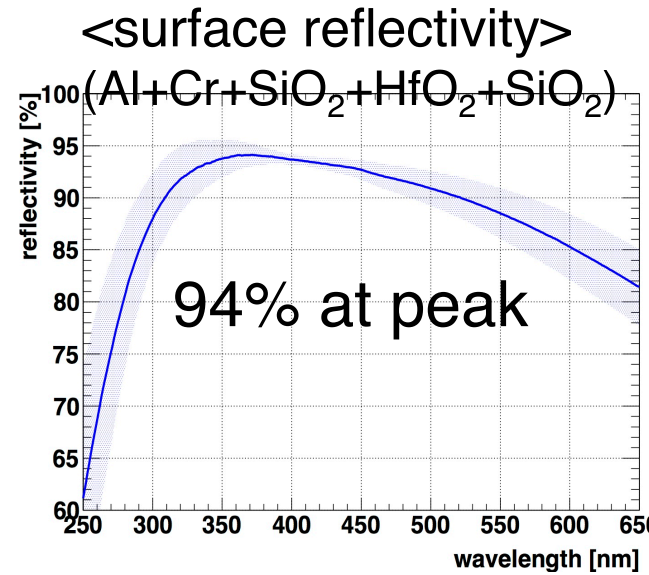
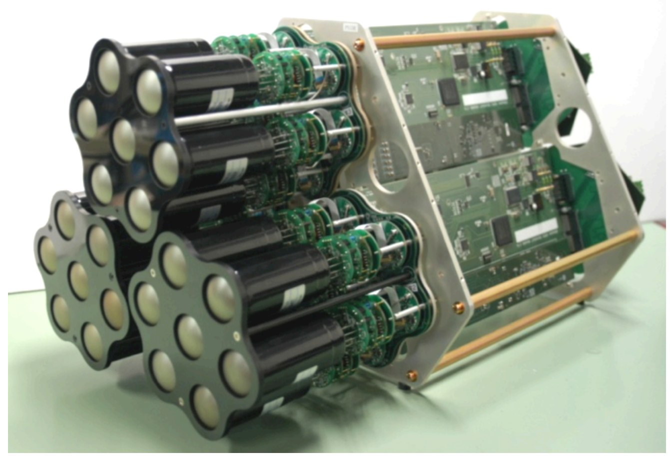
Mirror (200 for 1 LST)

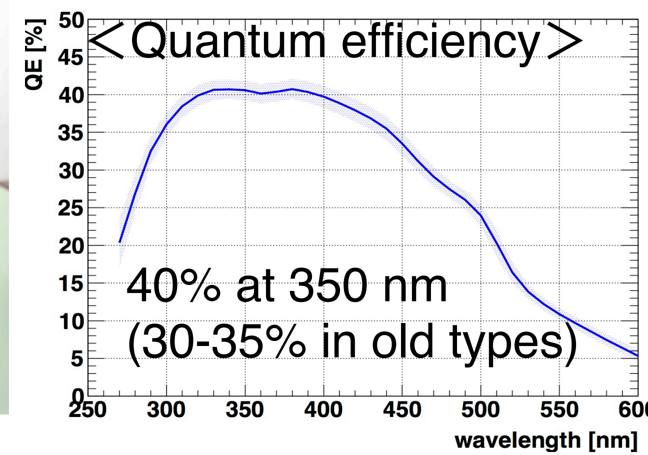
- Focal length: 28 m
- PSF: 0.03° (1/3 pixel)
- Weight: 47 kg
- developed with
  a company「Sanko」



Camera

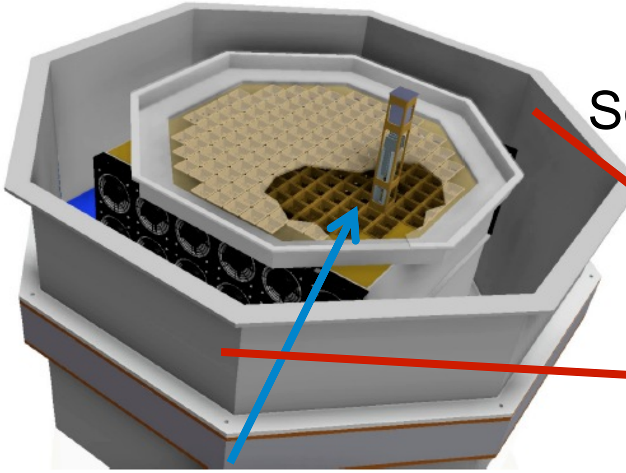
- 1855 pixel
- 30mm ϕ PMT
  (Hamamatsu)
- 0.1° pixel
- FOV 4.5°
- **0.1°pixel、FOV 4.5°**





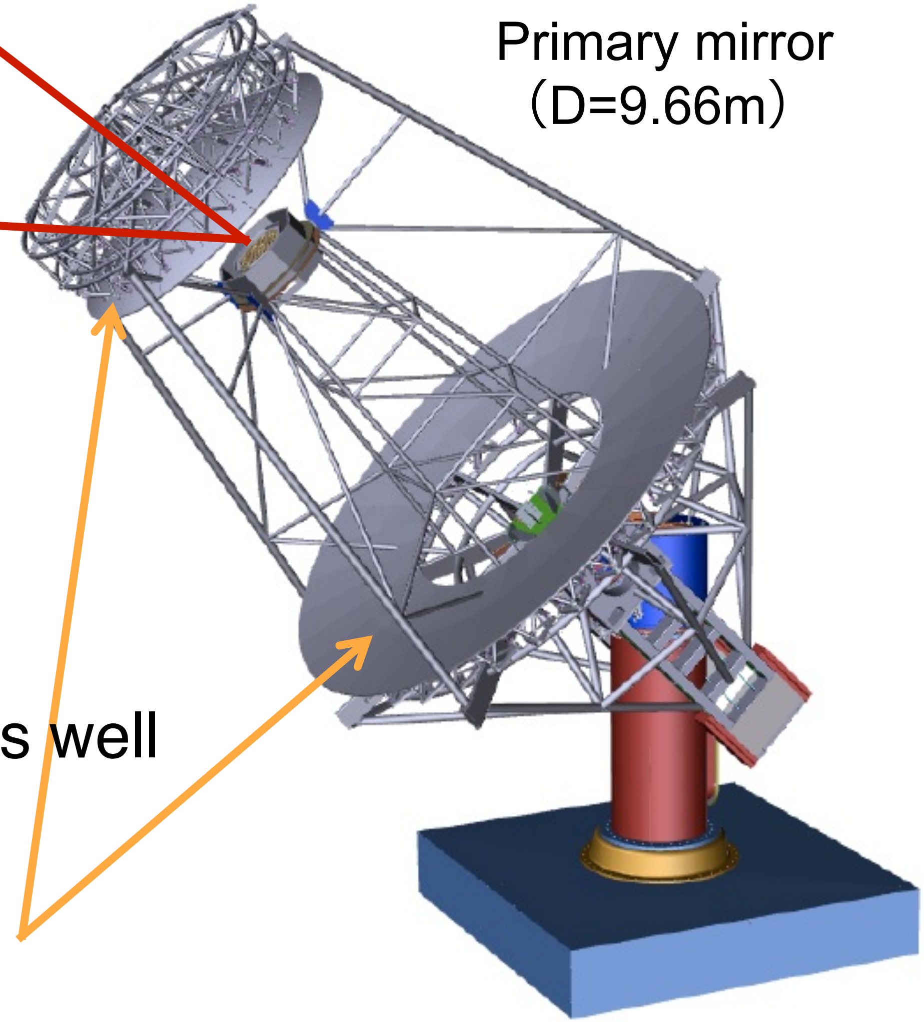
Japanese contributions : SCT

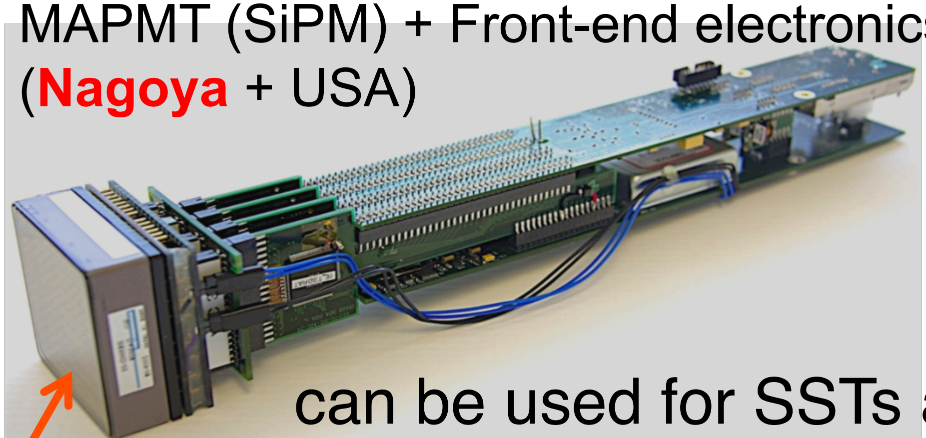
Camera
FOV: 8deg
11328 pixel



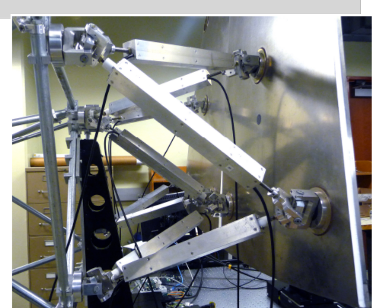
Secondary mirror (D=5.42m)

Primary mirror
(D=9.66m)





can be used for SSTs as well

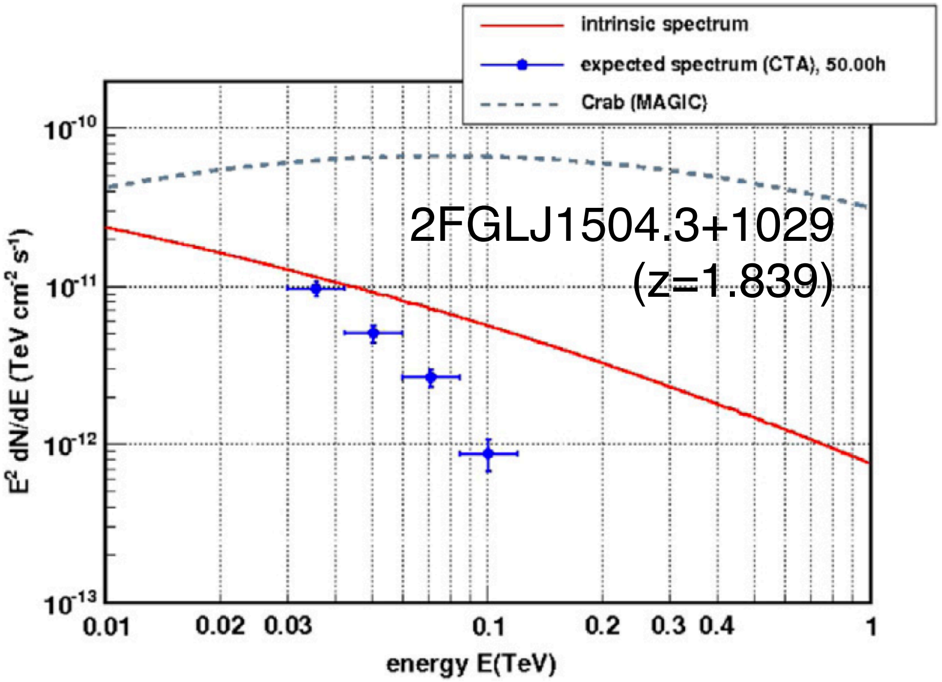


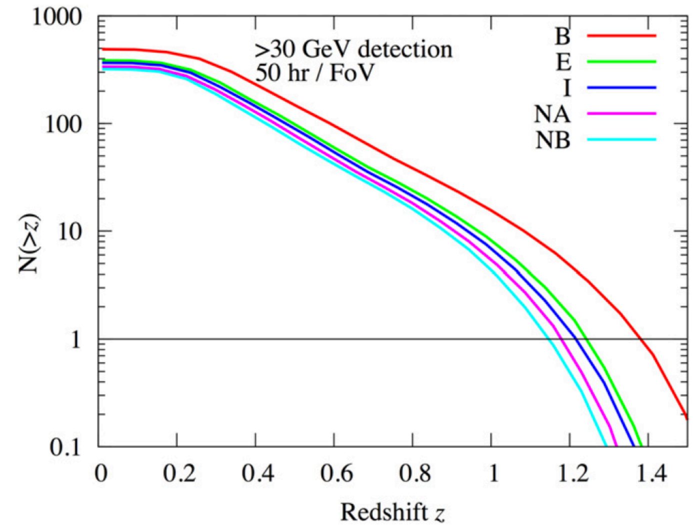
feasibility of blazar observations

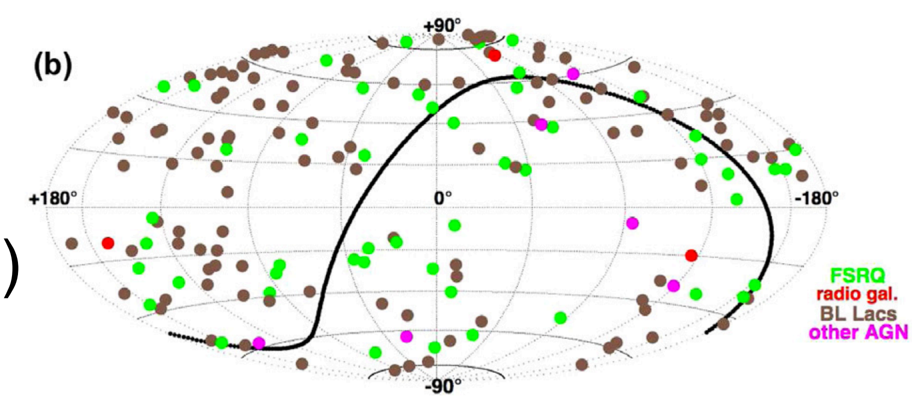
(Sol+13, APh, CTA special issue)

Based on Fermi-LAT results

survey (for 30 years)







up to z ~2

tens of FSRQs (in steady states)

capability of variability observations

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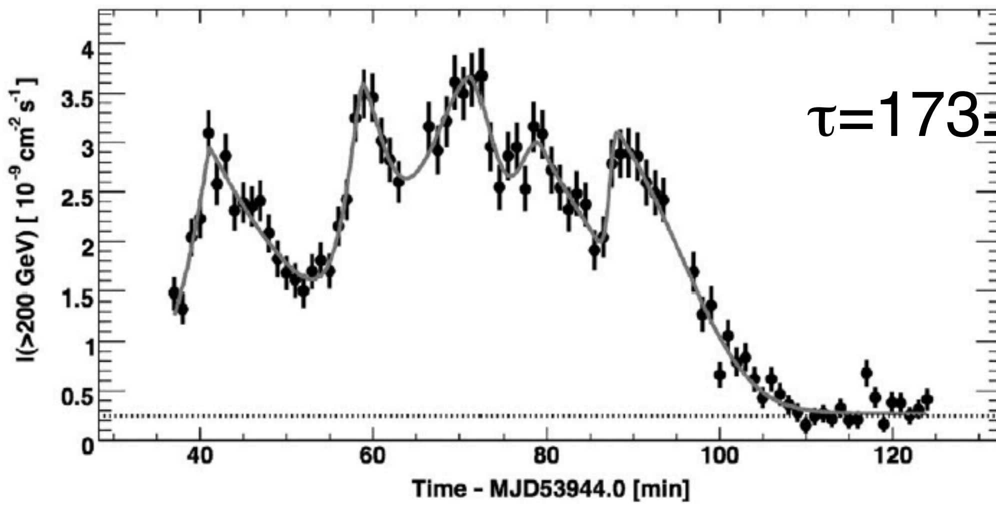
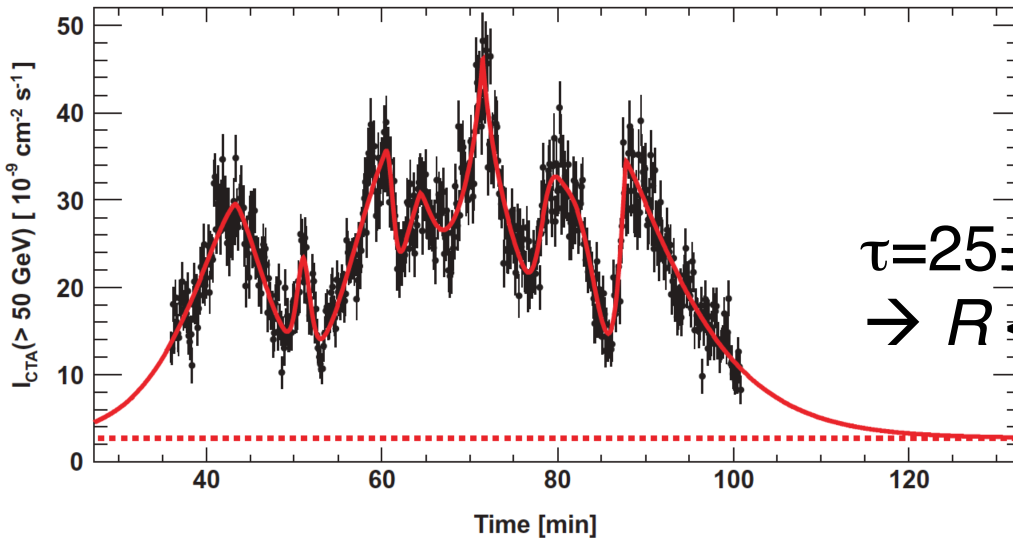
University of Tokyo

HESS
(observed
PKS2155-304)



τ=173±28 s

CTA
(simulated)



τ=25±4 s
→ $R < 7\times10^{11}\delta$ cm

Summary

- Fermi-LAT detected thousands of AGNs (blazars) and have revealed details of jet emission physics
  - no unique solution for the γ-ray emission site
    - it could change event by events
  - what is the dominant component in jet?
    - sub-mm VLBI also useful tool for U_B/U_e
- ***need Fermi in the CTA era for more AGN studies (after 2020~)***