Recent Fermi-LAT results on Active Galactic Nuclei and future CTA perspectives

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Outline

- Fermi Gamma-ray Space Telescope
- New observing strategy
- 2013年1月以降に出版されたFermi-AGN関連の結果を主に紹介
  - ✓ Fermi Bubble (Akermann+14, ApJ, Cat I)
  - ✓ EBL and High redshift blazars
  - ✓ TeV FSRQs
  - ✓ Radio galaxies: Cen A and M87
  - ✓ Extreme HBLs

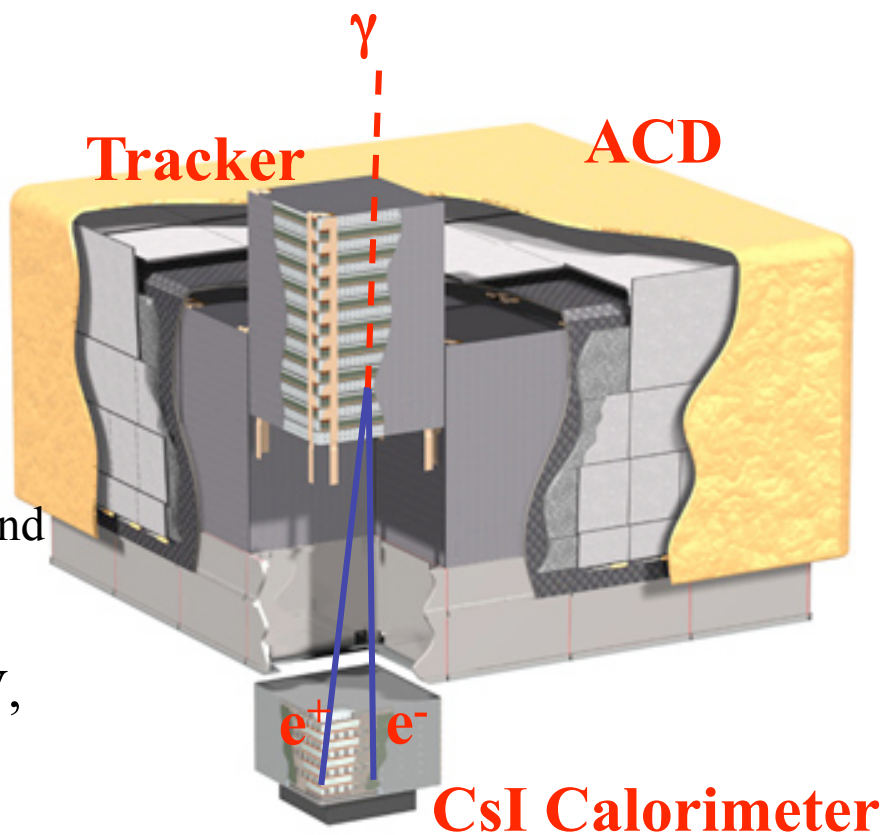
Large Area Telescope

Pair-conversion telescope

Si-strip Tracker with tungsten foil converter:
Measure the photon direction

CsI Calorimeter: Measure the photon energy,
Image the shower

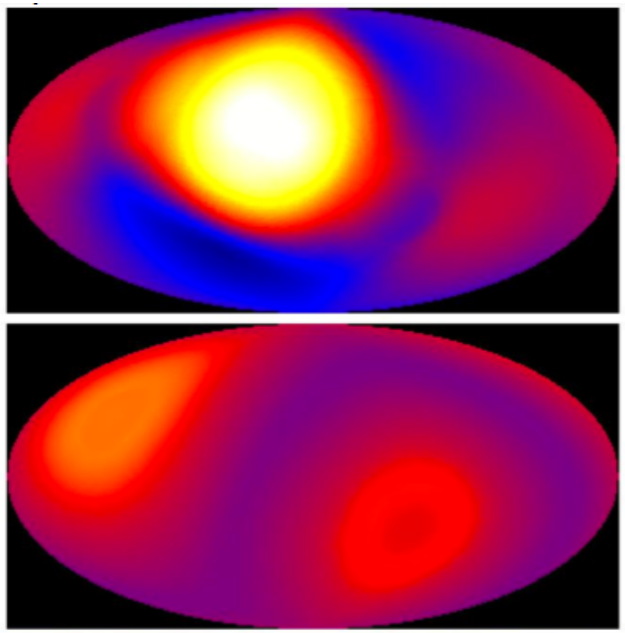
ACD (Plastic scintillator):
Reject charged-particle background



- Large effective area (9000 cm^2 @ 1 GeV, normal incidence)
- Large field-of-view (2.4 str)
- The entire sky is observed every ~3 hours
- Energy range: 20 MeV – 300 GeV
- Angular resolution (68% contaminant radius): 0.6 deg @ 1 GeV

4 x 4 modular array
3000 kg, 650 W

New observing strategy



exposure map

2013 Dec.~2014 Dec.
(とりあえず1年間)

all-sky survey until 2013 Dec.

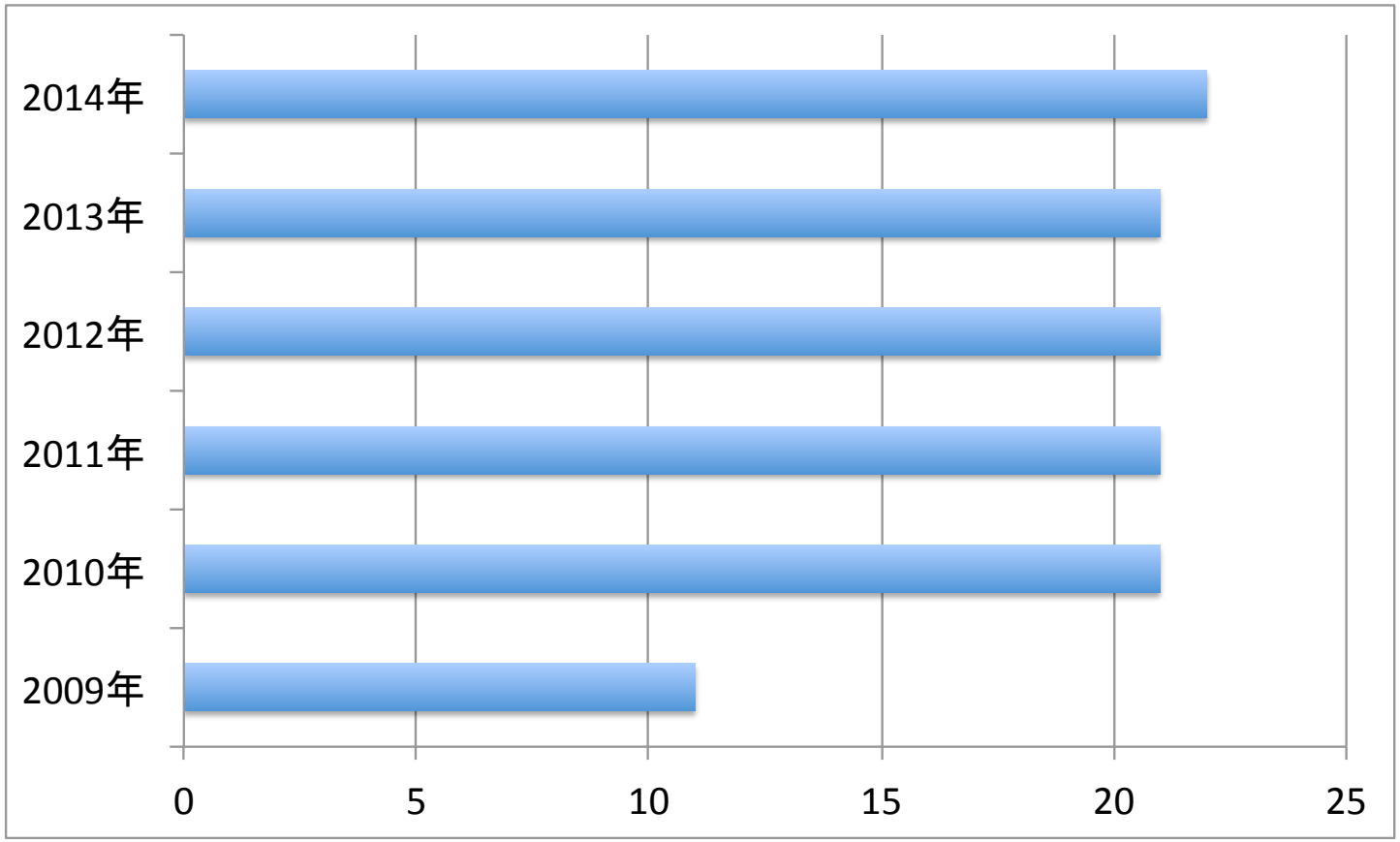
http://fermi.gsfc.nasa.gov/ssc/proposals/alt_obs/obs_modes.html

- 全天サーベイをしながら、銀河中心方向のexposureを増やす
  Modified survey modeでの観測が行われている

✓ Check for 130 GeV line

✓ Passage of the G2 cloud around Sgr A*

AGN関連のFermi論文数



https://www-glast.stanford.edu/cgi-bin/pubpub

- 約20本 per year (Category I, II, IIIの合計)

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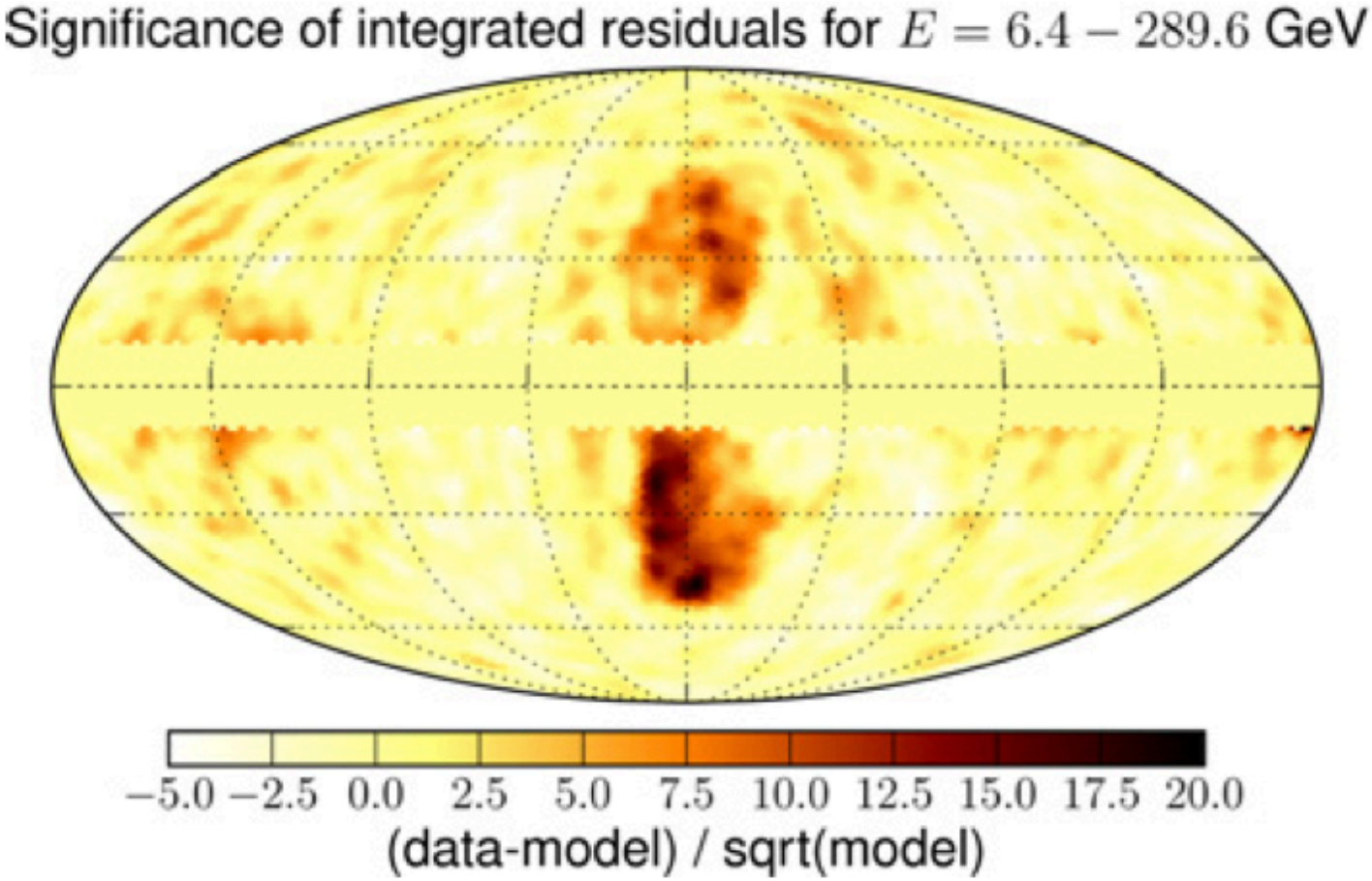
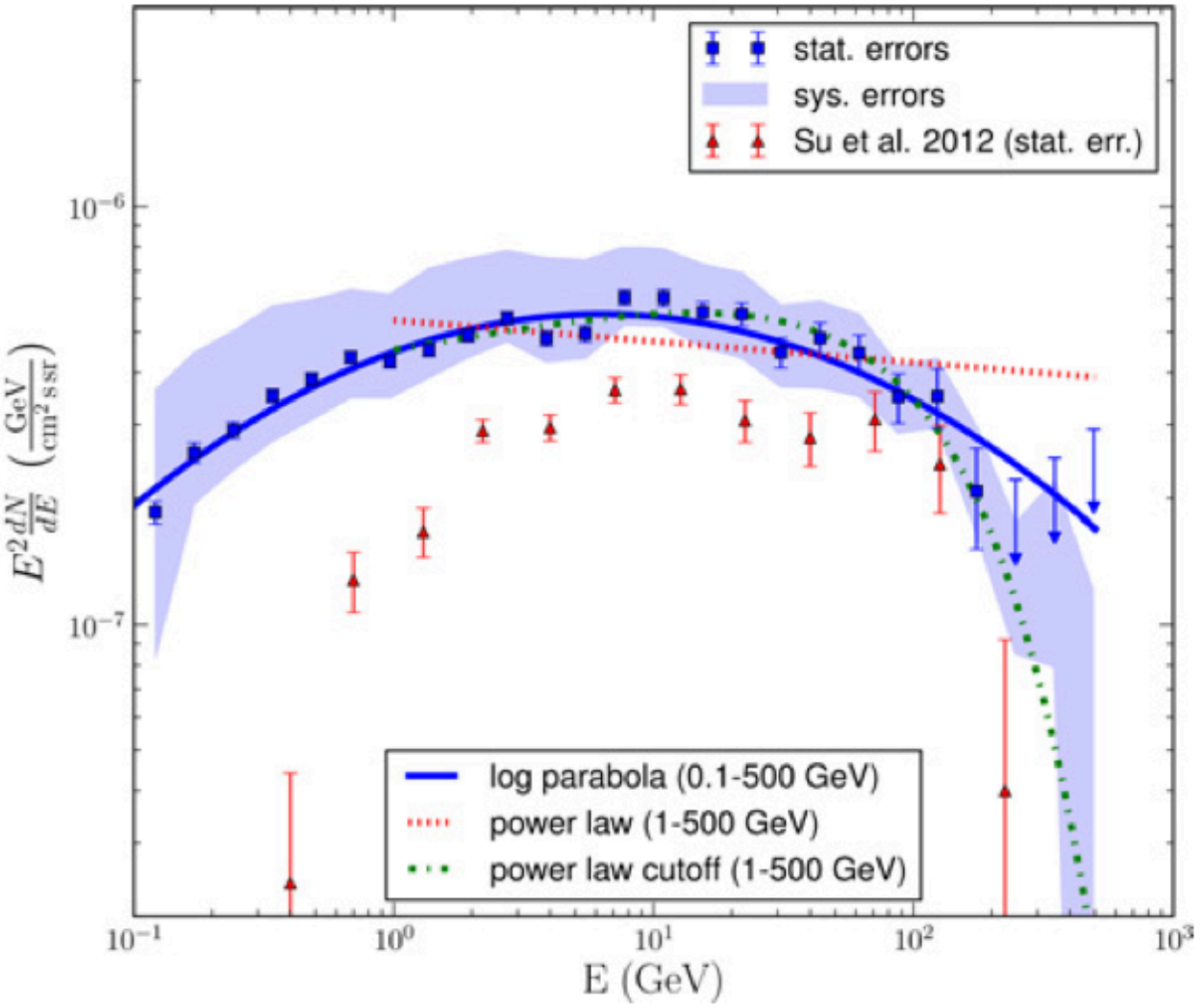
Fermi Bubble paper by Fermi team

Ackermann et al. 2014, ApJ, 793, 64



Spectrum



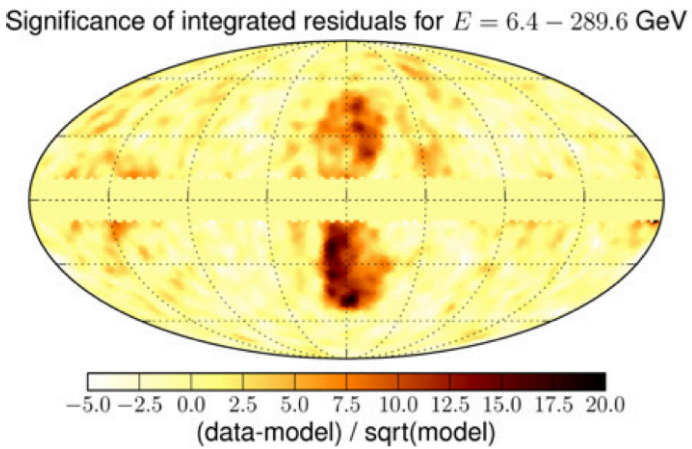
Cutoff PL with
Γ=1.9+/-0.2
E_{cutoff}=110+/-50 GeV

L=4.4x10^{37} erg/s
(0.1-500 GeV)

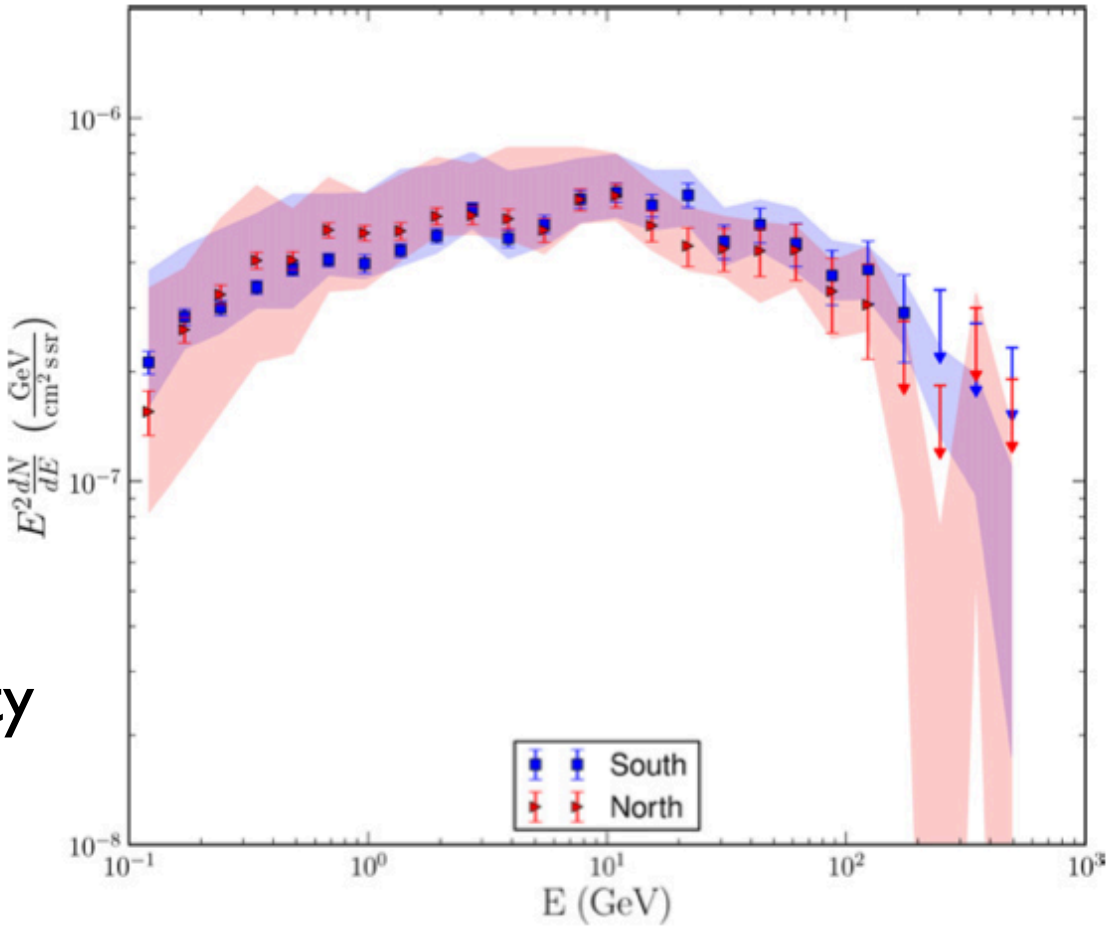
- Different diffuse model
- Small bubble area
- Large Gal. Plane mask

(20 deg, instead of 10 deg utilized here)

Northern and southern bubble spectra

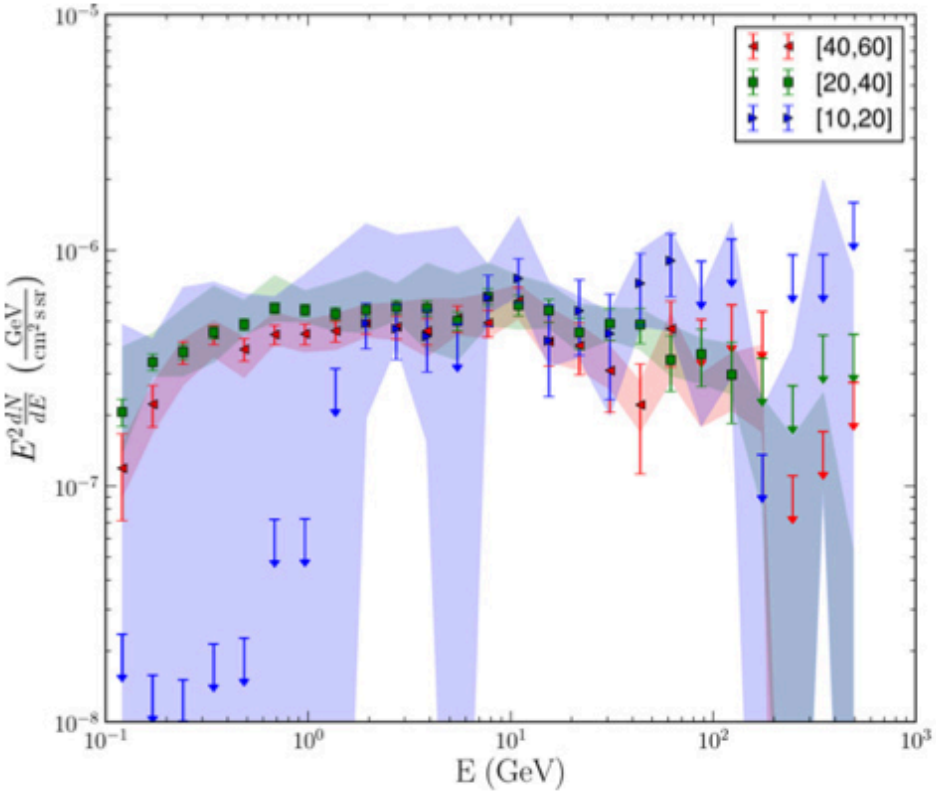


Spectral shape and intensity agree with each other

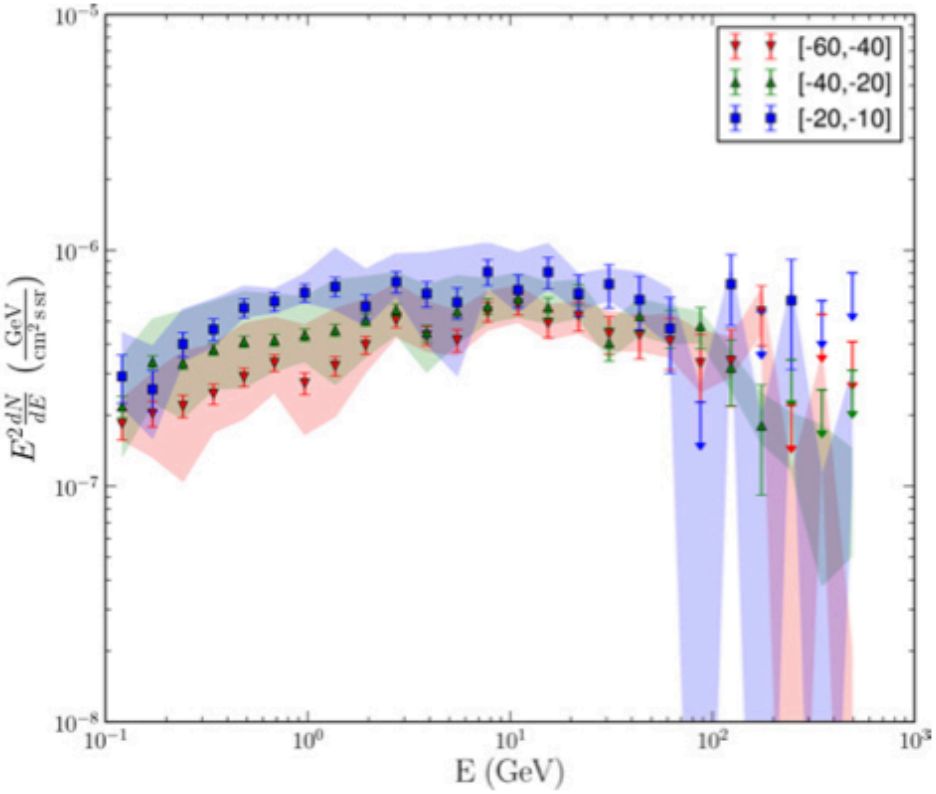


No significant variation of a spectrum as a function of latitude

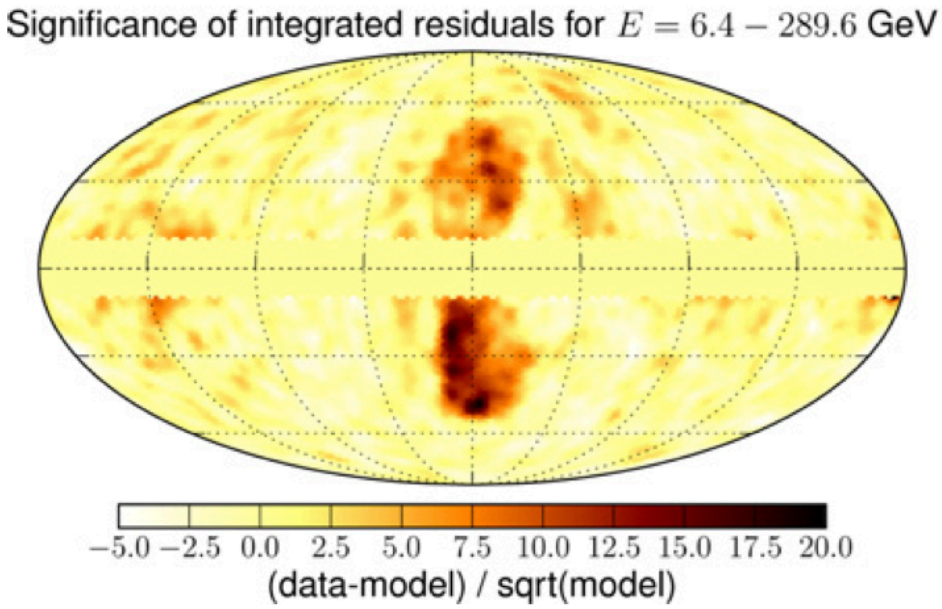
North

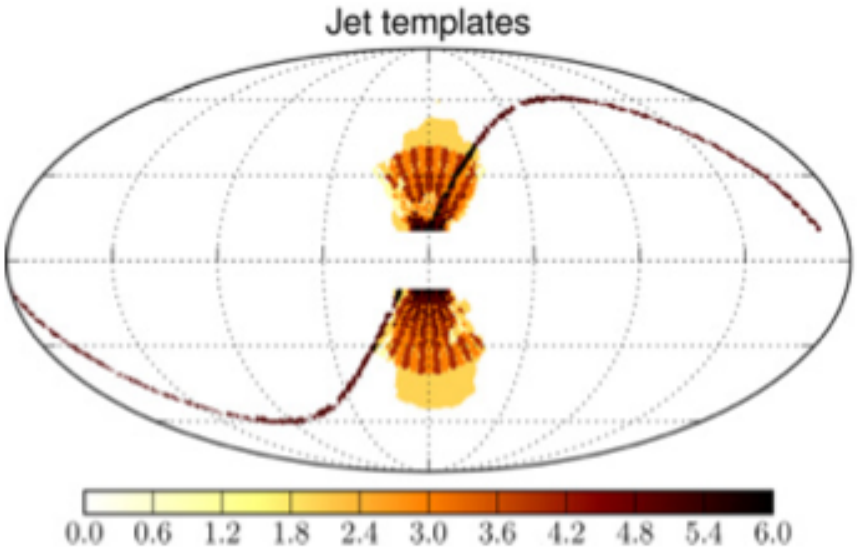


South



Morphology





Significant excess in south-east cocoon,
but no evidence of a jet

Hadronic model fit

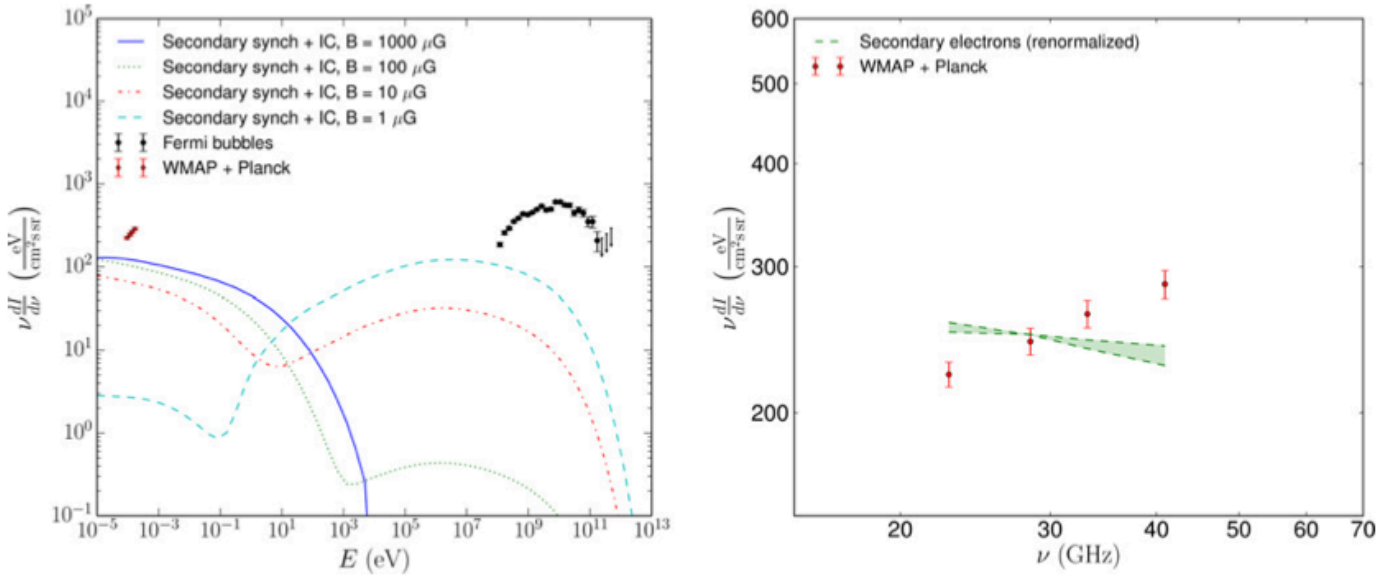


Figure 38. Left: synchrotron radiation produced by the secondary leptons in the hadronic model of the bubbles emission in comparison with the microwave haze (Ade et al. 2013). Right: the range of spectra for the synchrotron radiation from secondary leptons that corresponds to different models of the foreground gamma-ray emission and different definitions of the bubbles template.

Difficult to reproduce the WMAP+Planck data points

Leptonic model is favored

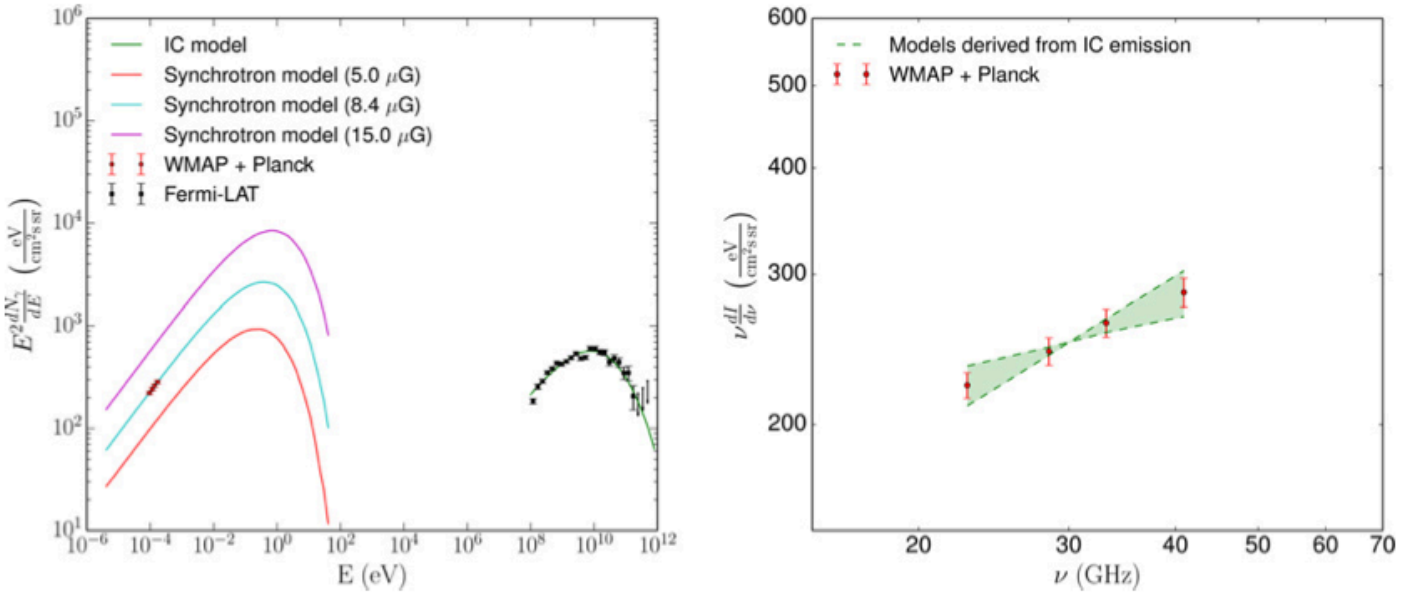


Figure 35. Left: IC and synchrotron emission from the same benchmark population of electrons. The electron energy density is derived from fitting the IC model to the gamma-ray data. We use the synchrotron emission from the same population of electrons to fit the *Planck* microwave haze data (Ade et al. 2013) by optimizing the value of the magnetic field. The best-fit magnetic field is about 8.4 μG. Right: microwave haze spectrum compared to the synchrotron emission from the electrons in the IC model of the *Fermi* bubbles. The green band shows the systematic uncertainties introduced by the systematic uncertainty in the gamma-ray spectrum of the bubbles.

Fermi Bubble summary

✓ Cutoff PL with index=1.9 and E_{cutoff}=110 GeV ✓ No spectral variation over latitude

✓ No evidence of a jet ✓ Leptonic model is favored

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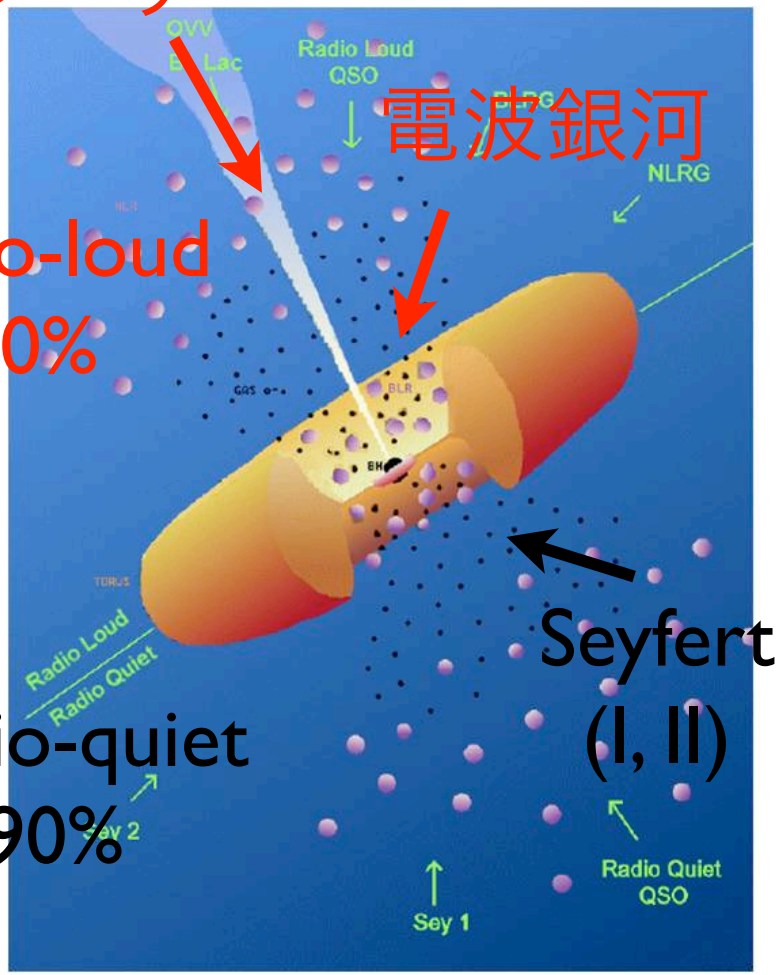
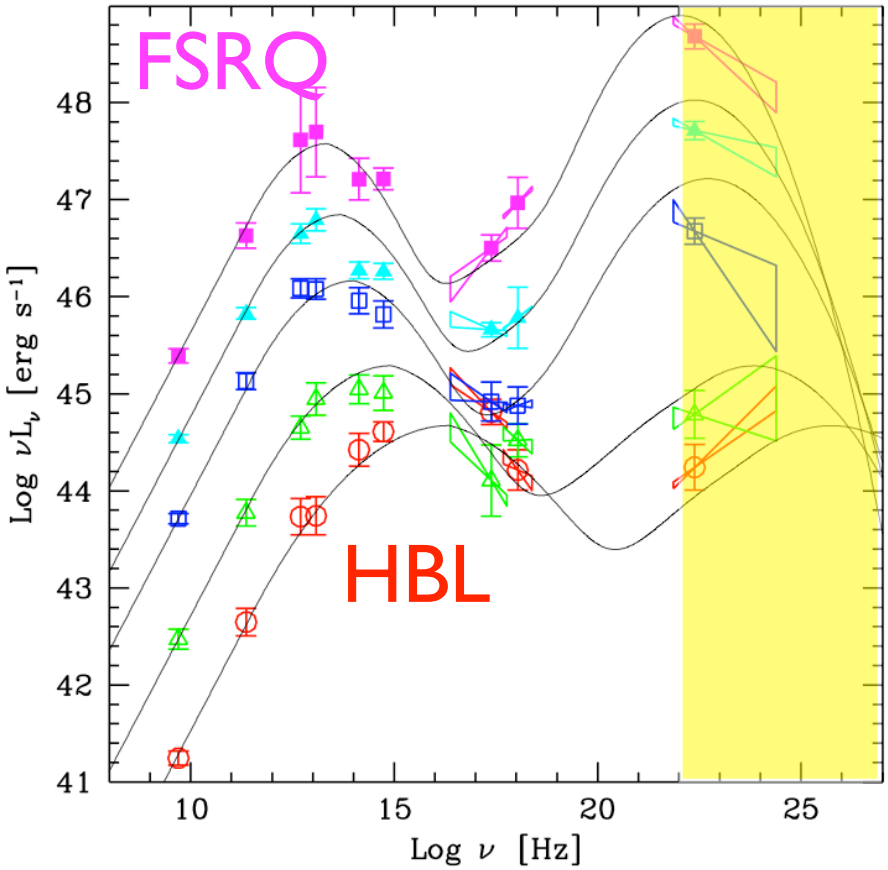
Blazars

ブレーザー

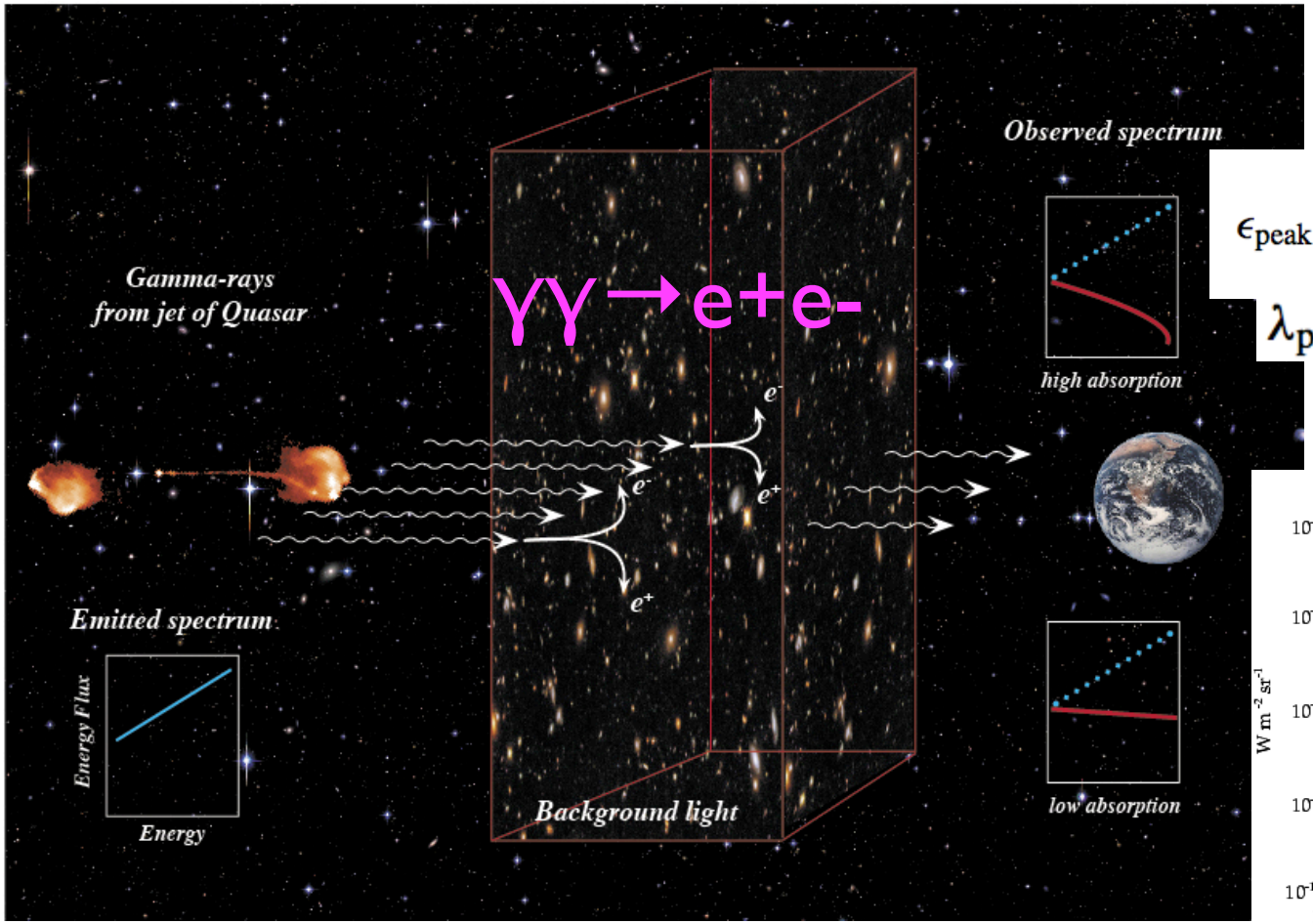




Fossati+98, Kubo+98,
Donato+01

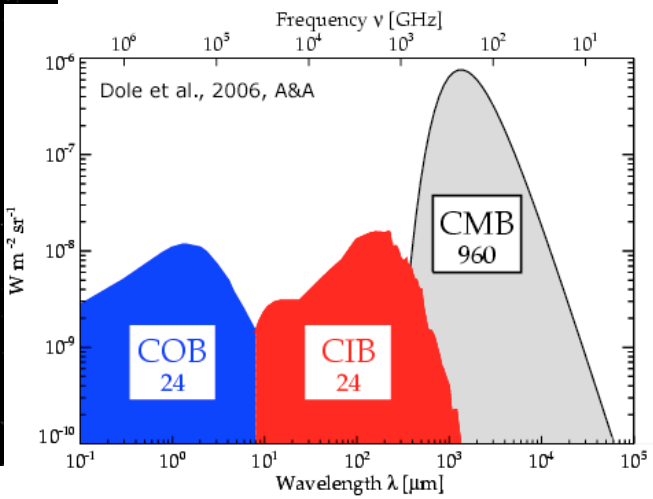
- Radio-loud AGN is ~10%
- Synchrotron + Inverse compton (external/synchrotron photons)

Extragalactic Background Light



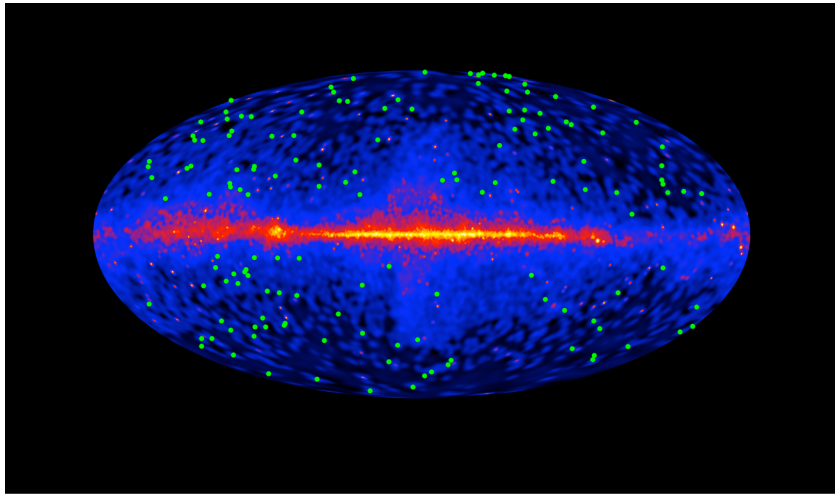
$$\epsilon_{\rm peak} \simeq \frac{2m_e^2c^4}{E_\gamma} \simeq 0.5\left(\frac{1\ {\rm TeV}}{E_\gamma}\right)\ {\rm eV},$$

$$\lambda_{\rm peak} \simeq 2.5(E_\gamma\,[{\rm TeV}])\ \mu{\rm m}.$$

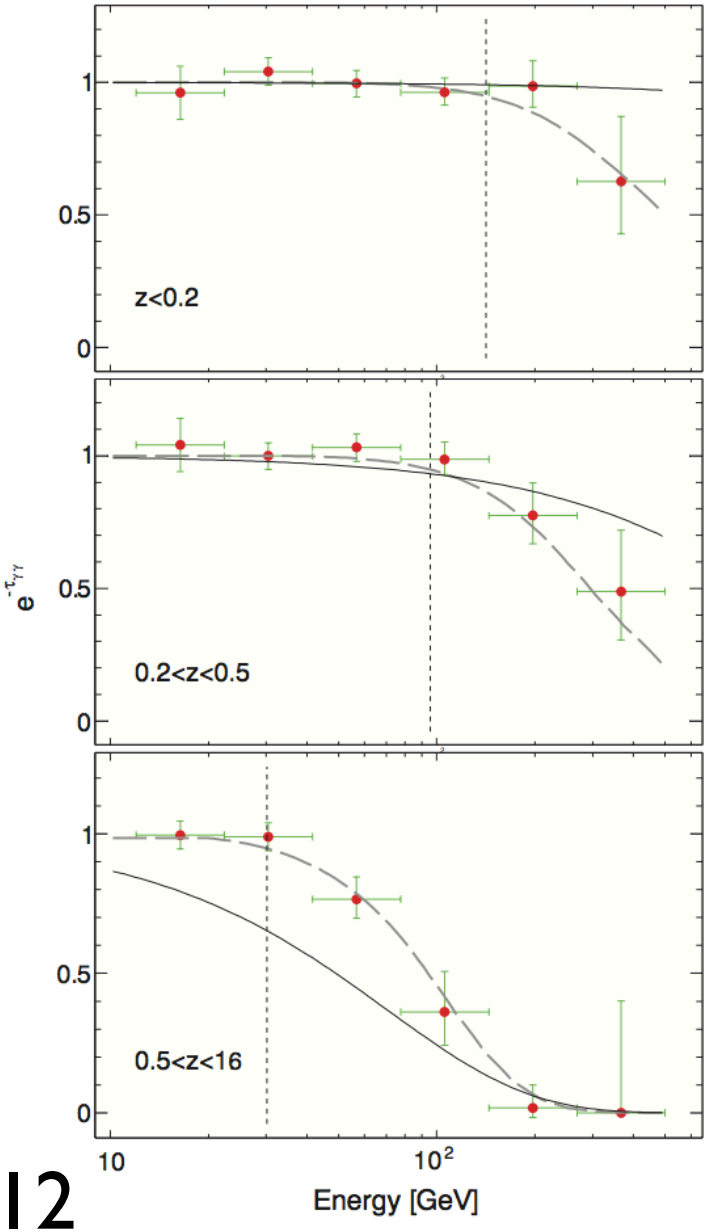


- Level of EBL intensity, which is difficult to measure directly, can be estimated by absorption feature in sub-TeV~TeV gamma rays

Fermi BL Lac 150天体の統計解析

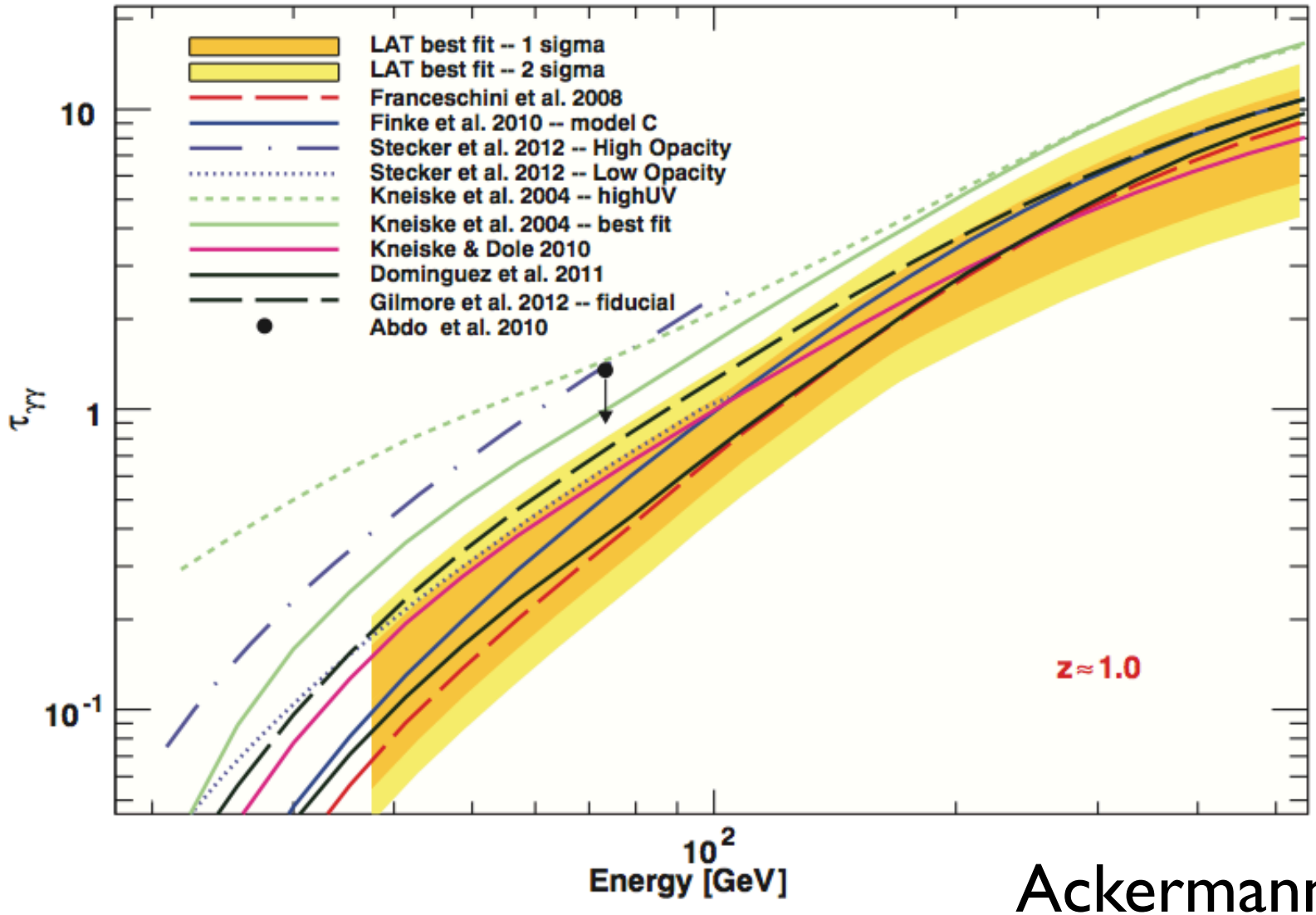


- Statistical anlaysis for 3 redshift bins (z=0-0.2, 0.2-0.5, 0.5-1.6, 50 objects in each bin)
- Significant detection of absorption feature caused by EBL
- Intrinsic spectral cut-off cannot explain the observed attenuation feature



Ackermann+12

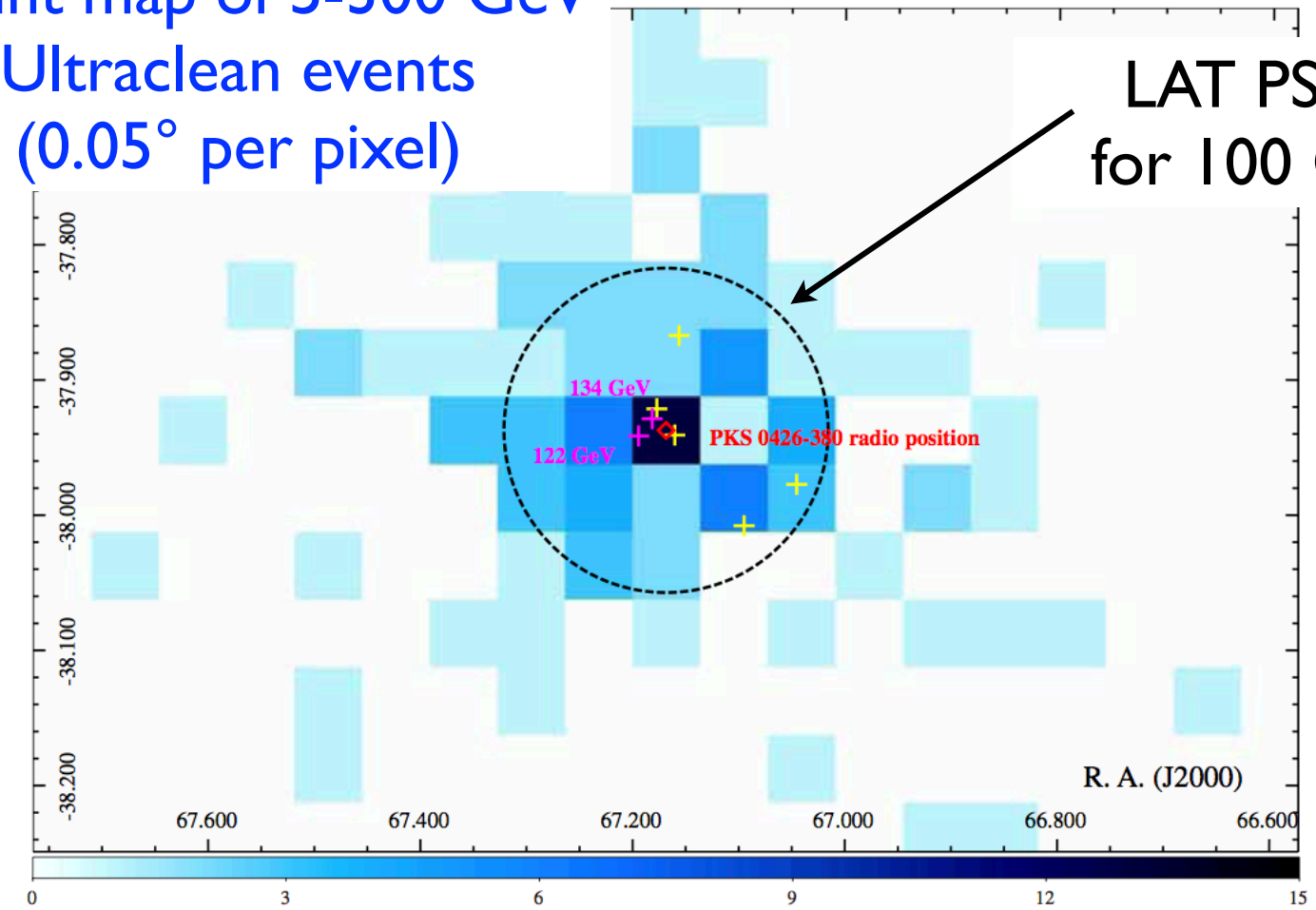
Observed gamma-ray opacity is consistent with minimal level of EBL intensity



Ackermann+12

2 VHE events from z=1.1 blazar PKS 0426-380

Count map of 5-300 GeV
Ultraclean events
(0.05° per pixel)

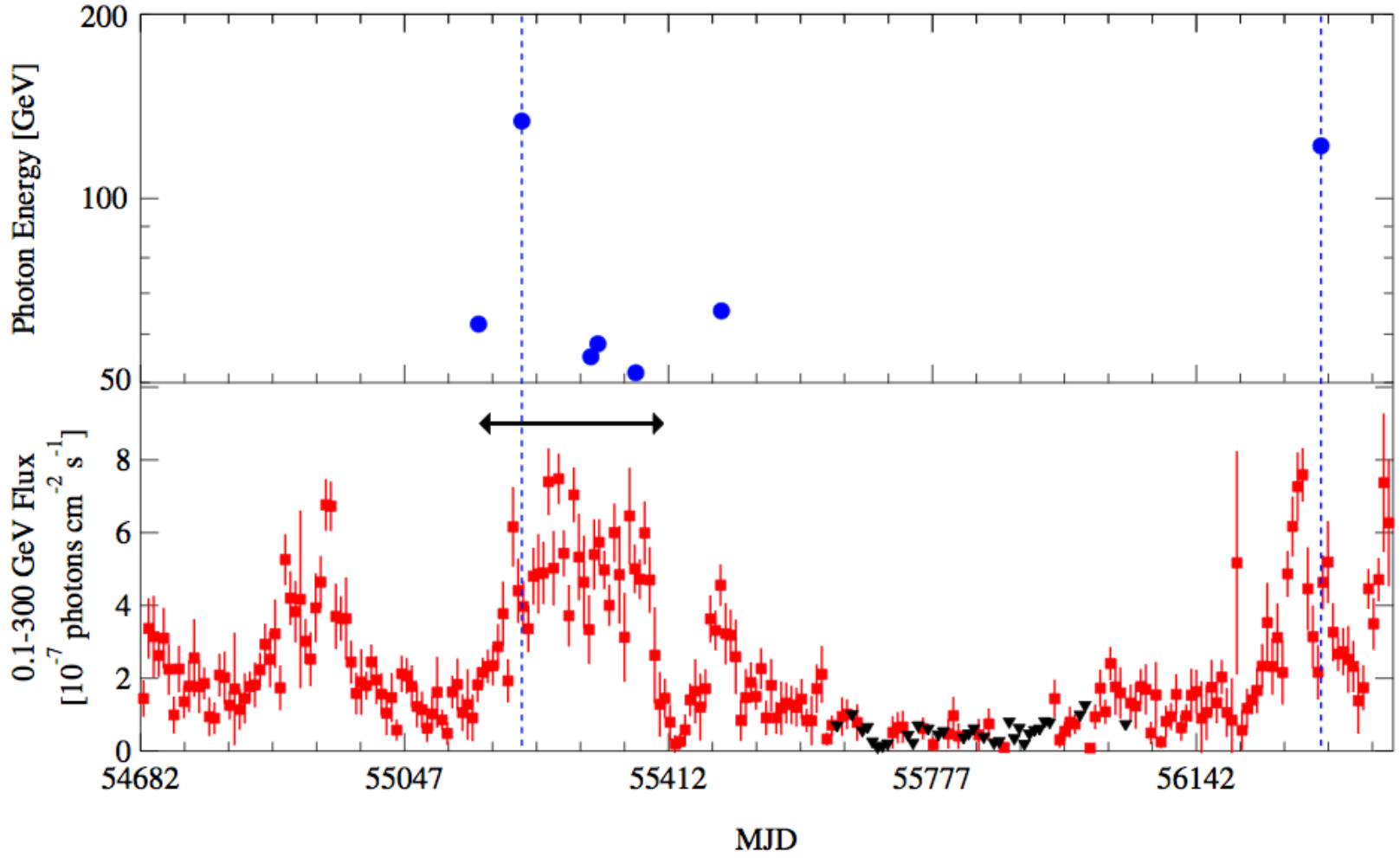


50-100 GeV events are also shown

Tanaka+13

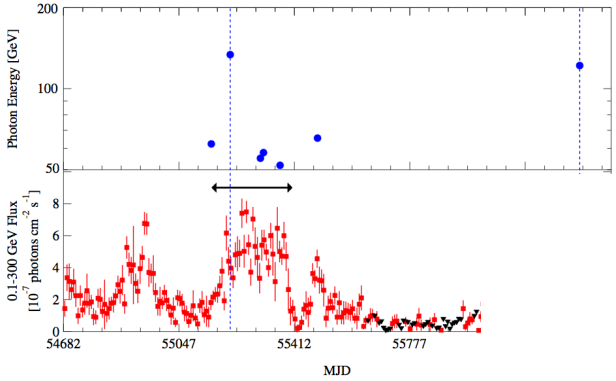
- 134 GeV and 122 GeV ULTRACLEAN events were detected from close vicinity of PKS 0426-380

Arrival times of E>50 GeV ULTRACLEAN events

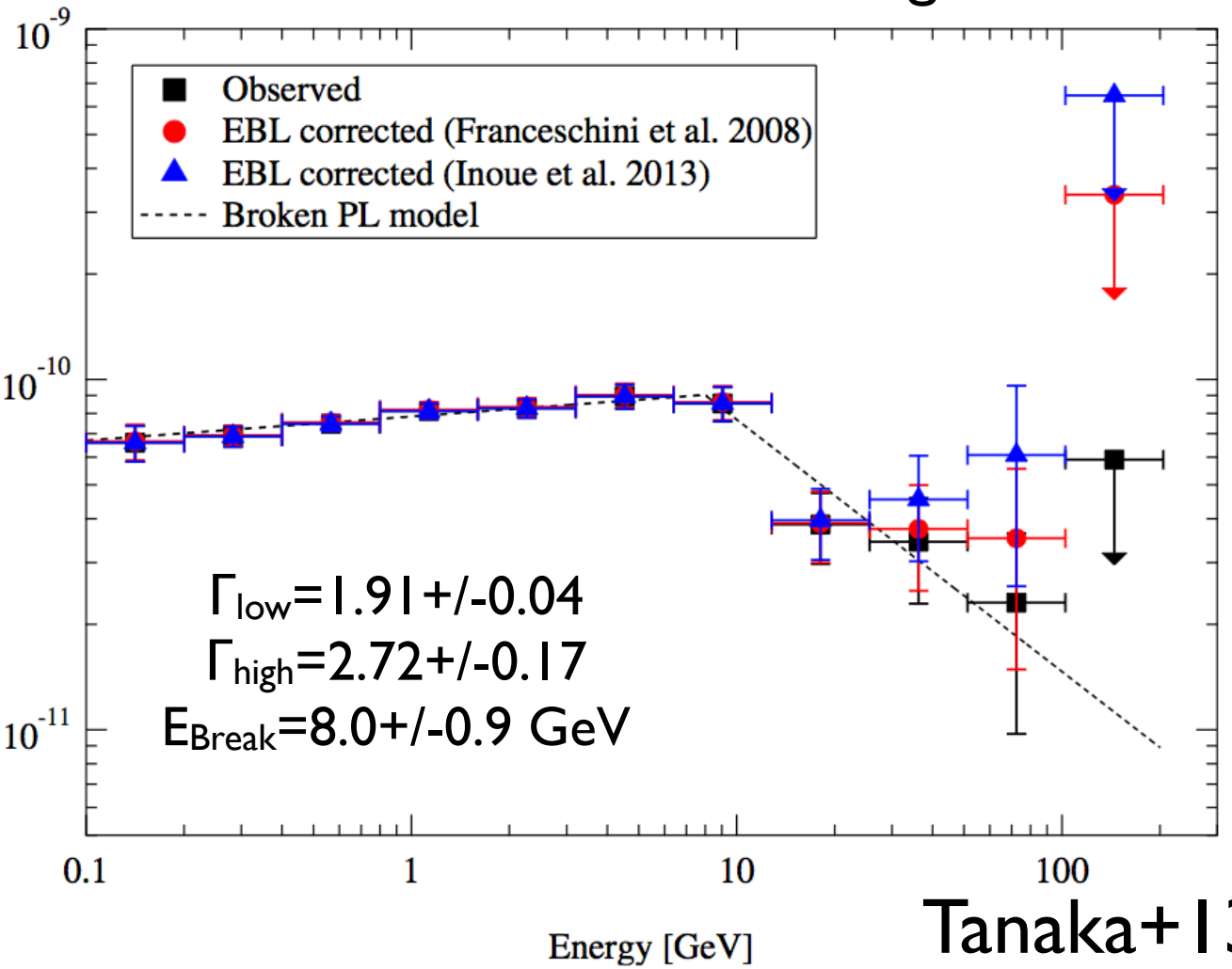


- All of the seven E>50 GeV events were detected during high state of the source

Spectral hardening??



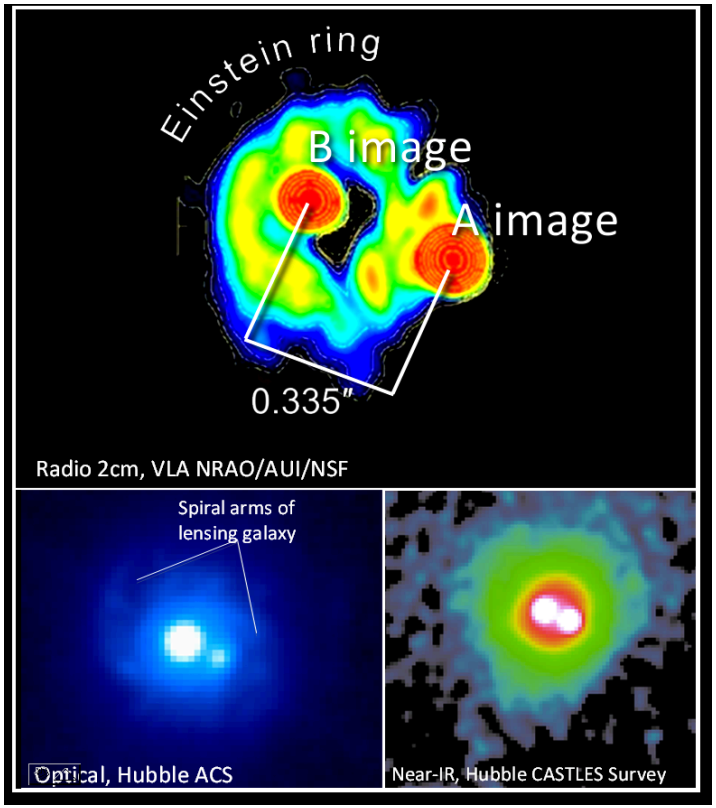
LAT spectrum accumulated
over the ~8 months high state

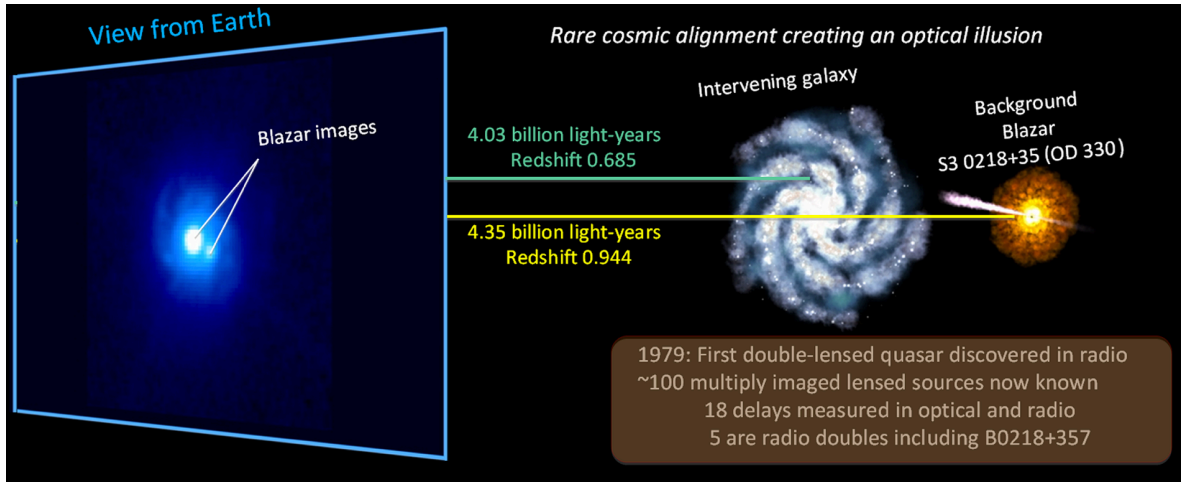


See also Finke+10,
Essey+12, Inoue+13

Tanaka+13

“Gravitationally lensed” blazar S3 0218+357

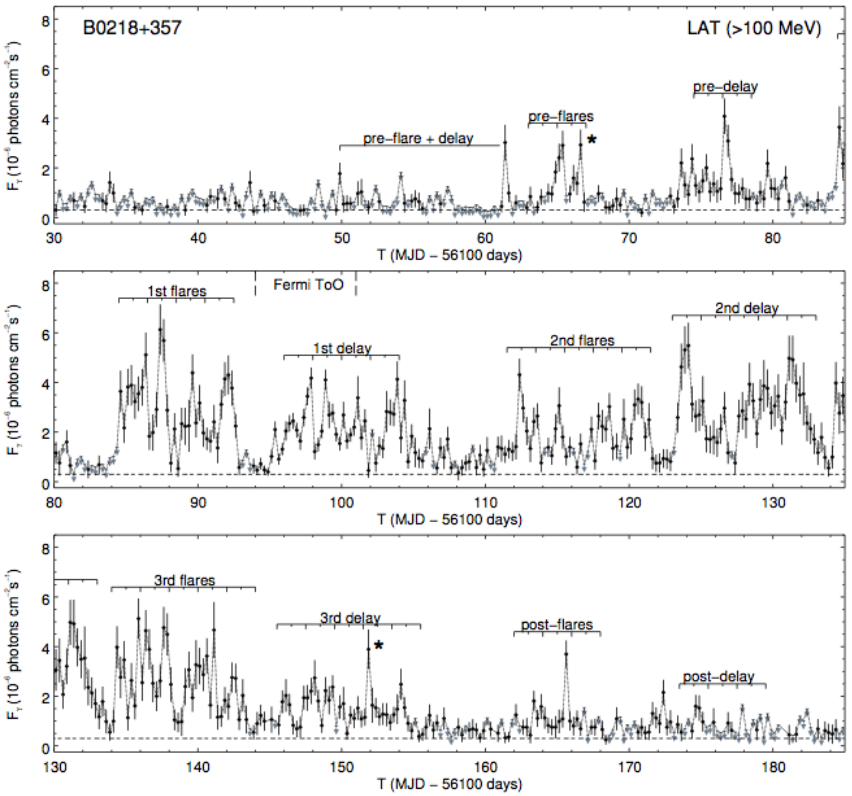




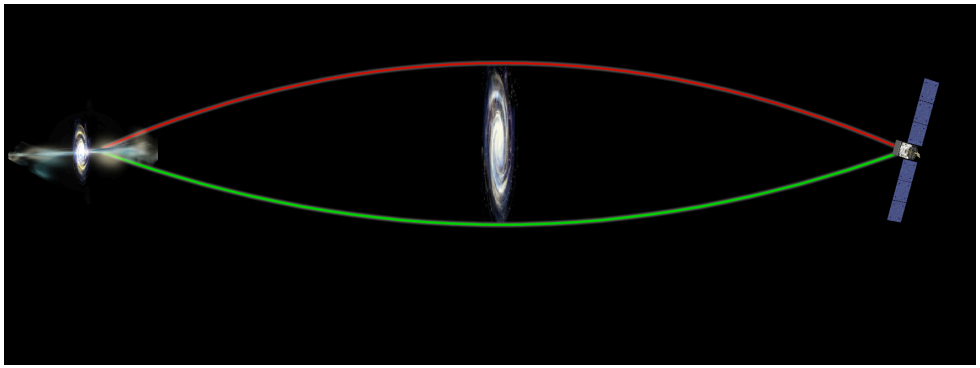
http://www.asdc.asi.it/news.php#299

- フェルミで検出されている重力レンズブレーザーは PKS 1830-211とS3 0218+357の2つ

Fermi-LAT light curve of 2012 flare



Cheung+14



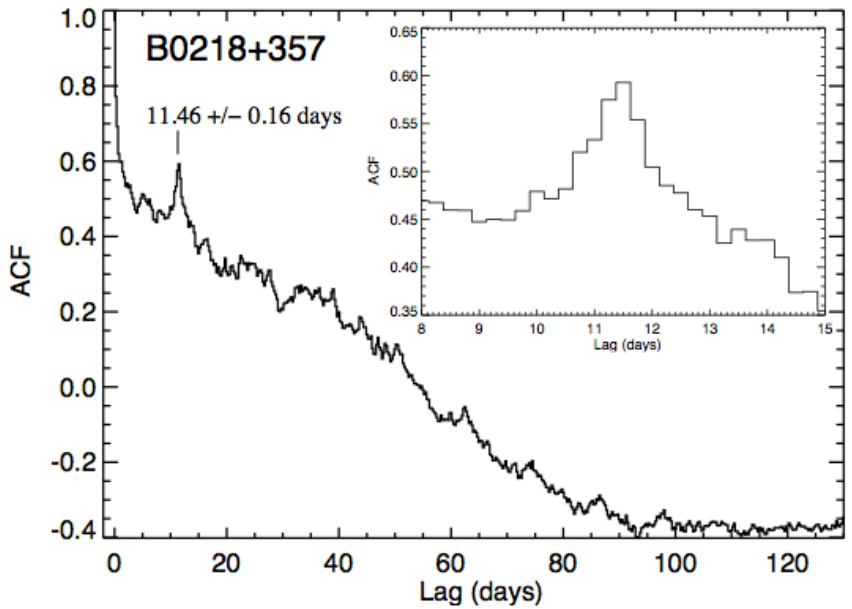


FIG. 3.— Auto-correlation function computed for the 6-hr binned LAT lightcurve of the 265-day flaring interval. The inset zooms in around the best-fit indicated lag peak.

- Delay of 11.46+/-0.16 days

Bright and hard GeV flare in 2014 July

[Previous | Next | ADS]

Fermi LAT Detection of a Hard Spectrum Gamma-ray Flare from Gravitationally Lensed Blazar S3 0218+357

ATel #6316; *S. Buson (INFN & Univ. of Padova), C. C. Cheung (NRL), on behalf of the Fermi LAT Collaboration*
on 16 Jul 2014; 11:02 UT
Credential Certification: Sara Buson (buson@pd.infn.it)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, AGN, Blazar

Referred to by ATel #: 6349

Tweet 3 Recommend 1

The Large Area Telescope (LAT) onboard the Fermi Gamma-ray Space Telescope has observed a gamma-ray flare from the gravitationally lensed blazar S3 0218+357 (lens B0218+357) with an unusually hard spectrum. Preliminary analysis indicates that on 2014 July 13 and 14, the gamma-ray source was observed with respective daily averaged fluxes (E>100MeV) of (6.5+/-1.4) x 10^-7 photons cm^-2 s^-1 with hard photon index of 1.4 +/- 0.1 and (6.7+/-1.5) x 10^-7 photons cm^-2 s^-1 with photon index of 1.6 +/- 0.1 (errors are statistical only).

The source, located at a redshift z=0.944+/-0.002 (Cohen et al. 2003, ApJ, 583, 67), was already observed in gamma-ray flaring state in 2012 (ATel #4343, ATel #4371). During past flares observed with the LAT, the spectral hardness did not change from the quiescent state index of 2.3. The gravitationally lensed delayed emission from past flares was also detected 11.46 +/- 0.16 days later (1 sigma; see Cheung et al. 2014, ApJ, 782, L14).

This source is one of the "LAT Monitored Sources" and consequently a preliminary estimation of the daily gamma-ray flux observed by Fermi LAT is publicly available (link:http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/source/S3_0218p35).

Because Fermi operates in an all-sky scanning mode, regular gamma-ray monitoring of this source will continue. We encourage further multifrequency observations of this source. For this source the Fermi LAT contact persons are Sara Buson (buson@pd.infn.it) and Teddy Cheung (Teddy.Cheung@nrl.navy.mil).

Related
6349 Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes
6316 Fermi LAT Detection of a Hard Spectrum Gamma-ray Flare from Gravitationally Lensed Blazar S3 0218+357
4411 Fermi LAT Detection of New Gamma-ray Flaring from Gravitationally Lensed Blazar S3 0218+35 and Scheduled Fermi Pointed Observations from 2012 September 24 - October 1
4371 Fermi LAT detection of a potential echo gamma-ray flare from gravitational lens S3 0218+35
4361
4351 Swift XRT/UVOT follow-up of the gravitationally lensed blazar S3 0218+35 after a gamma-ray flare
4343 Fermi LAT detection of a GeV flare from the gravitationally lensed blazar S3 0218+35

Daily PL index was ~1.5 in LAT band

MAGIC detection of VHE gamma-rays from the z=0.944 blazar S3 0218+357

Discovery of Very High Energy Gamma-Ray Emission From Gravitationally Lensed Blazar S3 0218+357 With the MAGIC Telescopes

ATel #6349; *Razmik Mirzoyan (Max-Planck-Institute for Physics) On Behalf of the MAGIC Collaboration*
on 28 Jul 2014; 14:20 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, UHE, AGN, Blazar, Cosmic Rays, Microlensing Event

Tweet 21 Recommend 108

The MAGIC collaboration reports the discovery of very high energy (VHE; E>100 GeV) gamma-ray emission from S3 0218+357 (RA=02h21m05.5s, DEC=+35d56m14s, J2000.0). The object was observed with the MAGIC telescopes for a total of 3.5 hours from 2014/07/23 to 2014/07/26. The preliminary analysis of these data resulted in the detection of S3 0218+357 with a statistical significance of more than 5 standard deviations. From the preliminary analysis, we estimate the VHE flux of this detection to be about 15% of the flux from the Crab Nebula in the energy range 100-200 GeV. S3 0218+357 is a gravitationally lensed blazar located at the redshift of 0.944+/-0.002 (Cohen et al., 2003, ApJ, 583, 67). Fermi-LAT observations during the flaring state of S3 0218+357 in 2012 revealed a series of flares with their counterparts after 11.46+/-0.16 days delay, interpreted as due to the gravitational lensing effect (Cheung et al. 2014, ApJ, 782, L14). On 2014 July 13 and 14 Fermi-LAT detected another flaring episode (ATel #6316). Due to the full-moon time, the MAGIC telescopes were not operational and could not observe

- Most distant VHE emitter to date

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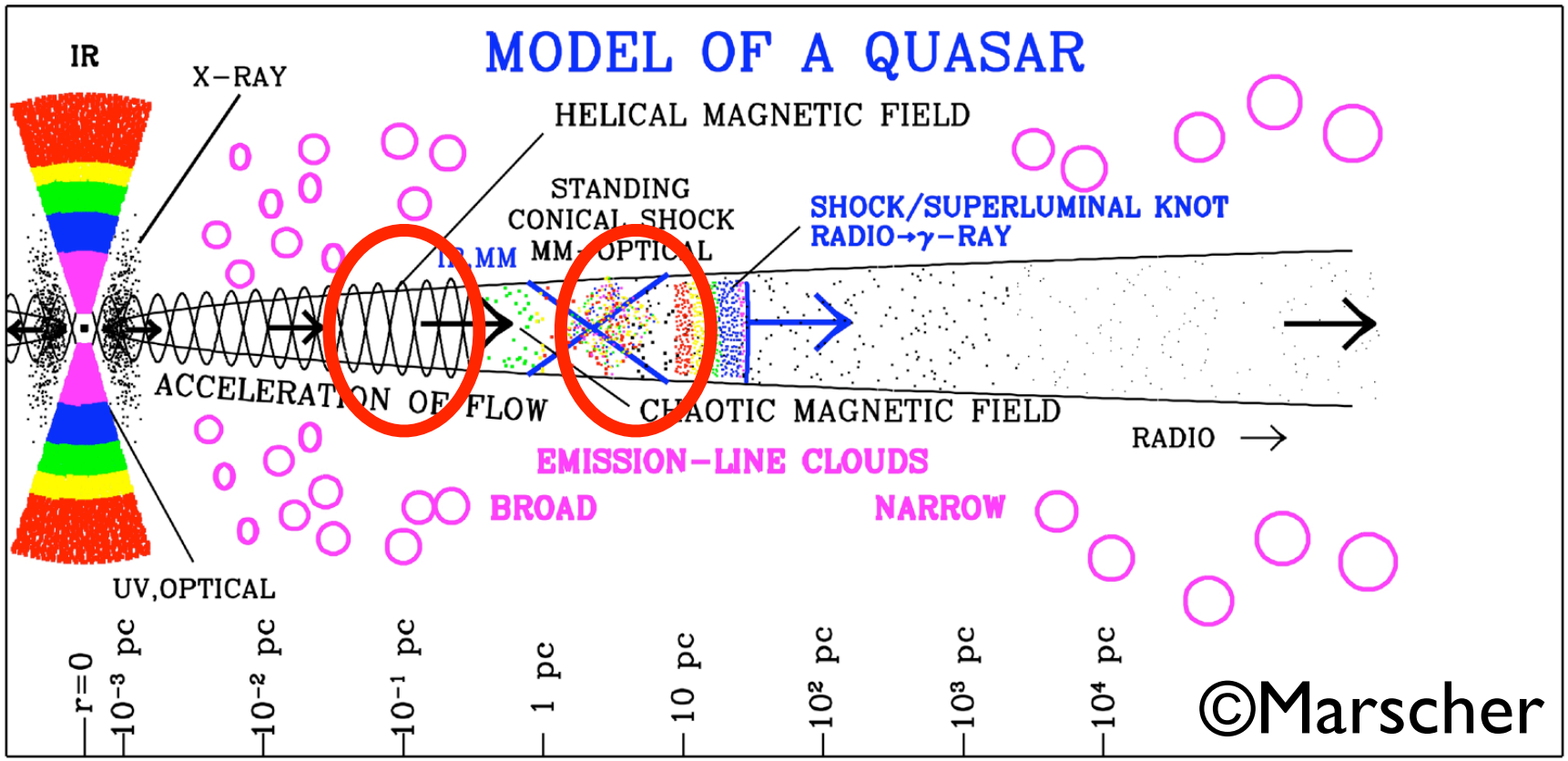
Recent results on 3 TeV FSRQs

- PKS 1510-089
  - ✓ Multiple bright GeV flares in 2011-12
  - ✓ Saito+13 (Fermi), Aleksic+14 (MAGIC), Orienti+13 (VLBI)
- 3C 279
  - ✓ Bright and hard GeV flare in 2013 Dec. (Atel #5680)
- 4C 21.35
  - ✓ VERITAS detection of steady VHE emission (Atel #5981)

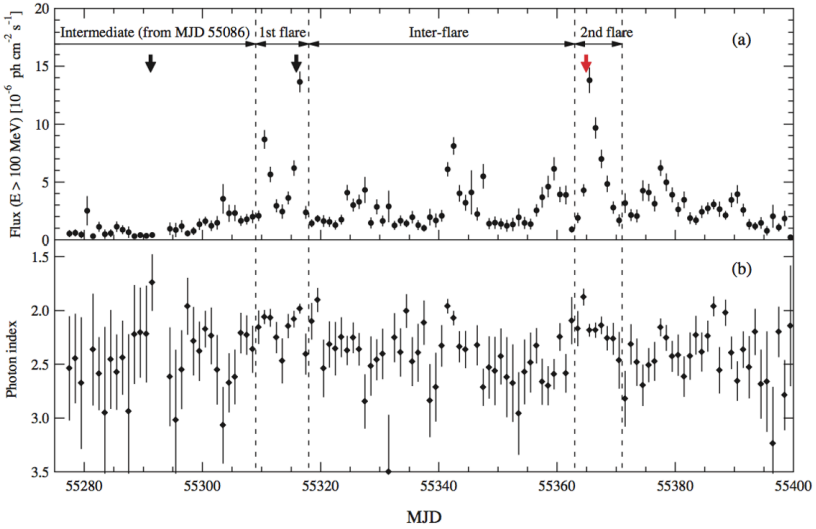
Where is blazar emission zone?



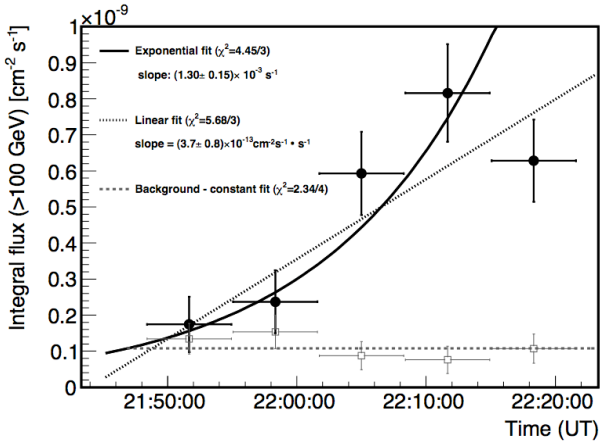
- Within BLR (<sub-pc)? or far away (~pc)?
- Seed photons are optical/UV? or IR photons?

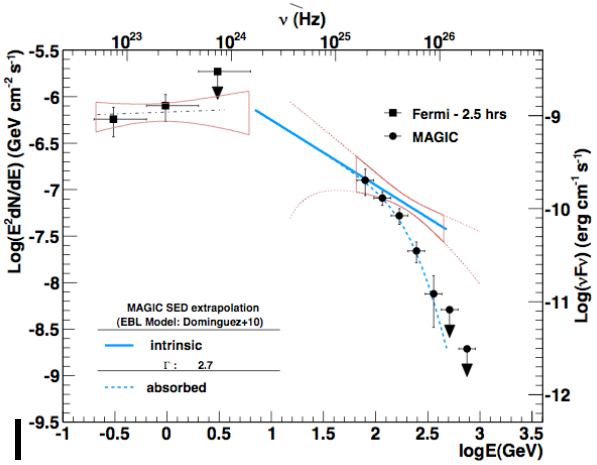
MAGIC+Fermi previous result

4C 21.35

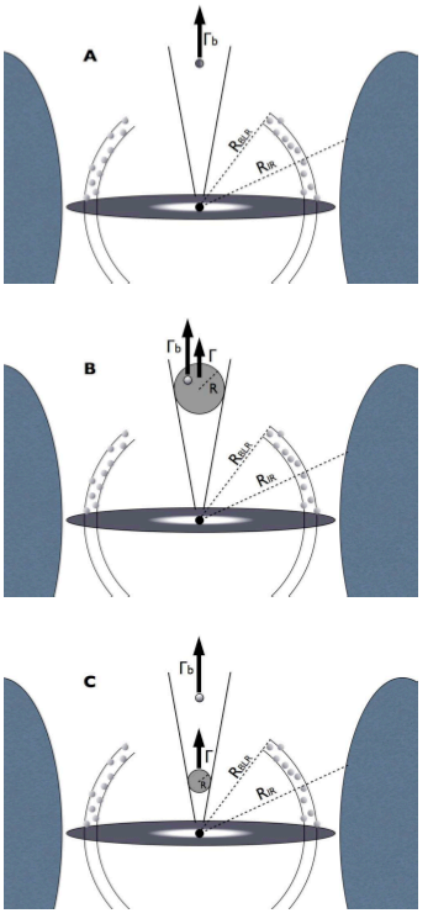


Tanaka+11





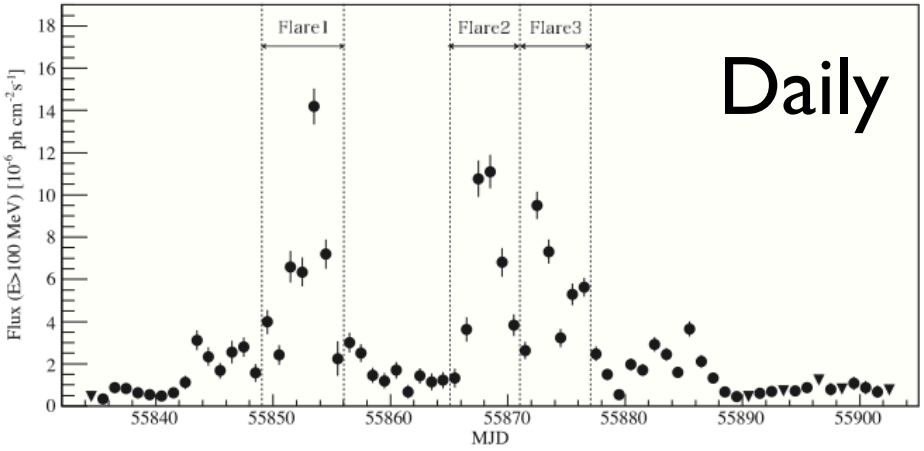
Aleksic+11



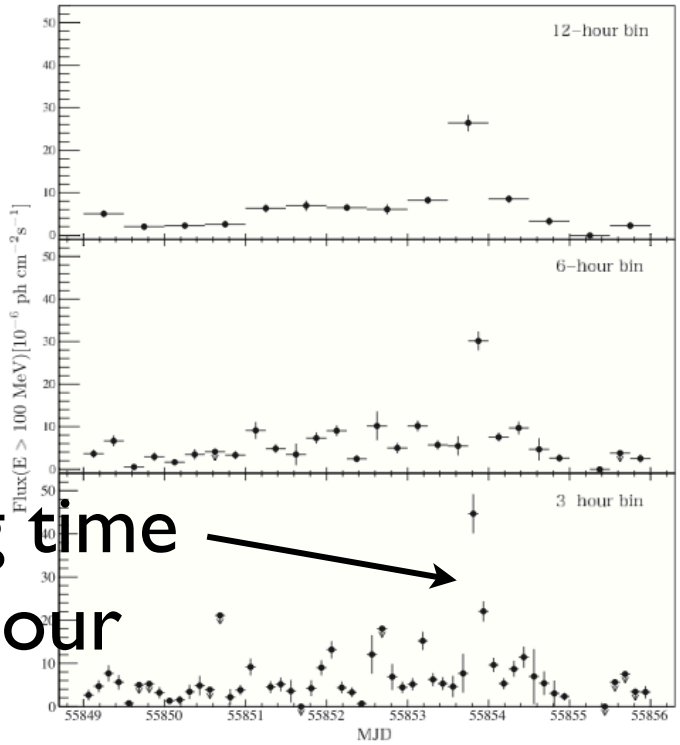
- Rapid variability and no spectral cutoff in sub-TeV band
- Compact emission region outside BLR (pc away from central BH), challenging the standard model

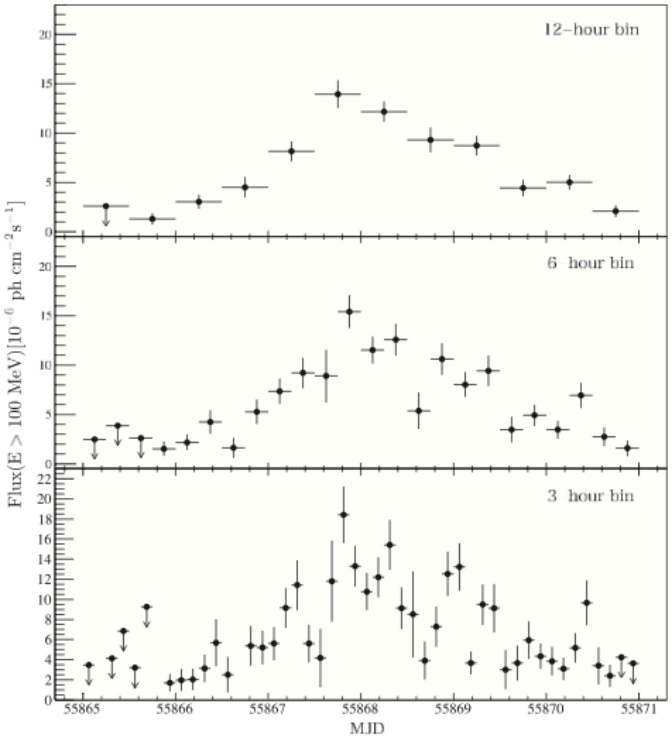
Rapid variability in LAT light curve

Saito+13



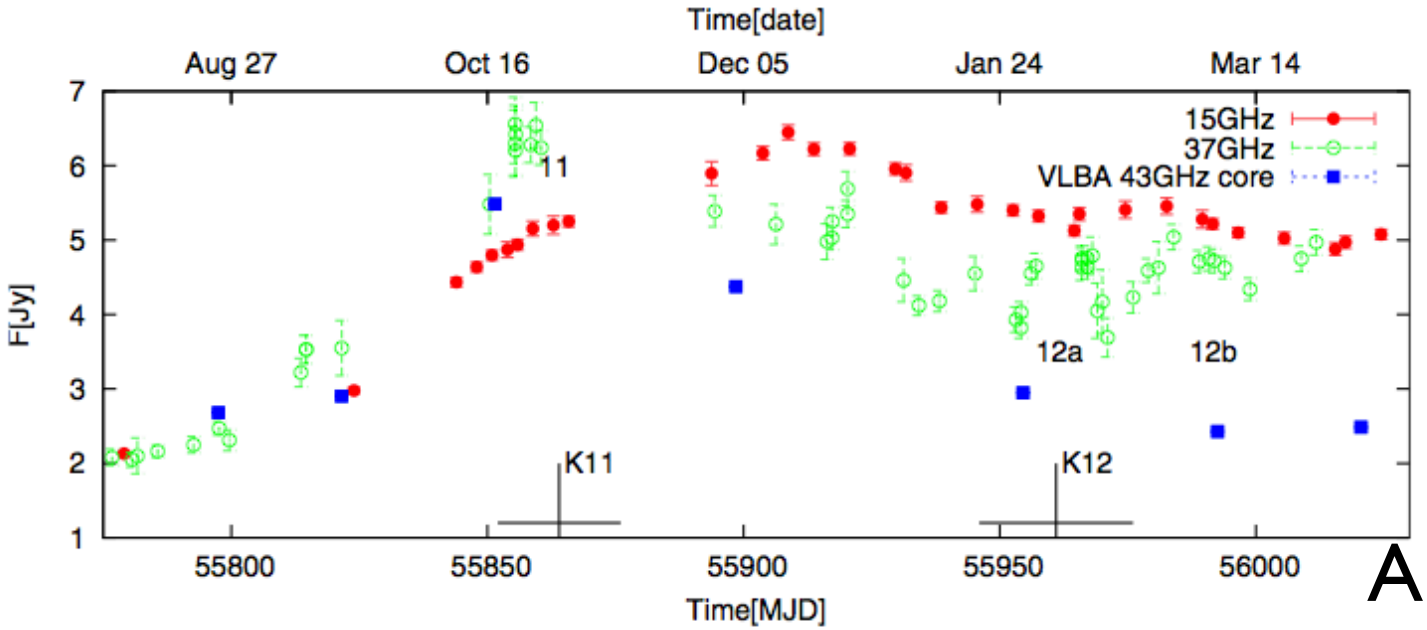
Resolved into multiple flares





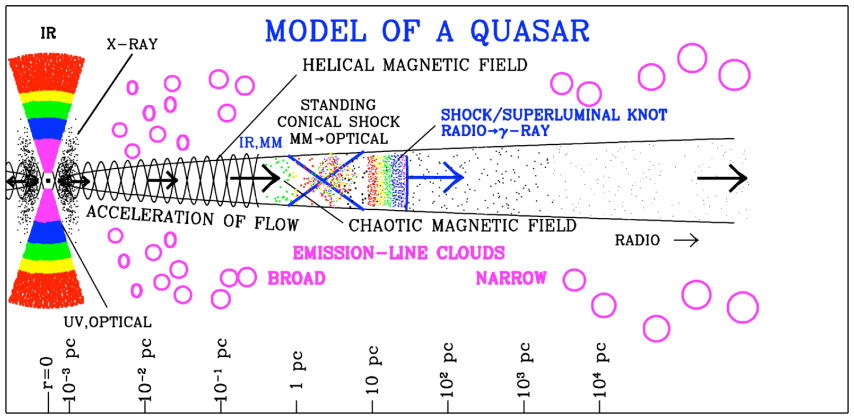
Doubling time of ~1 hour

VLBI follow-up

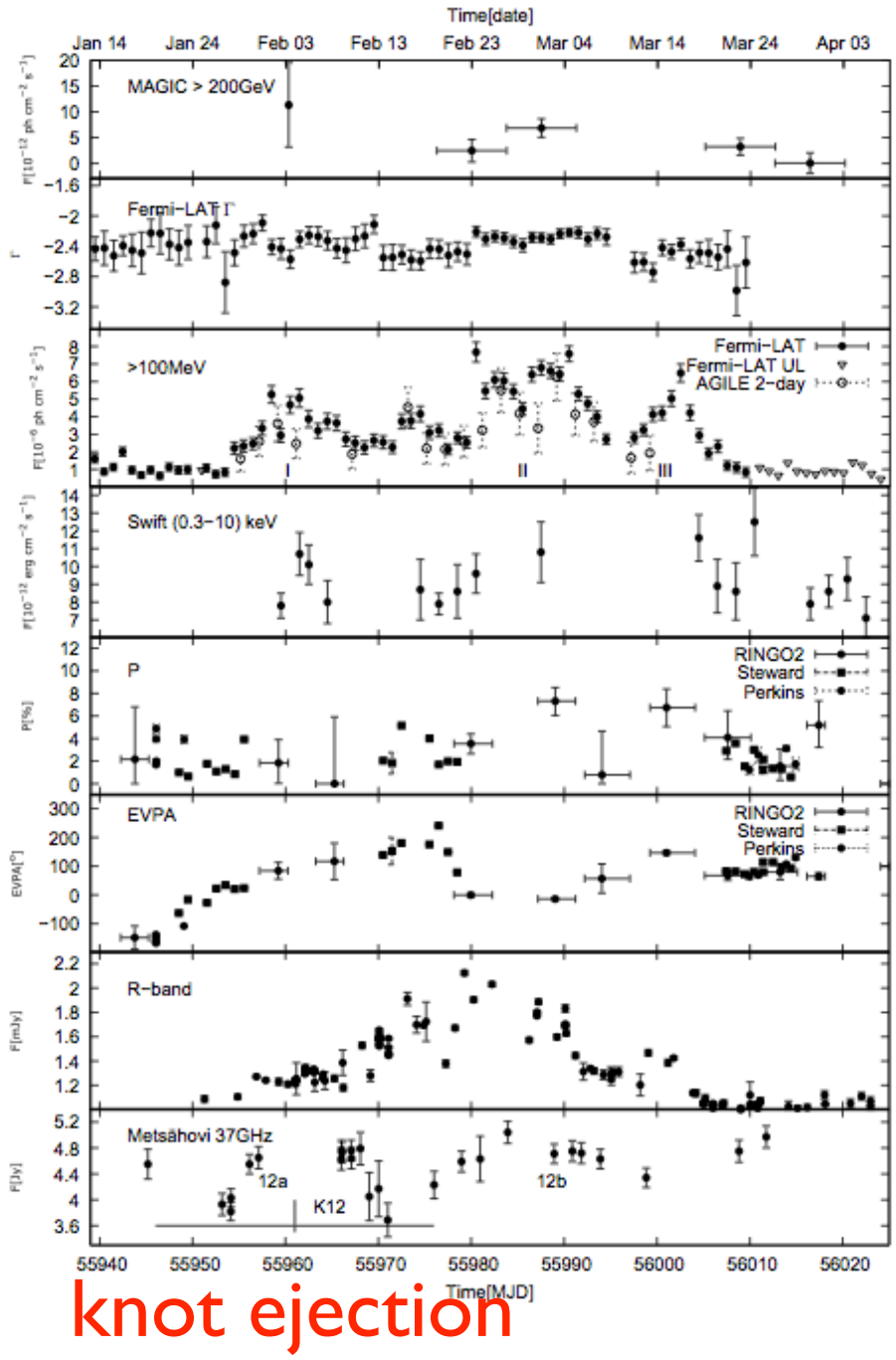


Aleksic+14

Fig. 8. 15 GHz, 37 GHz and 43 GHz VLBA core long-term light curves from MJD 55 750 (2011 July 8) to MJD 56 030 (2012 April 13). The flux of the VLBA core at 43 GHz traces the shape of the 37 GHz light curve, indicating that the major part of the total flux originates in there. Moreover, the new components found at 43 GHz are coincident with flux increase in the 37 GHz band. The symbols at the bottom of the plot show the zero separation epochs with the error bars of the components K11 and K12 from the 43 GHz VLBA core (see text).



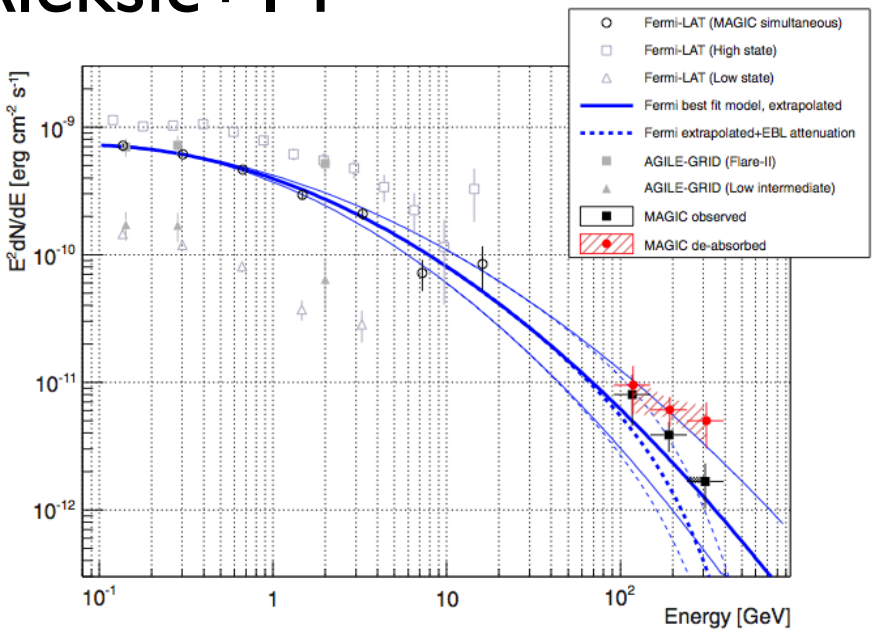
- Bright GeV flare occurred at knot ejection
- Compact emission region at ~pc away from central BH (as is the case of 4C 21.35)



knot ejection

TeV and MWL follow-up in 2012 Feb.

Aleksic+14



Smooth connection implies single emission region outside BLR

Bright and hard GeV flare from 3C 279 (ATel #5680)

[Previous | Next | ADS]

Fermi LAT detection of a GeV flare from the FSRQ 3C 279

ATel #5680; *Buson S. (University & INFN of Padova) on behalf of the Fermi Large Area Telescope Collaboration*
on 21 Dec 2013; 17:54 UT
Credential Certification: Sara Buson (buson@pd.infn.it)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, AGN, Blazar

Referred to by ATel #: 5682, 6036

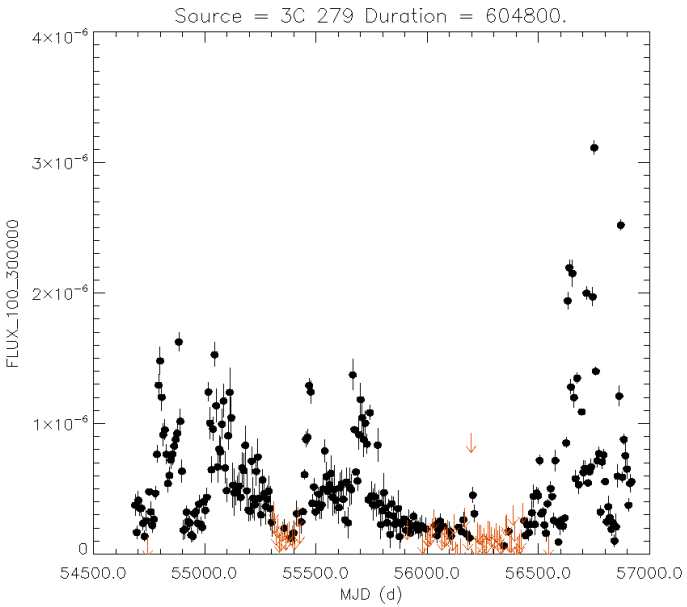
Tweet 5 Recommend 1

The Large Area Telescope (LAT), one of the two instruments on the Fermi Gamma-ray Space Telescope, has observed an increasing gamma-ray flux from a source positionally consistent with the blazar 3C279 (RA: 194.0465271, Dec: -5.7893119 , Johnston et al.1995, AJ, 110, 880, J2000). This source is classified as a flat spectrum radio quasar (FSRQ) at redshift of 0.536 (Marziani et al. ApJS, 1996, 104, 37) and is one of the three FSRQs known to be VHE gamma-ray emitters.

Preliminary analysis indicates that on 2013 December 20 the daily averaged flux (E>100MeV) was (6 +/- 1) x 10^-6 photons cm^-2 s^-1, more than a factor of 10 greater than reported in the second Fermi LAT catalog (2FGL J1256.1-0547, Nolan et al. 2012, ApJS 199, 31). This intense gamma-ray flare corresponds to the highest flux observed by the LAT since the start of the Fermi mission and follows an increasing trend recorded during the course of this month. Beside this, the source showed a particularly hard gamma-ray spectrum with a daily photon index of 1.80 +/- 0.06 (errors are statistical only) on 2013 December 20. Average photon indices for LAT-detected FSRQs are typically greater than 2.0.

Related
6075 Fermi-LAT Blazars in Low Optical States
6053 KAIT Optical Observations of the Flaring Blazar 3C 279
6036 Fermi LAT detection of renewed GeV activity from blazar 3C 279
5682 Confirmation by AGILE of increased gamma-ray emission from the blazar 3C 279

Fermi-LAT Public LC



2013/12/20=MJD 56646

LAT features seem similar to previous 4C 21.35 and PKS 1510-089 cases

http://fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/

VERITAS detection of 4C 21.35 during GeV brighening

Detection of Persistent VHE emission from PKS 1222+216 (4C +21.35) with VERITAS

ATel #5981; *J. Holder for the VERITAS Collaboration*
on 14 Mar 2014; 18:34 UT
Credential Certification: Jamie Holder (jholder@physics.udel.edu)

Subjects: X-ray, Gamma Ray, >GeV, TeV, VHE, AGN

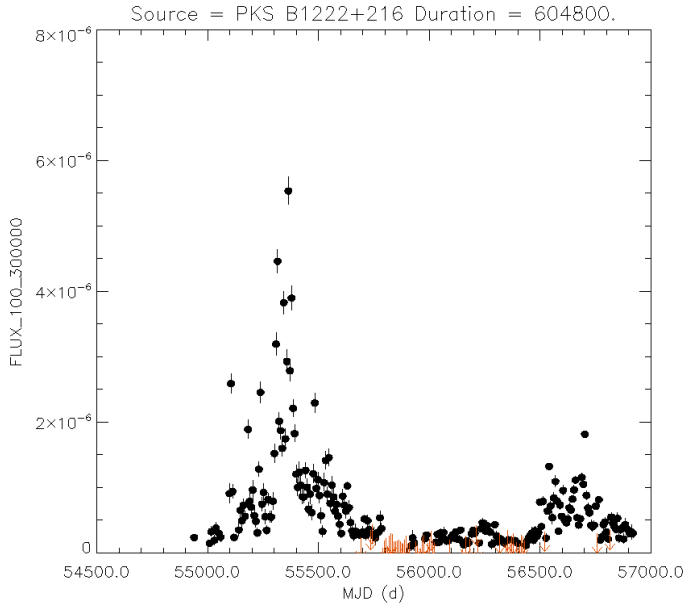
Referred to by ATel #: 6194, 6207

Tweet 5 Recommend 17

The VERITAS collaboration reports the detection of very-high-energy (VHE, E>100GeV) gamma-ray emission from the flat spectrum radio quasar PKS 1222+216 (z=0.432). This source has previously shown intense and rapid flaring episodes in the gamma-ray band (ATel #2584, ATel #2684, ATel #2687).

VERITAS observations of PKS 1222+216 started 11 days after a bright GeV flare reported by the Fermi-LAT Collaboration. An enhanced flux in the optical band was also reported (Larionov et al, ATel #5921). The VERITAS dataset consists of 5.9 hours of quality-selected exposure spread over 10 nights between Feb 26 and Mar 10 2014 (MJD 56714 - 56726). A preliminary analysis of these data reveals a gamma-ray excess with statistical significance of ~6 standard deviations. The integral flux above 100 GeV corresponds to (1.4 +/- 0.3) x 10^-11 ph cm^-2 s^-1 (equivalent to ~3% of the Crab Nebula flux). The excess is consistent with a constant flux over the ten nights of observation, although we note that there are limited statistics. This is the first VHE detection of this source since the brief VHE flare detected by MAGIC on June 17th 2010 (Aleksic et al. 2011, ApJL, 730, 8).

Optical follow-up from MIRO
6194 A New NIR flare of PKS1222+216
5981 Detection of Persistent VHE emission from PKS 1222+216 (4C +21.35) with VERITAS



1222+21)
2684 MAGIC detects a VHE

- The E>100 GeV flux is constant over 10 nights

Outline

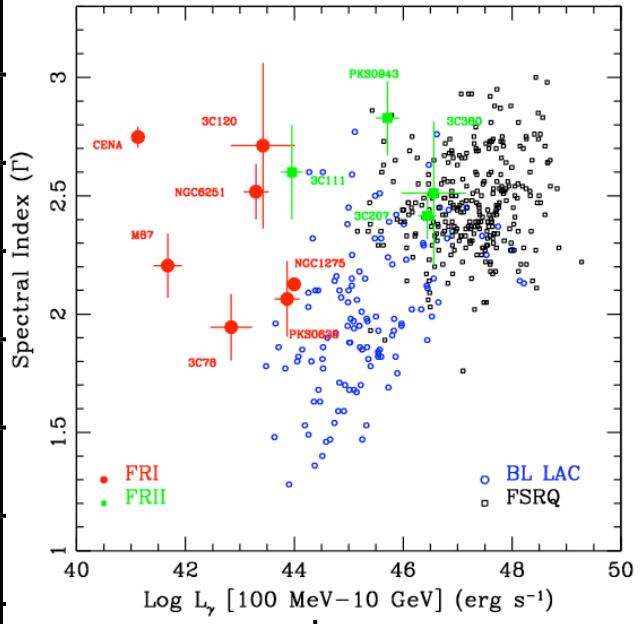
- Fermi Gamma-ray Space Telescope
- New observing strategy
- 2013年1月以降に出版されたFermi-AGN関連の結果を主に紹介
  - ✓ Fermi Bubble (Akermann+14, ApJ, Cat I)
  - ✓ EBL and High redshift blazars
  - ✓ TeV FSRQs
  - ✓ Radio galaxies: Cen A and M87
  - ✓ Extreme HBLs

Radio galaxies

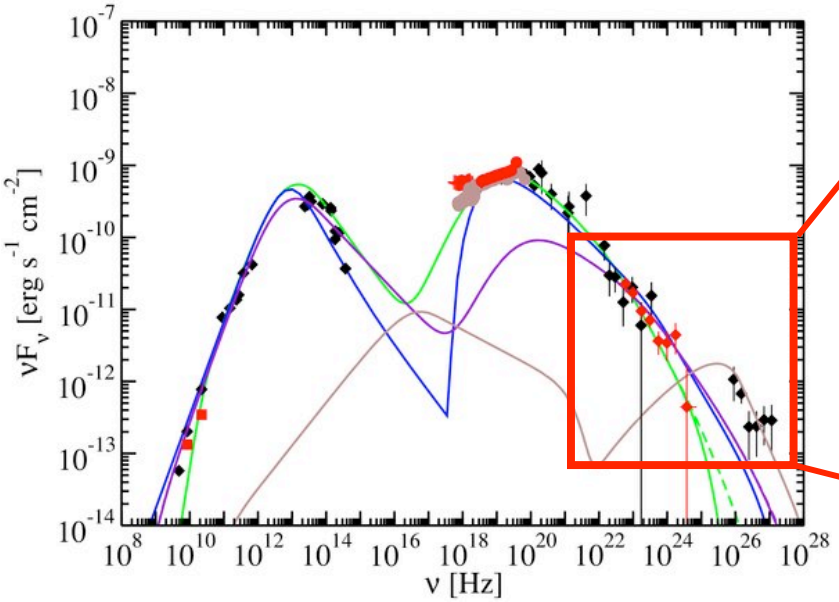
- Cen A core (Sahakyan+13)
  - ✓ Spectral hardening in GeV band
  - ✓ Constant flux over 4 years (?)
- M87 multi-wavelength
  - ✓ 10-year MWL monitoring result (Abramowski+12)
  - ✓ TeV+VLBI (Hada+14)

Fermi-detected Radio galaxies

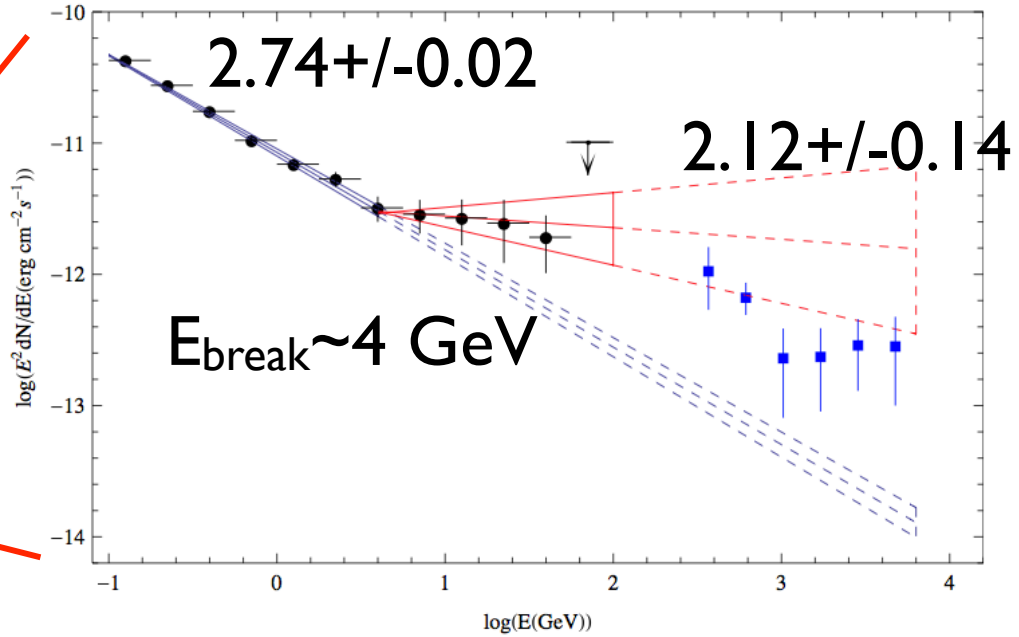
Name	Distance [Mpc]	FR I or II	TeV
Cen A	3.7	FR I	Yes (non-variable)
M87	16	FR I	Yes +rapid flares
Fornax A	18	FR I	
Cen B	56	FR I	
NGC 1275	75	FR I	Yes
NGC 6251	106	FR I	
3C 78	124	FR I	
3C 120	142	FRI	BLRG, UFO
3C 111	213	FR II	BLRG, UFO



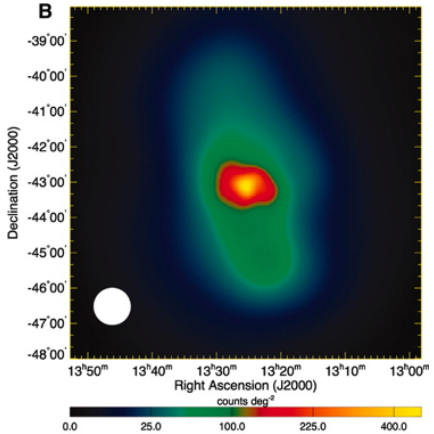
Cen A core: spectral hardening



Abdo+10



Sahakyan+13



- Additional component at E>~4 GeV
- スペクトルの精密測定 (PL index, cutoff/breakの探査)と変動探索→放射機構の解明

MeV/GeV variability

Flux
(E>100 MeV)

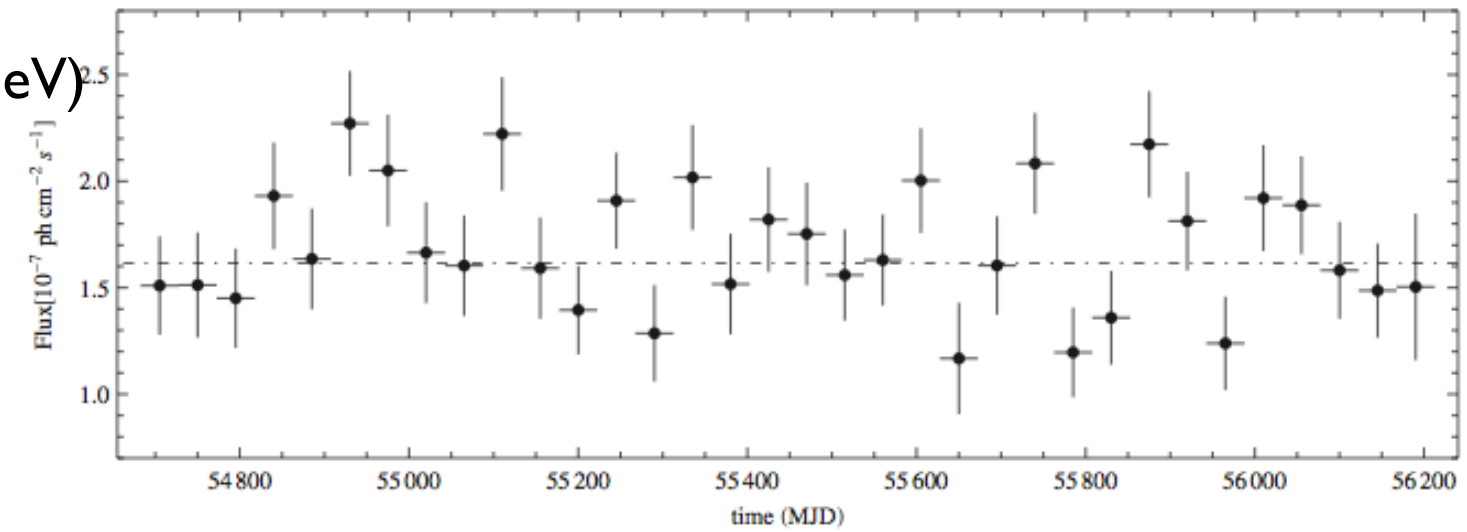
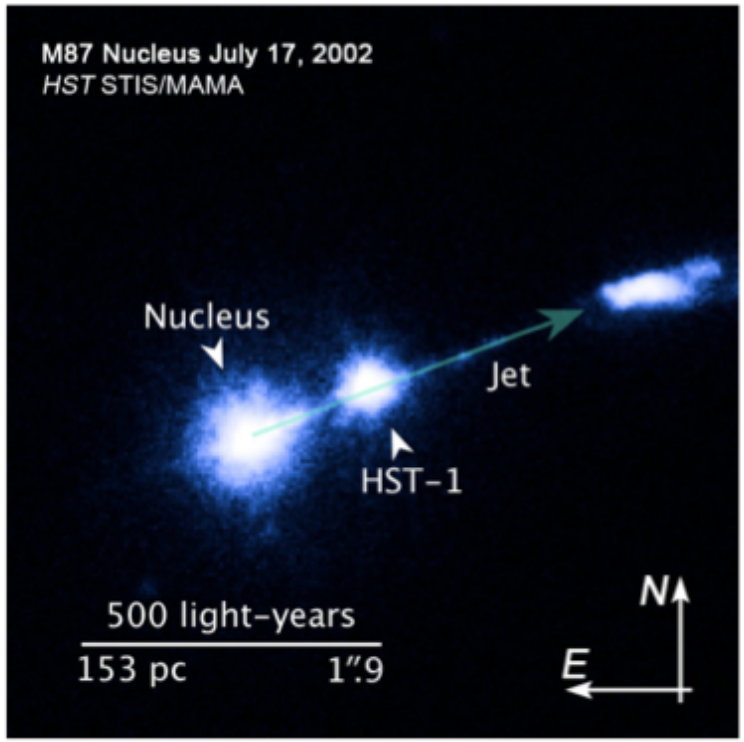


Figure 2. Gamma-ray light curve from 2008 August 4 to 2012 October 1. The bin size is 45 days. The background diffuse emission (both galactic and extragalactic) is fixed to the best-fit parameters obtained for the overall time fit. While some variability may be present, limited statistics do not yet allow us to make definite conclusions.

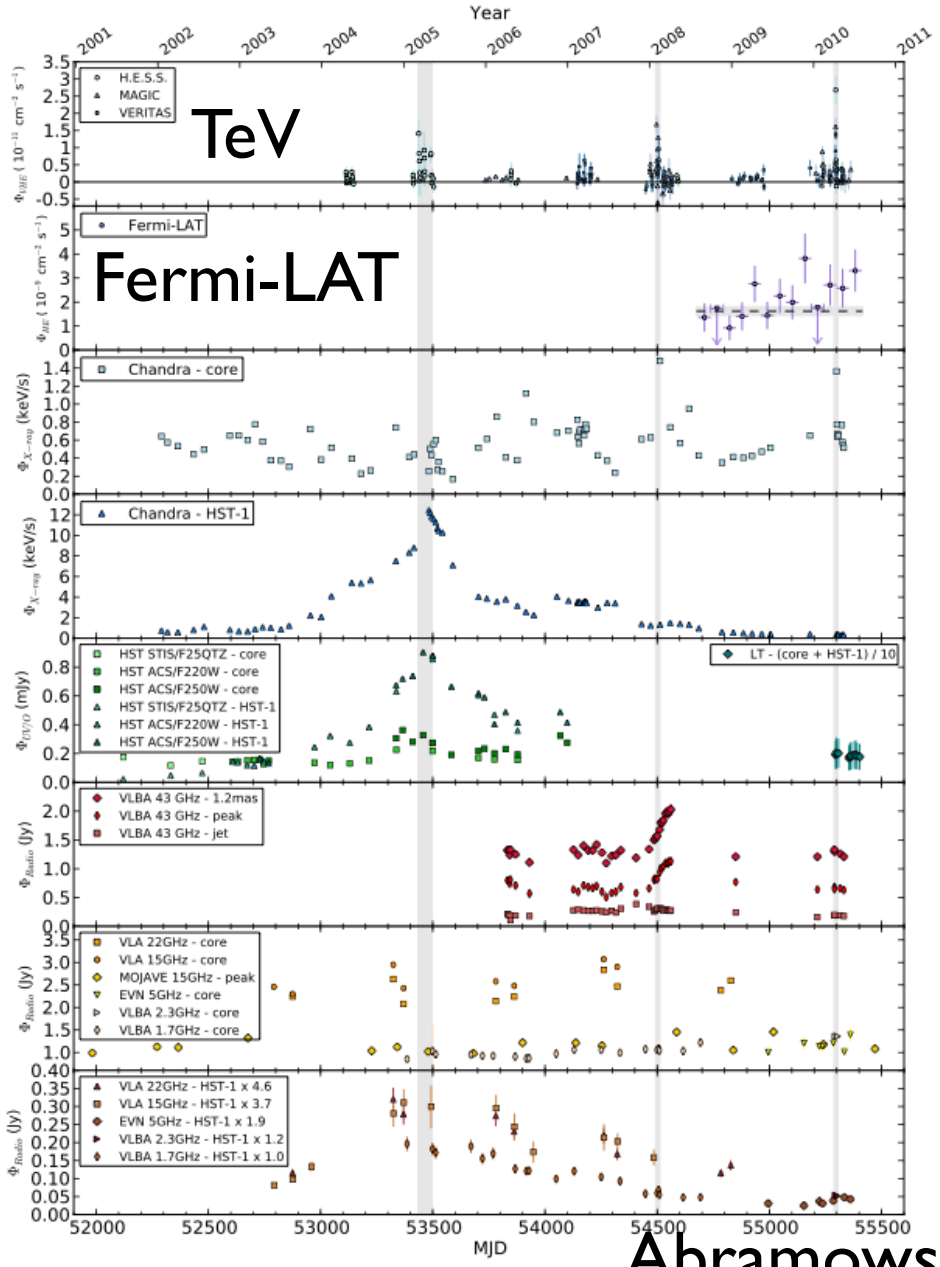
To search for variability, a χ^2 test was performed. The results for the light curve with 15, 30, and 60 day bins give a probability $P(\chi^2) = 0.07$, 0.04, and 0.127, respectively, and are consistent with no variability. Interestingly, however, a similar test for the light curve with 45 day bins gives in $\chi^2/\mathrm{dof} \approx 1.61$ and $P(\chi^2) = 0.015$, indicating a possible variability on 45 day timescale. Because of limited statistics, however, no definite conclusion can be drawn. The light curve with 45 day bins is

No clear evidence of variability

M87 TeV flares and MWL light curves

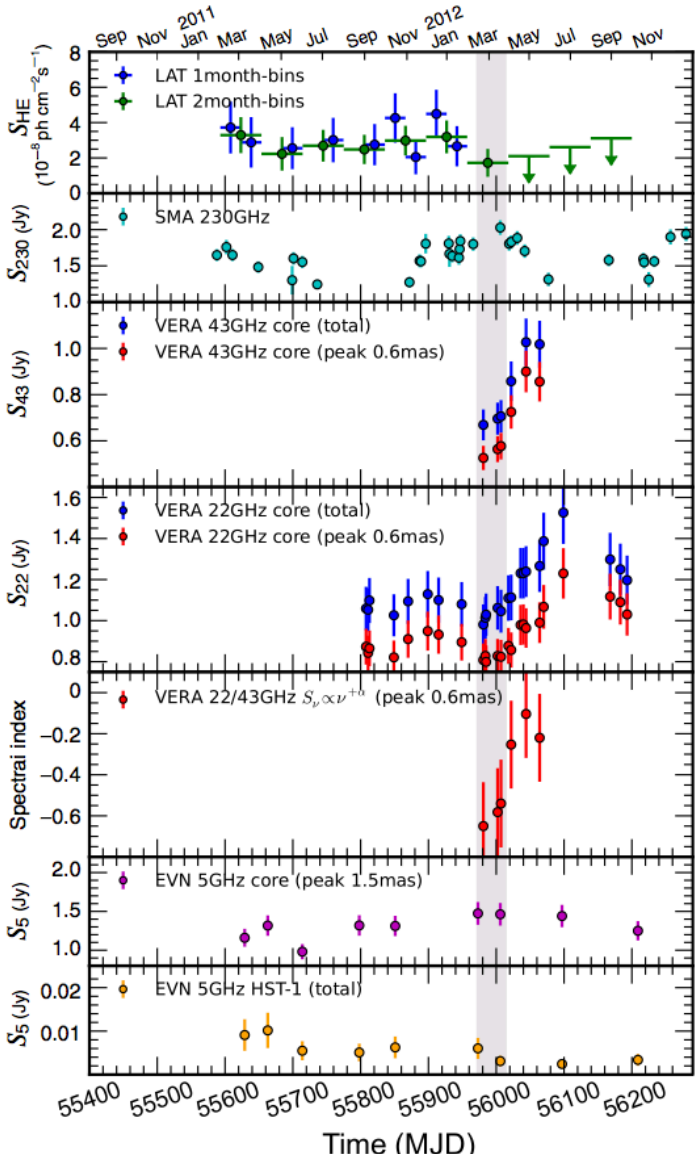


- TeV emission region is located at the core or pc-scale knot (HST-1)?
- GeV flux is always steady during TeV flare?



Abramowski+12

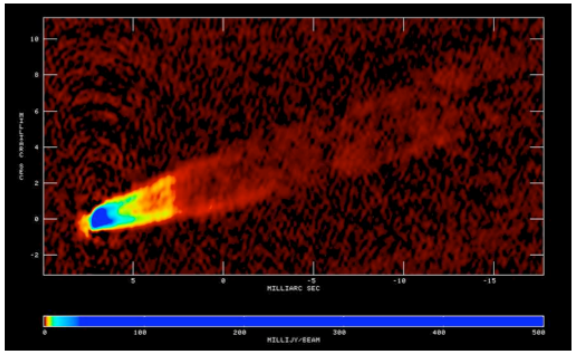
MWL follow-up of weak TeV flare in 2012

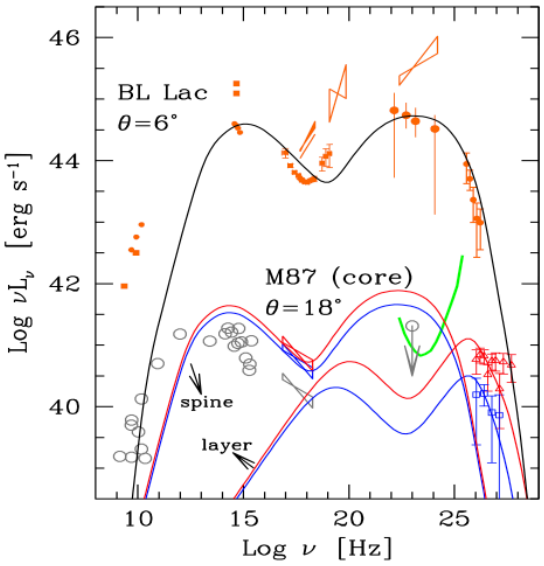


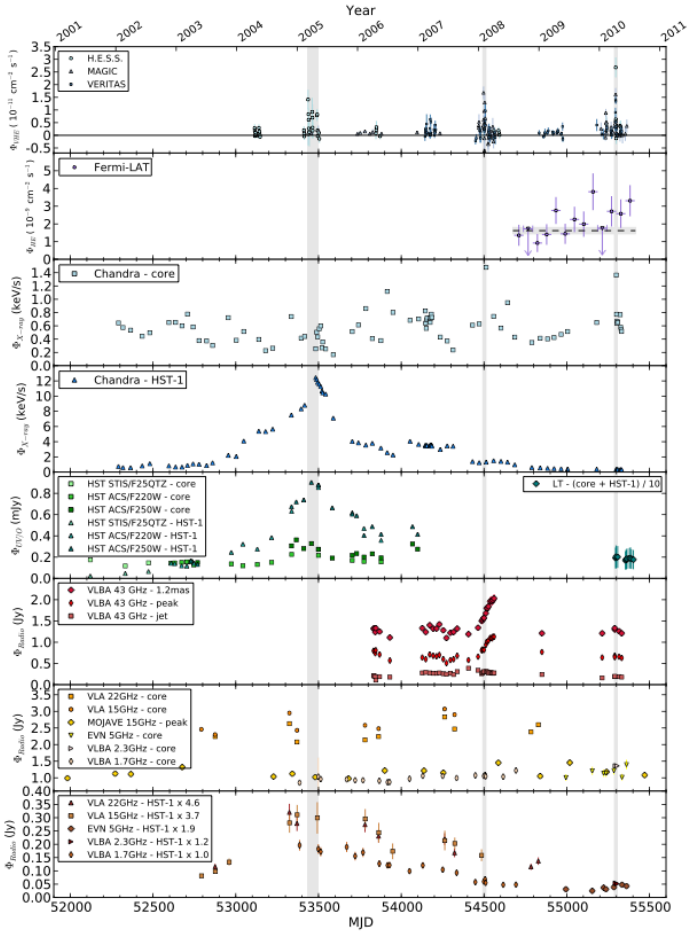
- After the TeV flare, the radio core brightened, suggesting that the TeV photons are emitted at jet base (as is the case of 2008 flare)
- HST-1 flux remains constant and no new component emerged
- HE emission is constant before the flare
- After the flare, the LAT flux decreased by a factor of ~2 (6-month-bin data)

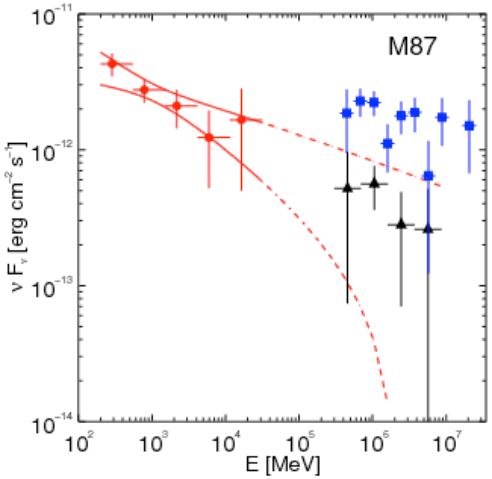
Hada+14

Spine-layer? (2成分必要)





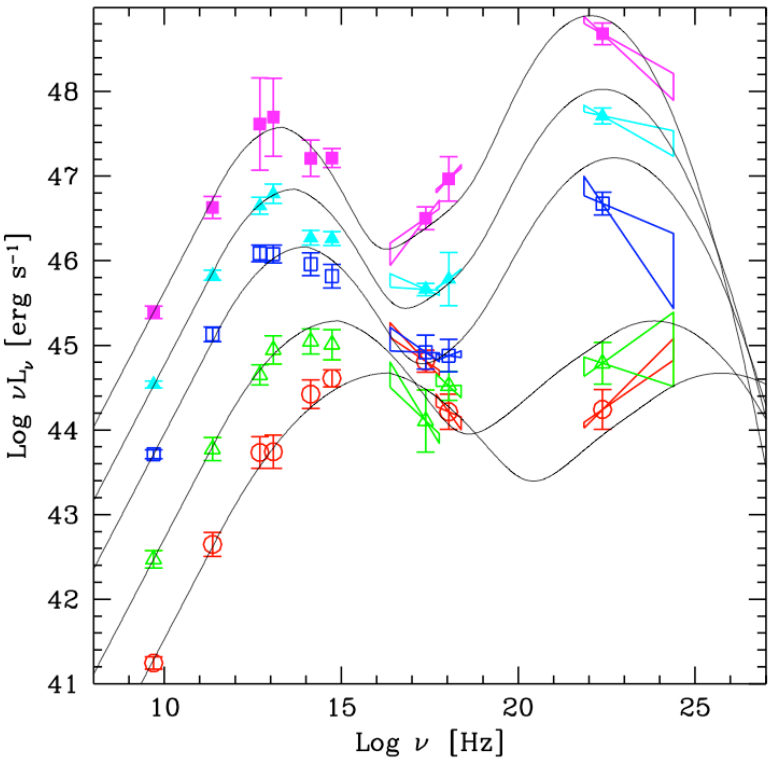


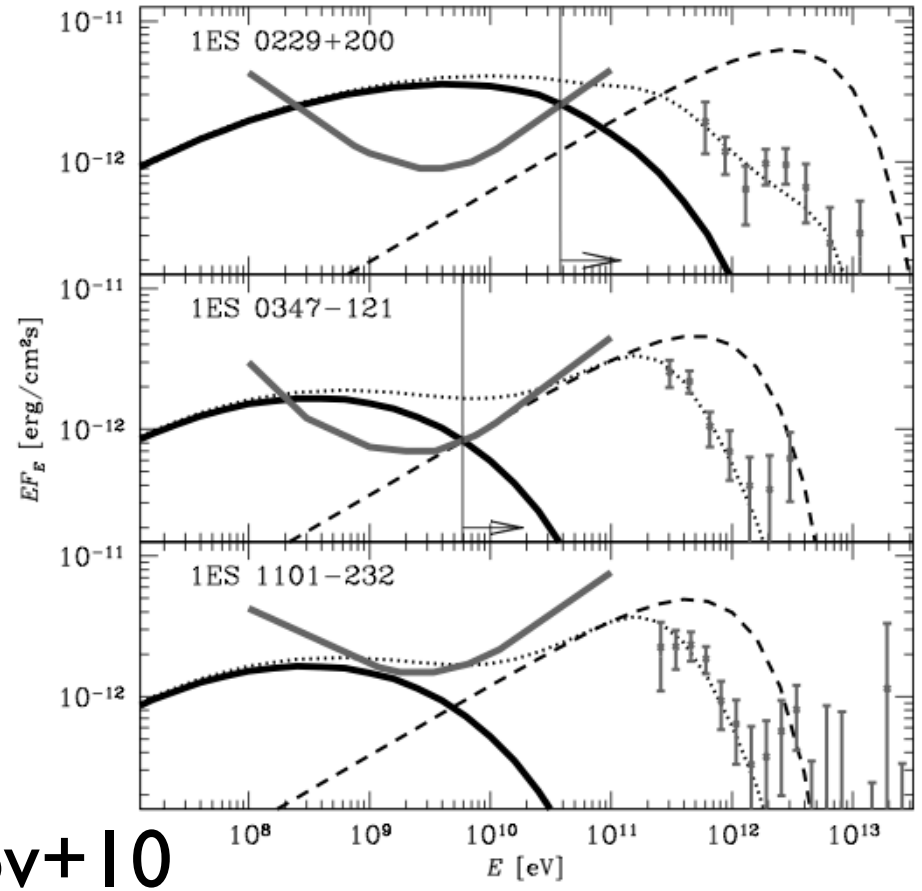


1. GeVとTeVは別成分
2. X線とTeVが同期して変動 (GeVはX線と同期しないのでspine-layer modelは棄却?)

- Snapshot daily monitoring by CTA

Extreme HBLs





Neronov+10

- Very faint in GeV band, but finally detected over several-year data accumulation (e.g, Vovk+12, Tanaka+14, Finke+13)
- More accurate constraint on IGMF

Summary

- Fermi Bubble
  - ✓ Cutoff PL with index=1.9 and E_{cutoff}=110 GeV
  - ✓ No spectral variation over latitude
  - ✓ No evidence of a jet
  - ✓ Leptonic model is favored
- EBL and High redshift blazars
  - ✓ Minimum level of EBL model
  - ✓ Fermi alert and MAGIC follow-up allowed to detect most distant z=0.944 blazar
- TeV FSRQs
  - ✓ Far dissipation (pc away from central BH) scenario is favored for PKS 1510 flare in 2011 and 2012
- Radio galaxies: Cen A and M87
  - ✓ Additional component above E~4 GeV, which smoothly connects to TeV data
  - ✓ Weak TeV flare in 2012 would take place within 43 GHz core, rather than HST-1
- Extreme HBLs: Fermi-LAT finally detects GeV counterparts and constraint on IGMF