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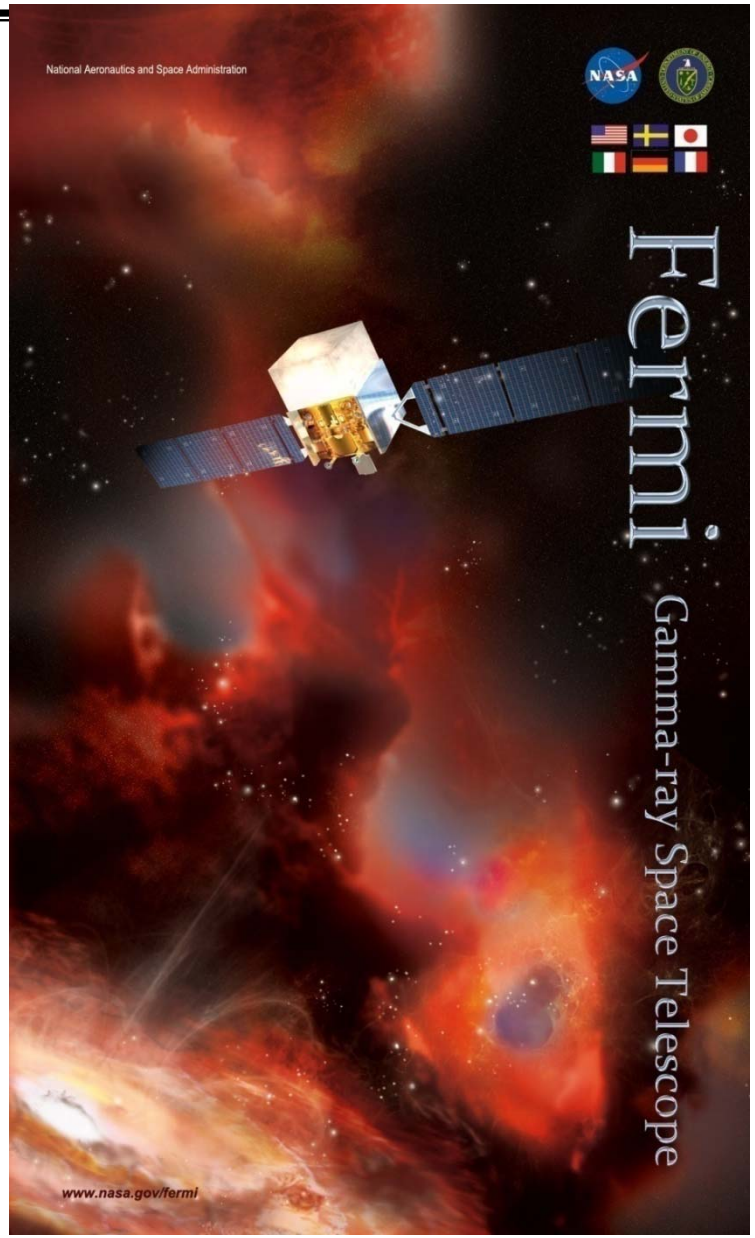
JSPS meeting @Konan Univ.

Recent Highlights from AGN Observations with Fermi-LAT

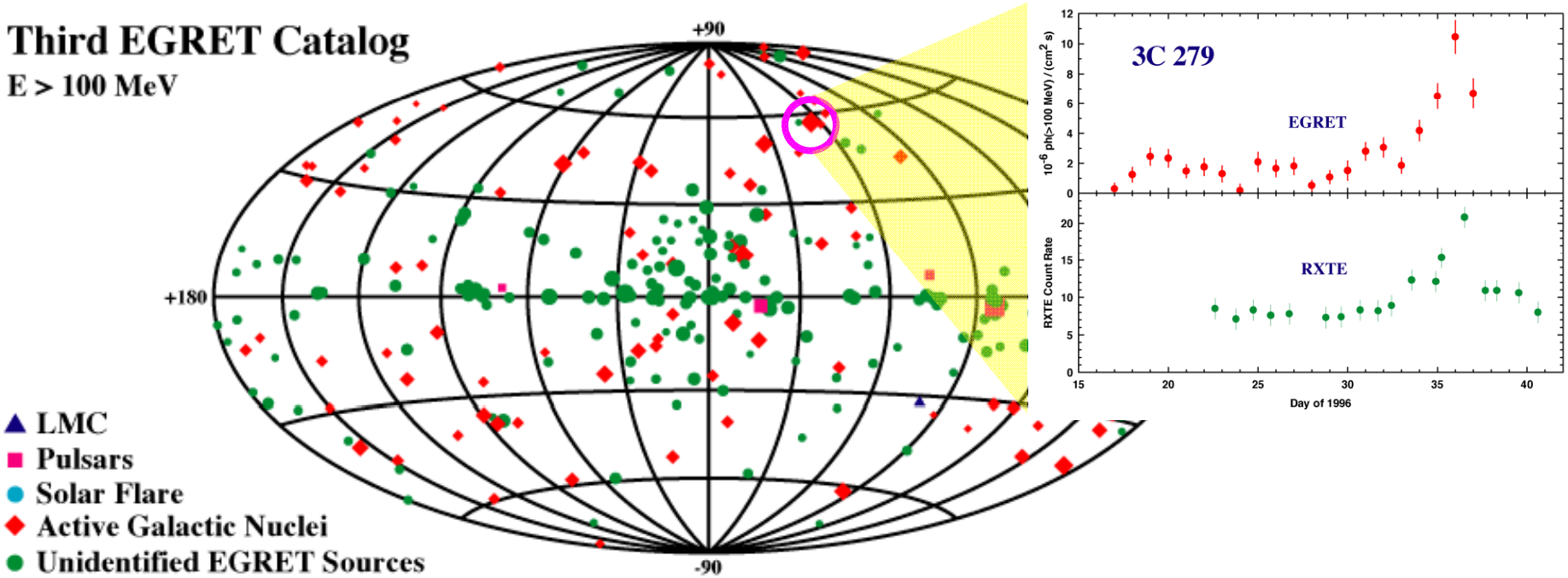
活動銀河ジェット観測の新展開

Jun KATAOKA
(早大理工研/物理応物)

on behalf of the Fermi-LAT Collaboration

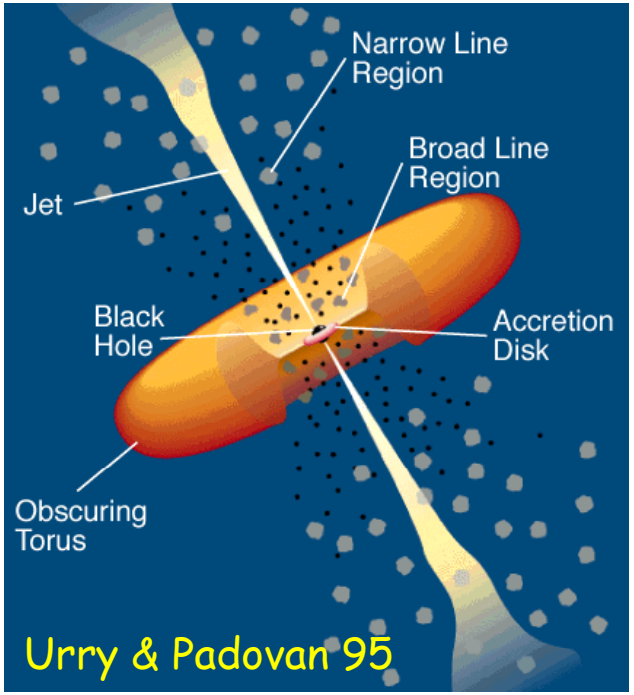


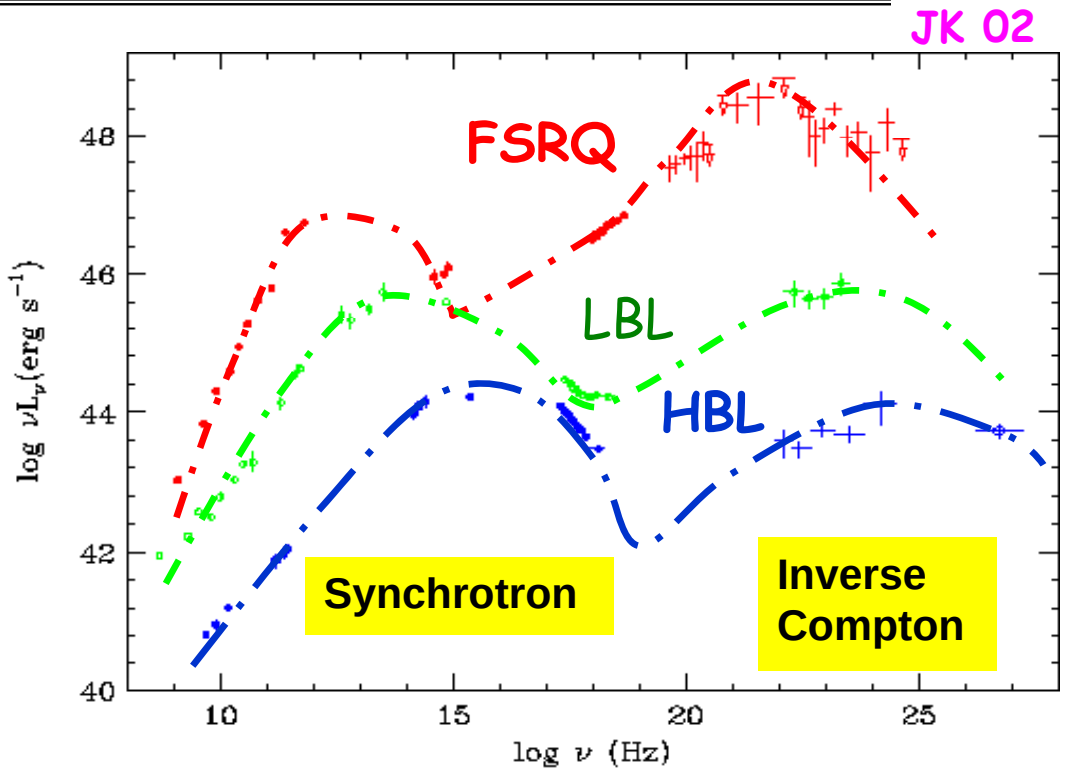
AGNs: EGRET View



- EGRET discovered about 70 (3rd Catalog, Hartman et al 1999; >100 Sowards-Emmerd et al. 2003,2004) AGNs emitting γ-rays.
- About 20 sources were detected at E>200 GeV by the ACTs.
- Except for a few marginal detection of RGs, all sources are "flarting AGNs, classified as "blazars".

Blazars Overview

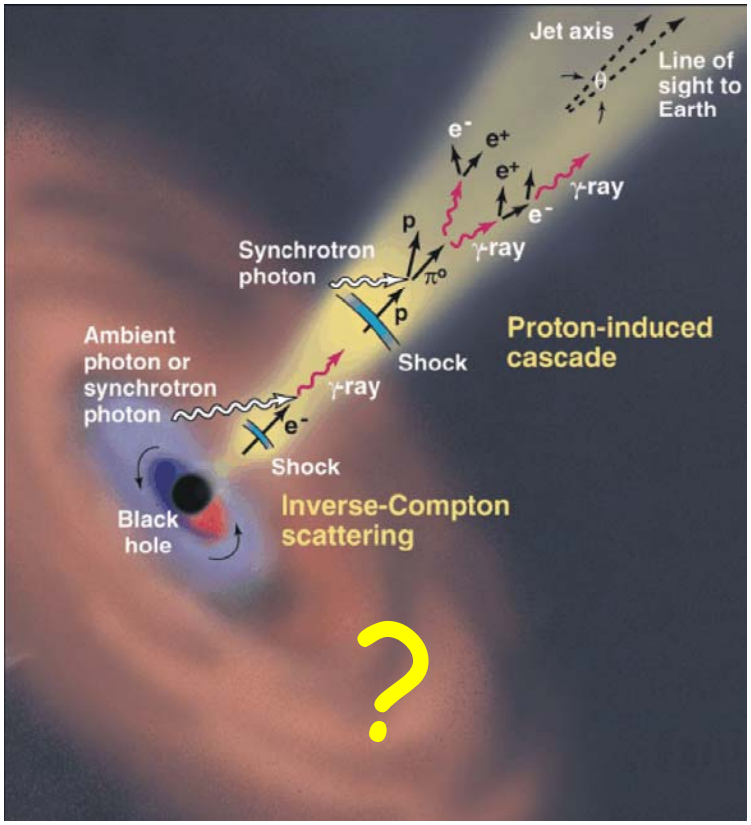




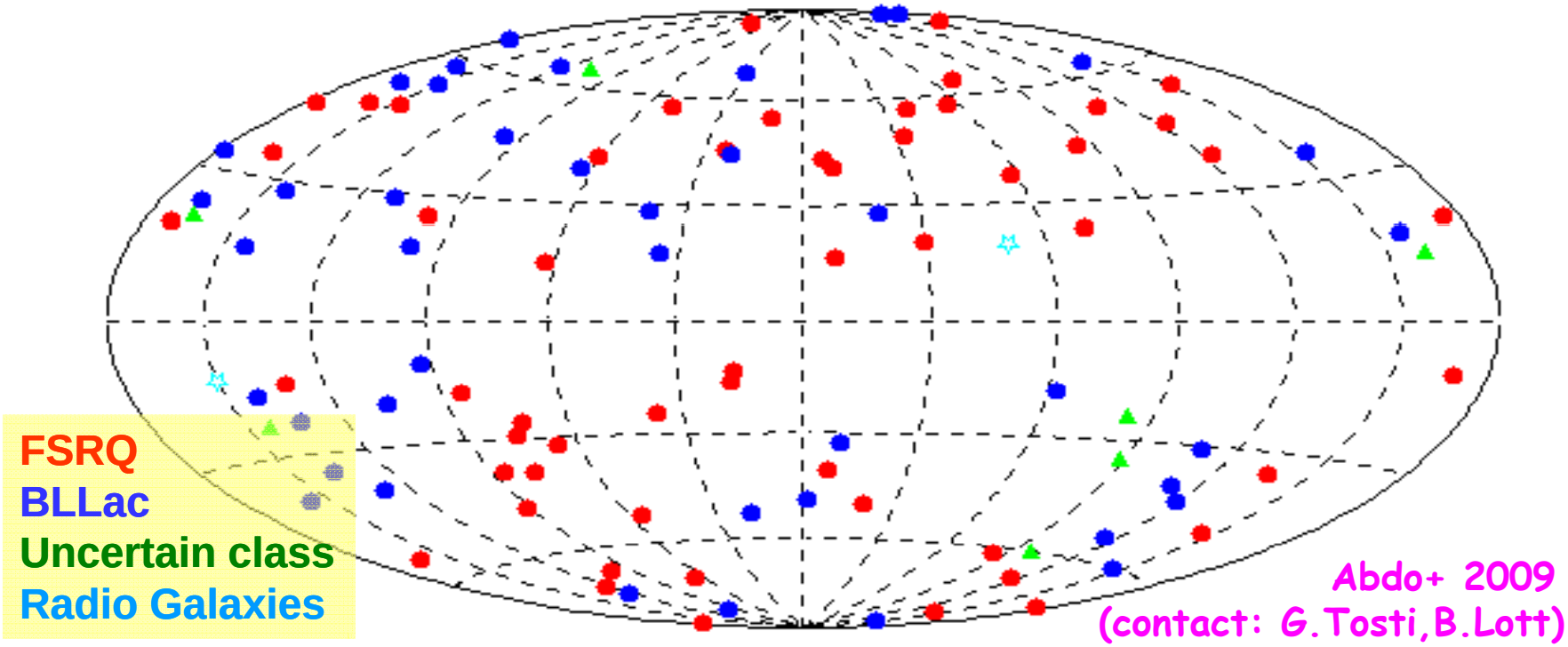
- Blazars: jet closely aligned to our line of sight.
  - SL motion, one-sided jet ➡ $\beta_{jet} \sim 0.99\ c$ or $\Gamma_{jet} \gtrsim 10$
- "Double peaks" over two decades in ν
  - Sync + Inv. Compton, but wide variety ➡ BL Lac , FSRQs
  - Most powerful objects peaks at lower ν ➡ "Blazar Sequence"

Key Questions for Blazars

- Emission mechanisms (especially for high-E component)
  - Leptonic (IC of sync or ext photons) vs hadronic ($\pi^0 \rightarrow \gamma\gamma$, proton synchrotron)
- Emission location
  - Single zone for all ν (constraining for simplest leptonic models)
  - Opacity effects and E-dependent photospheres
- Particle acceleration mechanisms
  - Shocks, Blandford-Znajek process
- Jet composition
  - Poynting flux, leptonic, ions
- Jet confinement
  - External pressure, B stresses
- Accretion disk—BH—jet connection
- probes of the extragal BGD light (EBL)
- Effect on host galaxies and galaxy clusters

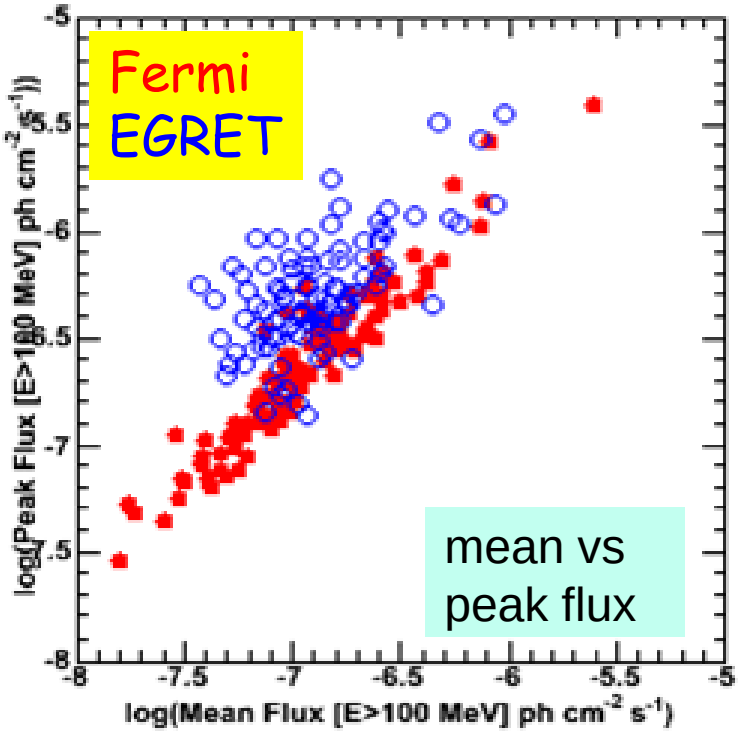


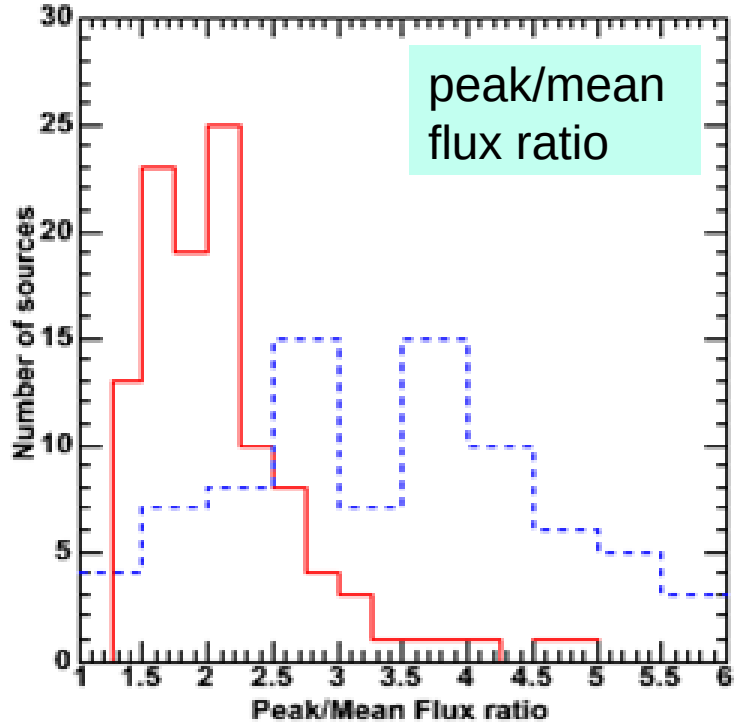
AGNs: Fermi View (3 month)



- Note, EGRET found fewer than 30 src above 10 σ in its lifetime.
- 57 FSRQs, 42 BL Lac (HBL+LBL), 2 RGs and 6 unID class. (34 % BL Lac fraction vs 19 % by EGRET)
- Typical 95 % error is less than 10′ .

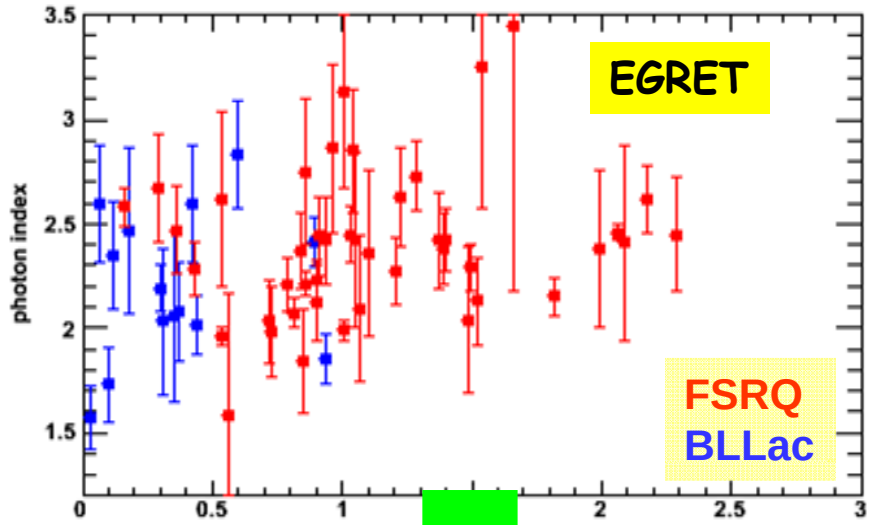
Flux Distributions

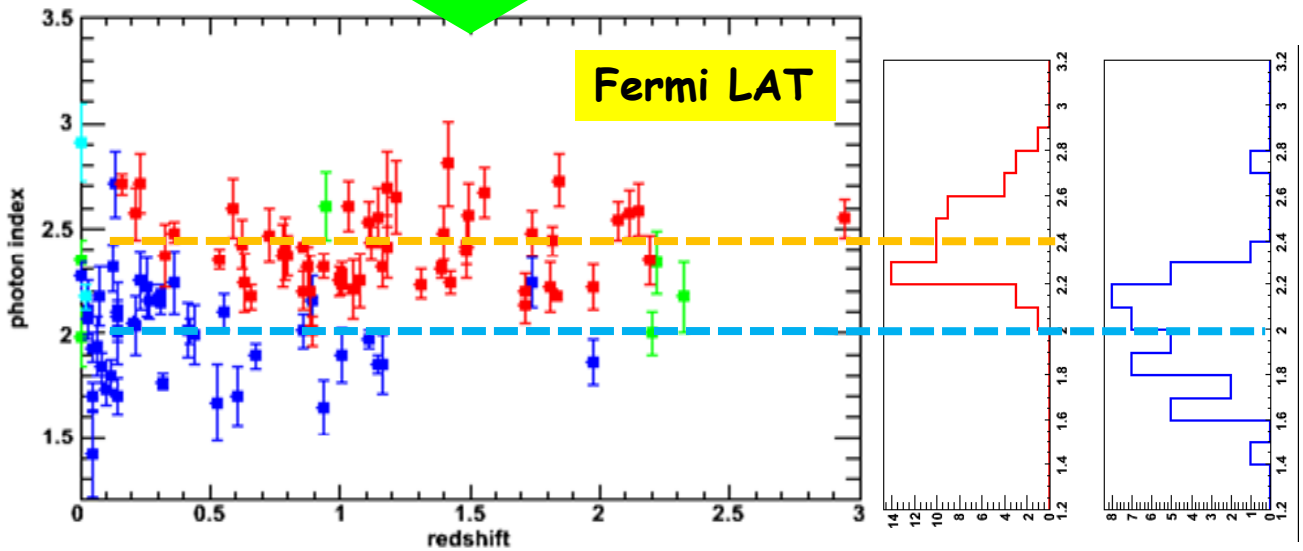




- Due to its limited sensitivity, EGRET observations were strongly "biased" to blazars' flaring states.
- Fermi can observe quiescent nature of flaring AGNs everyday, <u>even in its low activity states</u>.

Redshift (z) Distributions



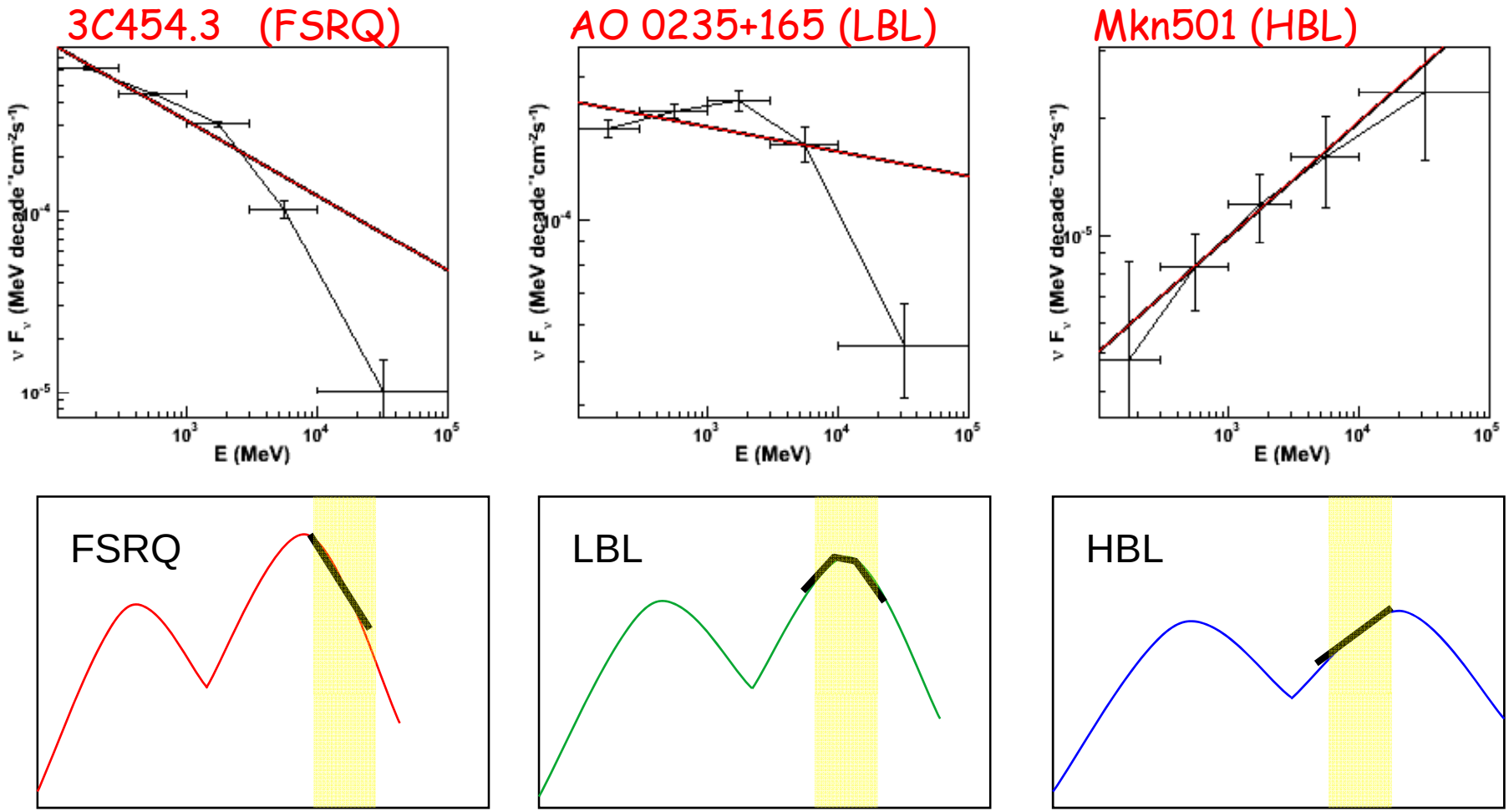


- Most distant Fermi blazar at z = 2.944.
- More and more faint (i.e. distant) BL Lac visible!
- Clear separation of photon index distribution between FSRQs and BL LACs.

FSRQs
$\langle\Gamma\rangle = 2.33 \pm 0.01$

BL Lacs
$\langle\Gamma\rangle = 1.99 \pm 0.01$

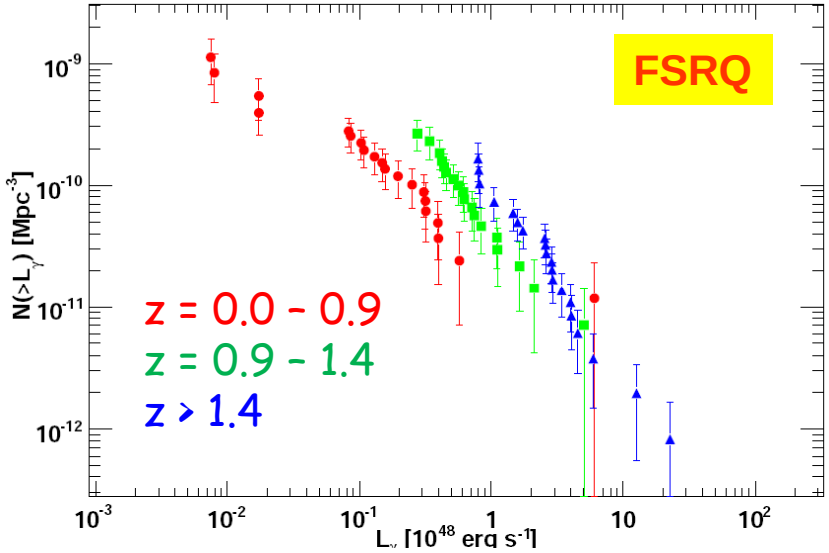
Typical Gamma-ray Spectra

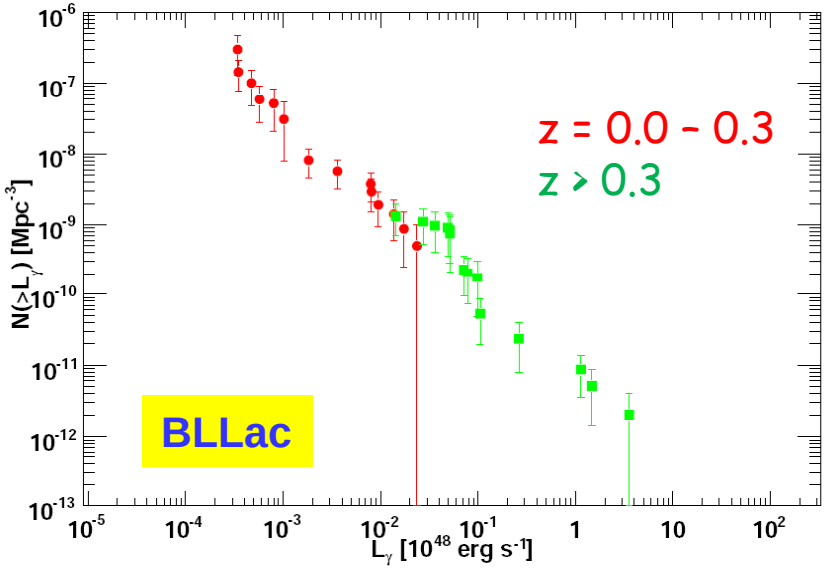


- Significant departures from single PL for bright blazars.

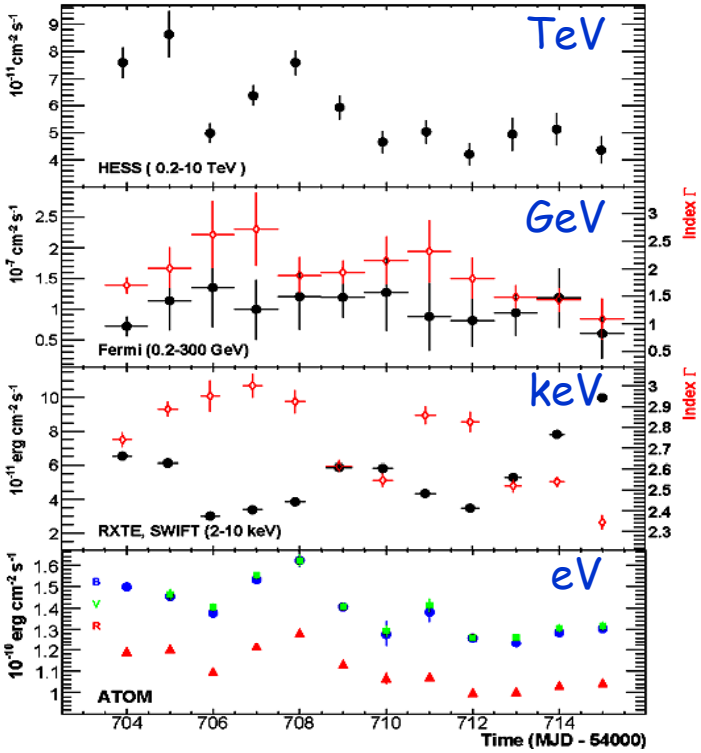
Luminosity Functions

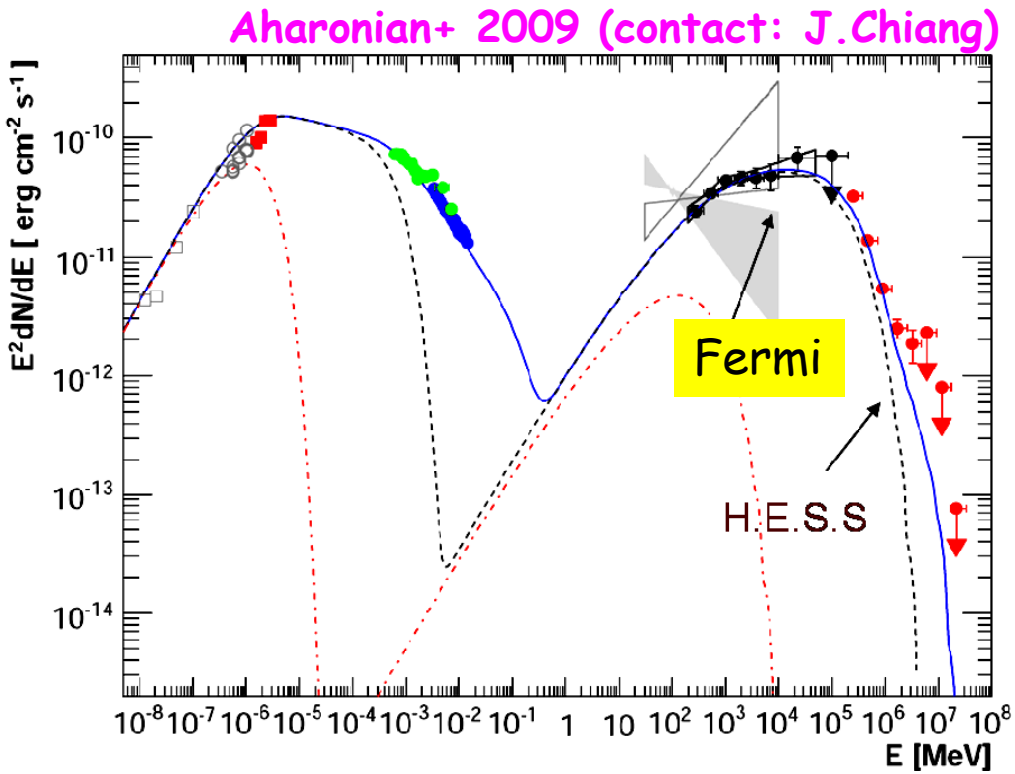
- FSRQs
  - Strong evolution
  - The 3 month LAT AGN sample measures the bright end of the luminosity distribution.
- BL Lac objects
  - No evidence of evolution
- Combined emission from individual blazars in 3 month sample corresponds to 7% of EGRET extragalactic diffuse gamma BGD.





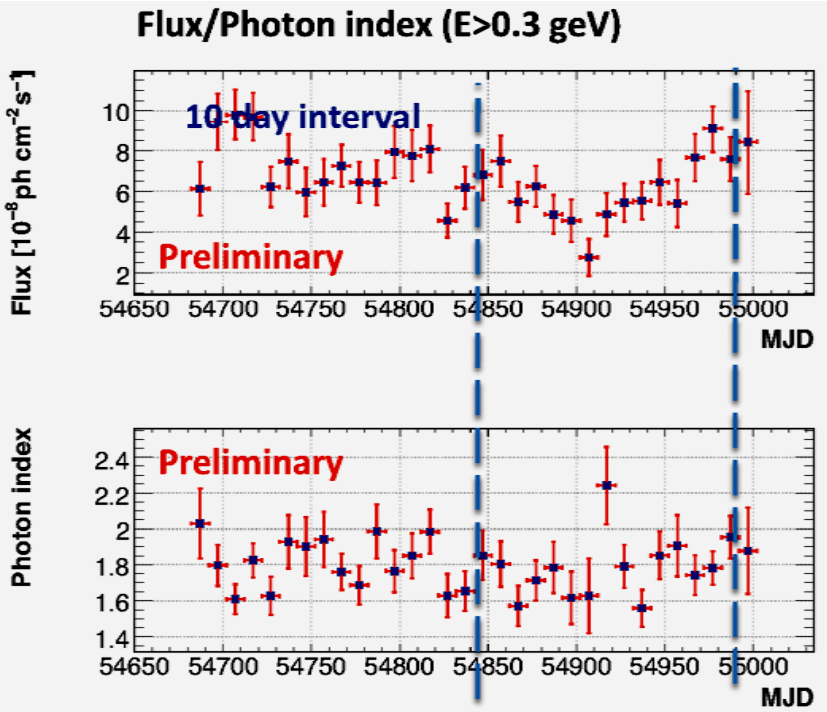
HBL: PKS 2155-304



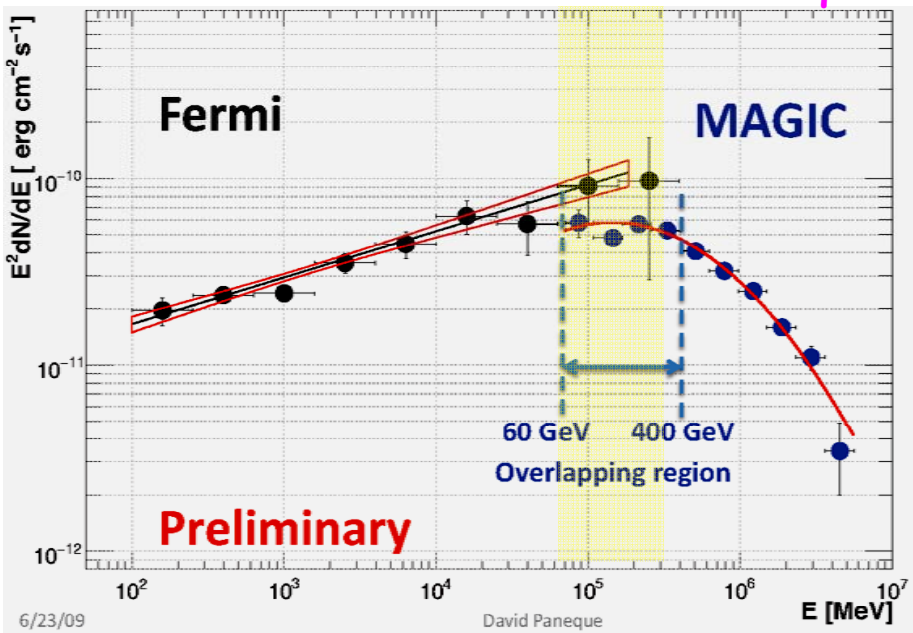


- Joint obs with H.E.S.S and Fermi – the first multi MeV-TeV SEDs.
- Relatively little variability, but clear optical/VHE correlation.
- X-rays may vary independently of VHE emission - serious challenges to the standard picture of SSC model.

HBL: Mrk 421



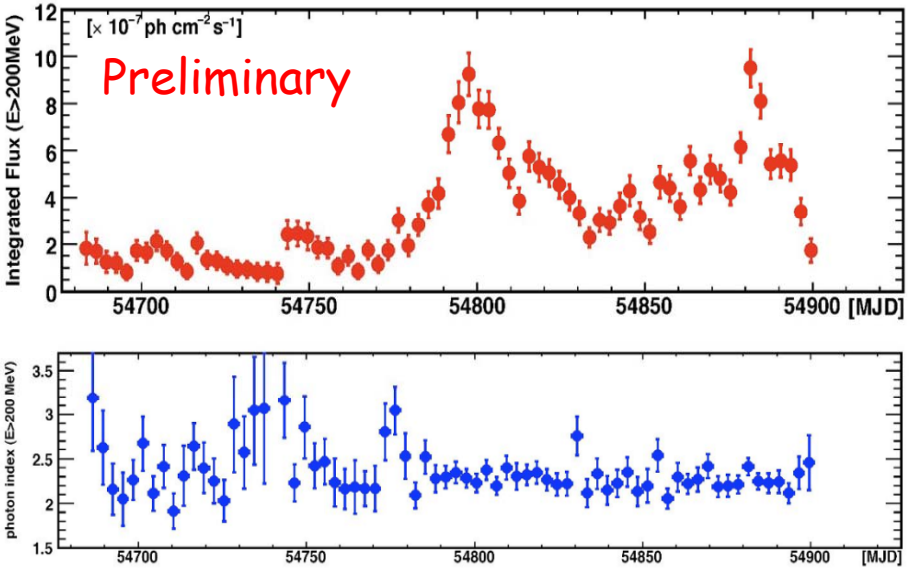
Contact: D.Paneque

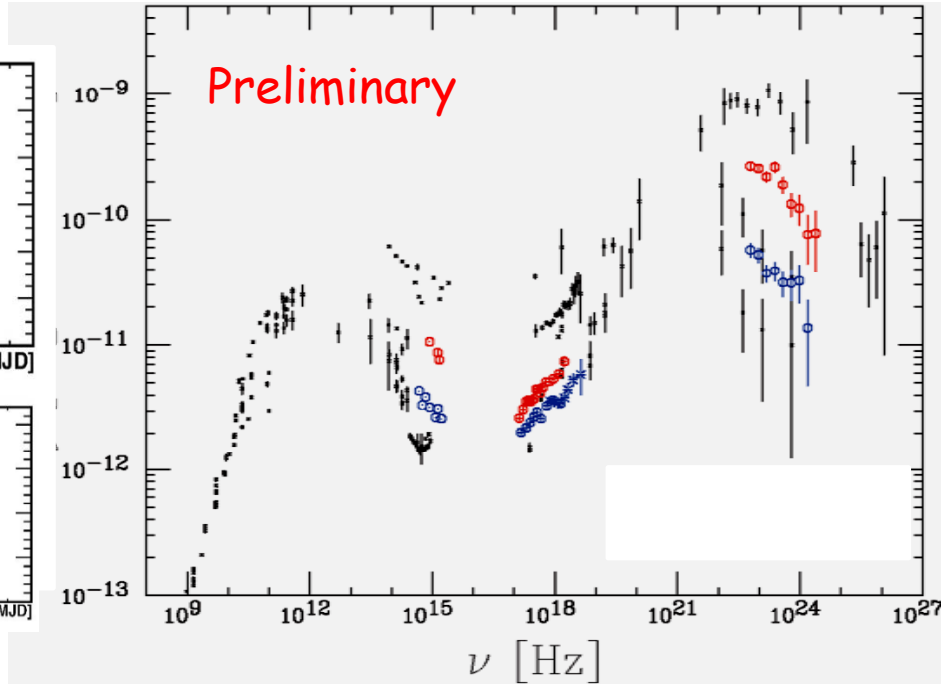


- Significant variability, but not as impressive as those in X-rays.
- Hard Gamma-ray spectrum with Γ =1.79±0.03 – nicely overlap w/ the energy ranges covered by the ground Cherenkov telescopes.
- MAGIC data, simultaneously taken during a low state nicely connects w/ Fermi-LAT data - spectral break at ~ 100 GeV?

QHB: 3C 279

Contact: G.Madejski & M.Hayashida

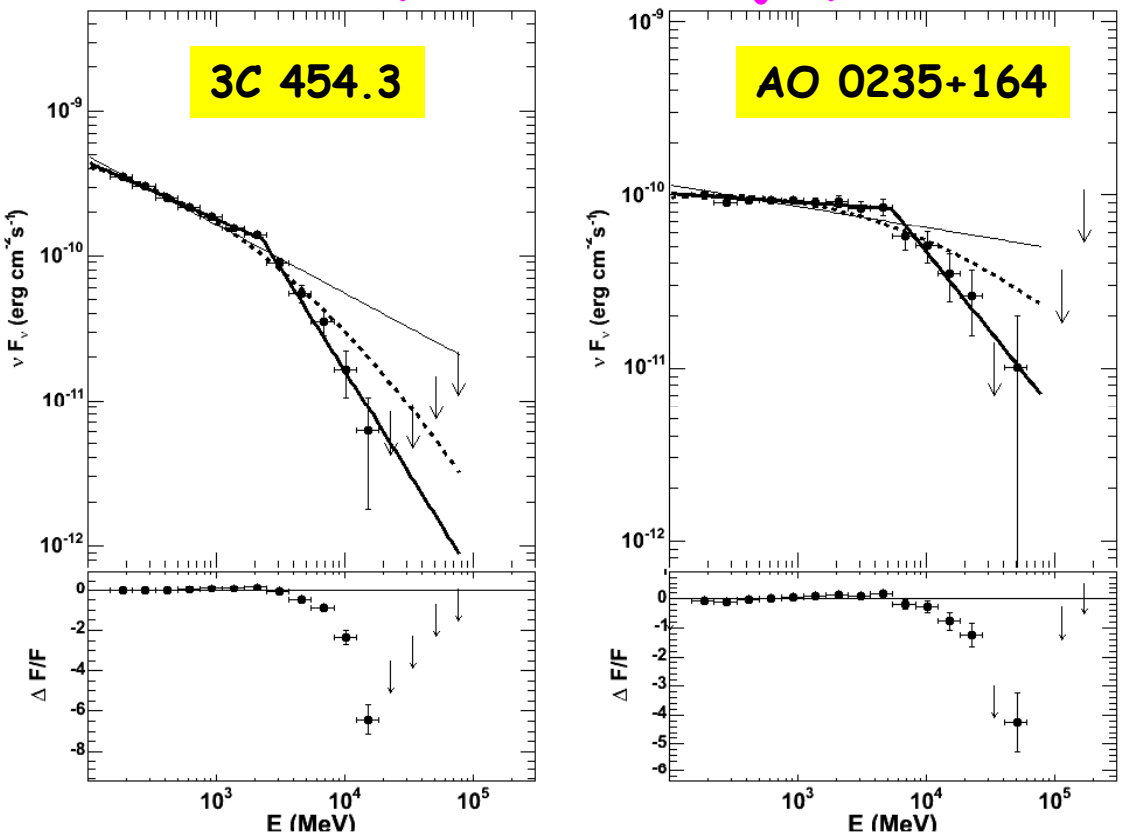




- Significant flux variability over an order of magnitude with flux doubling time scale of Δt ~ 5 days.
- Interestingly, no significant "energy-dependent" variability, meaning that spectra do NOT change/evolve even among its historical low and high states.

Cutoff in the QHB Spectra

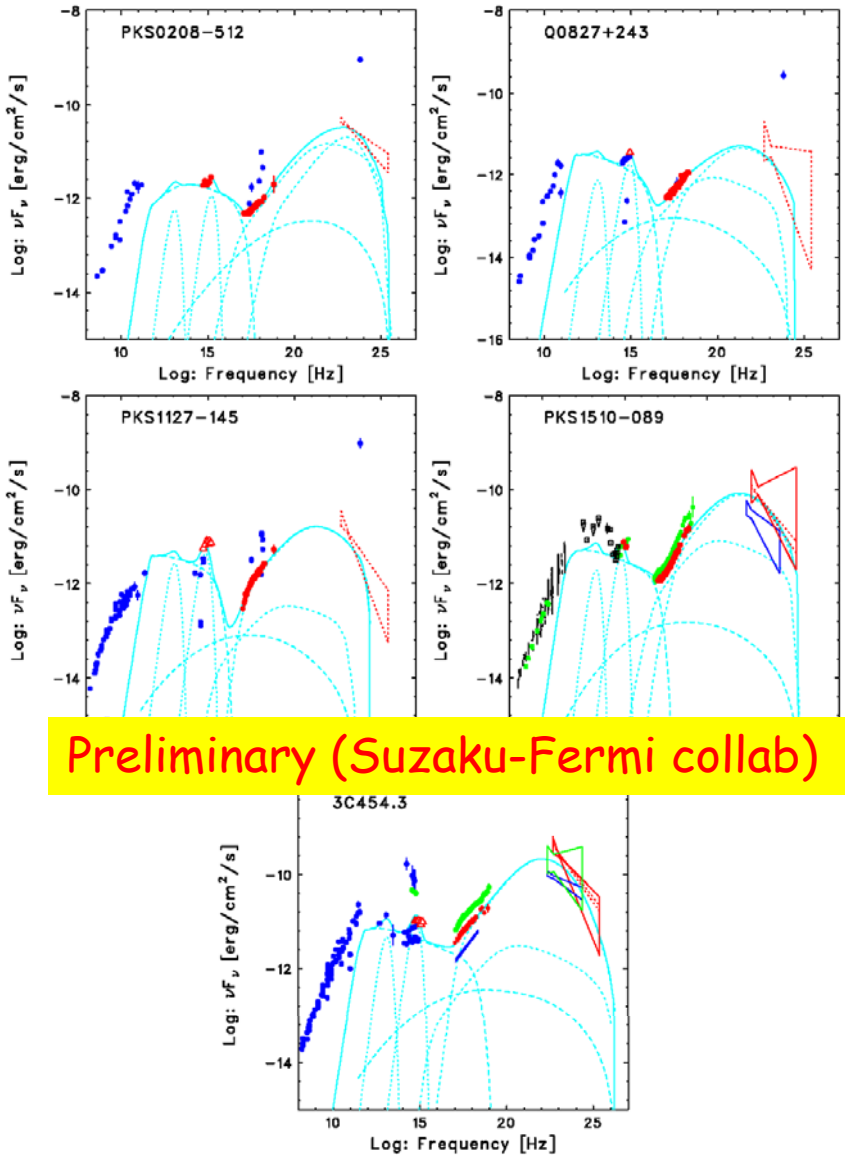
Abdo+ 2009 (contact: G.Madejski)



- In many FSRQs, clear spectral signature, i.e., high energy cutoff has been observed between 1 - 10 GeV.
- In case of 3C 454.3, spectrum breaks from $\Gamma_1 = 2.3$ to $\Gamma_2 = 3.5$. (not very smooth as an exponential cutoff)

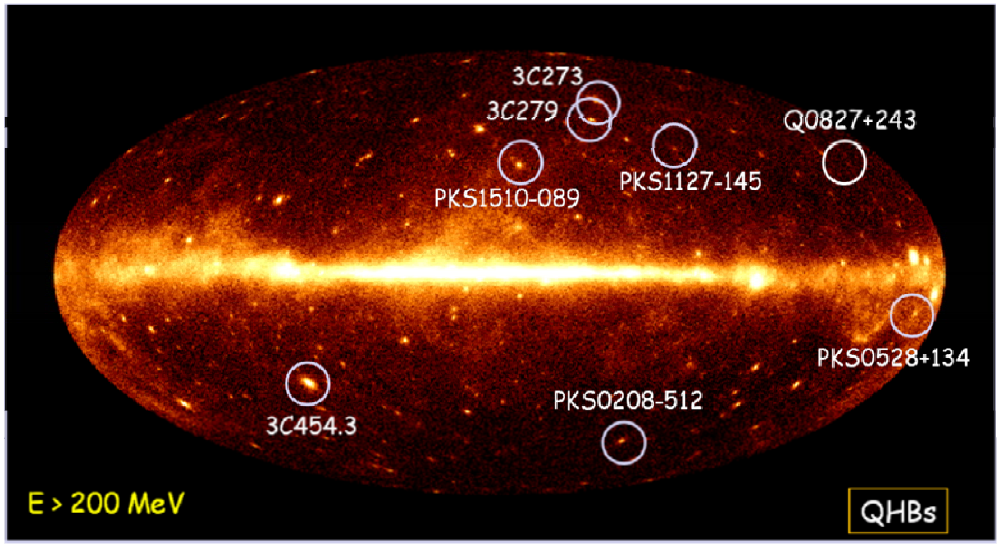
- Not consistent with typical cooling break of $\Delta\Gamma = 0.5$, but intrinsic spectral break in the energy distribution of electrons.

MW campaigns: on going!



Preliminary (Suzaku-Fermi collab)

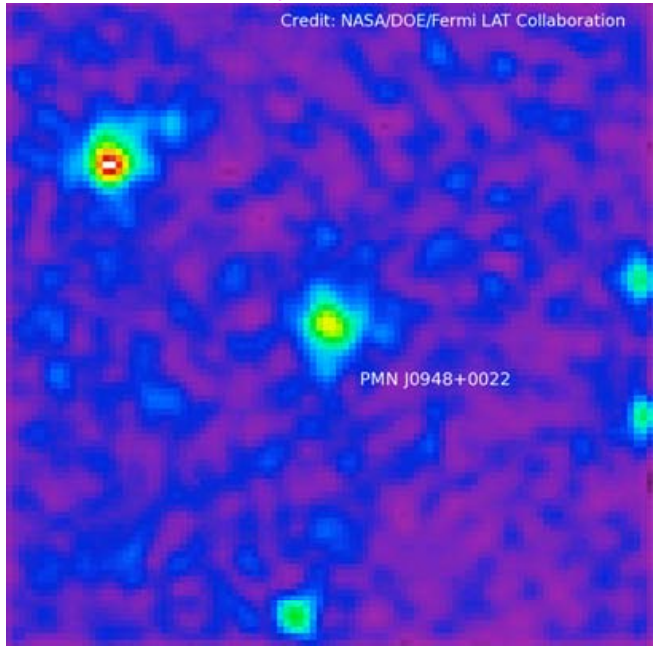
Contact: R.Sato & J.Kataoka

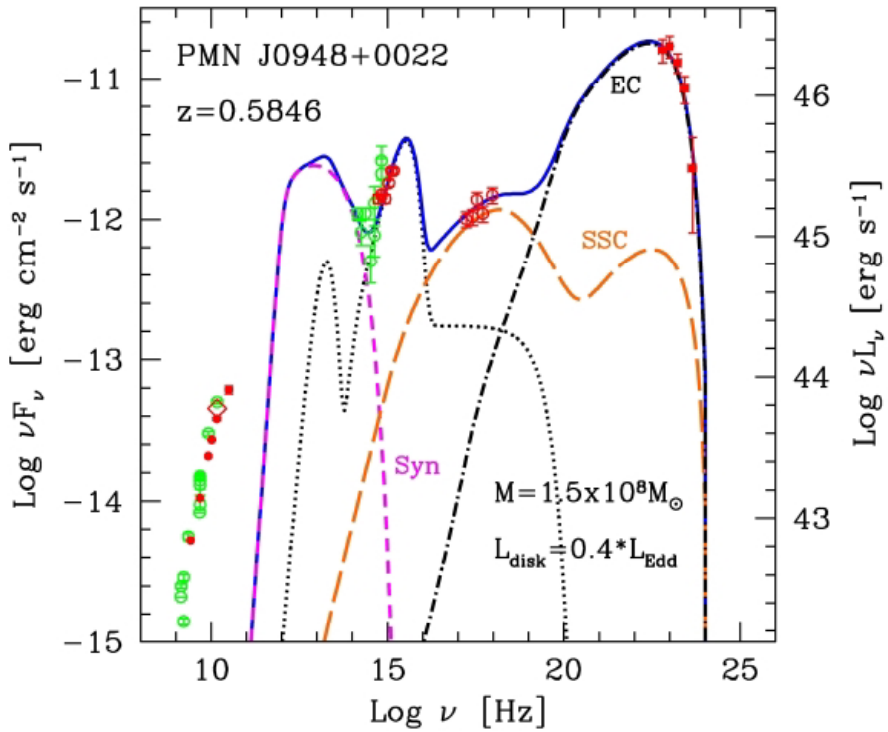


- A number of MW campaigns from radio to TeV energy bands have been conducted and ongoing.
- Thanks to Fermi's all-sky monitor, scheduling the MW campaigns now become easier than in EGRET era.

Surprise! : Narrow Line Sy1

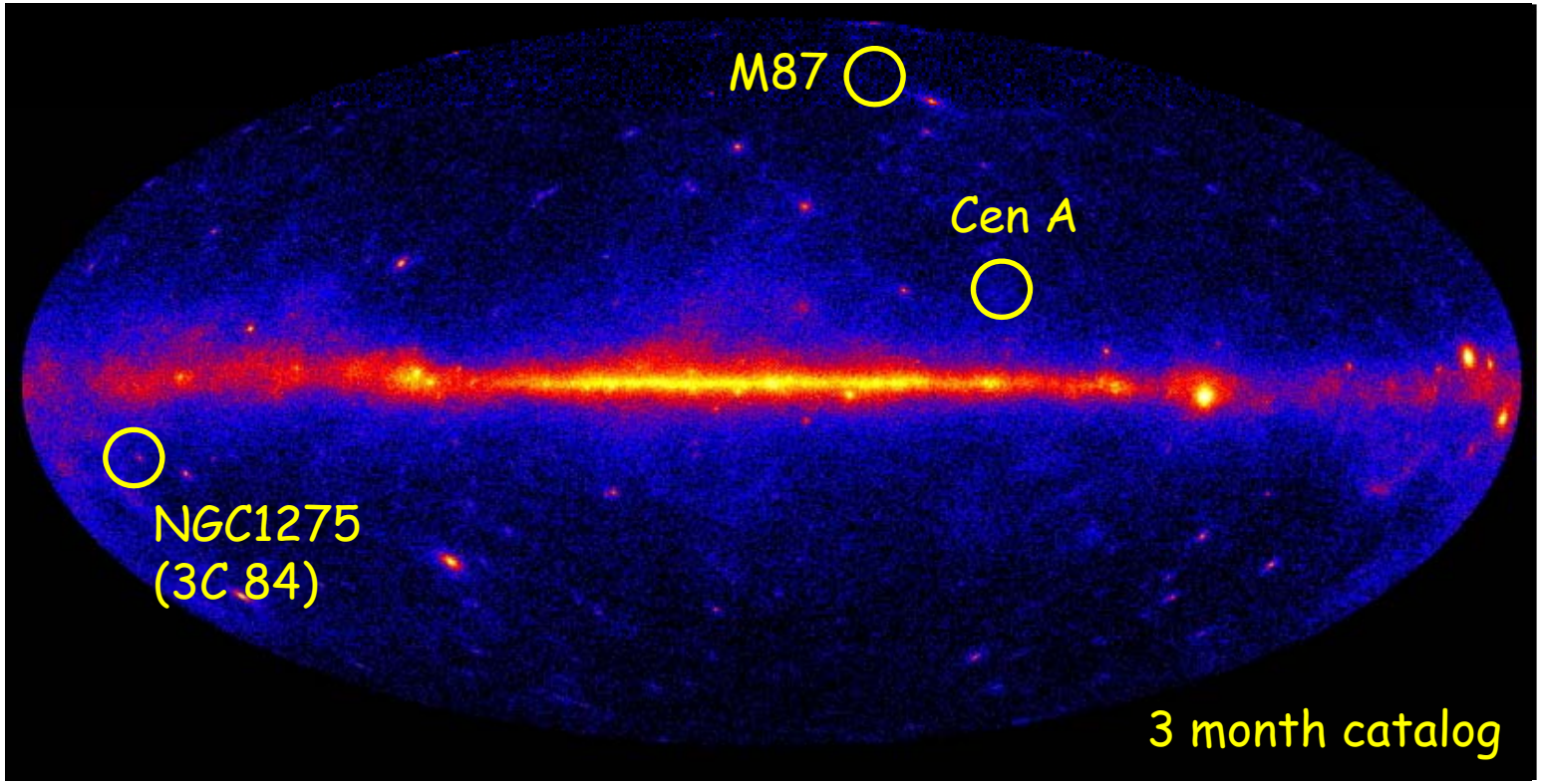
Abdo+ 2009 (contact: L.Foschini)





- Narrow line Sy-1 are usually radio quiet and hosted in spiral galaxy.
- Radio emission of PMN J0948 is, however, strongly variable, suggesting Doppler boosting w/ jet - now confirmed by LAT.
- SED modeling shows this is a typical FSRQ, although with a relatively low power.

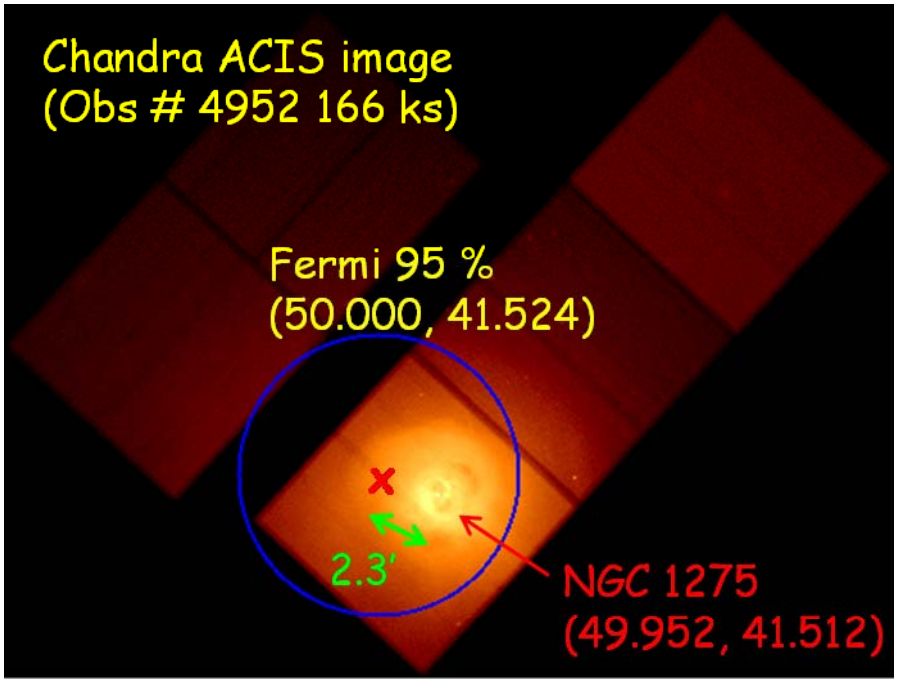
Radio Galaxies w/ Fermi

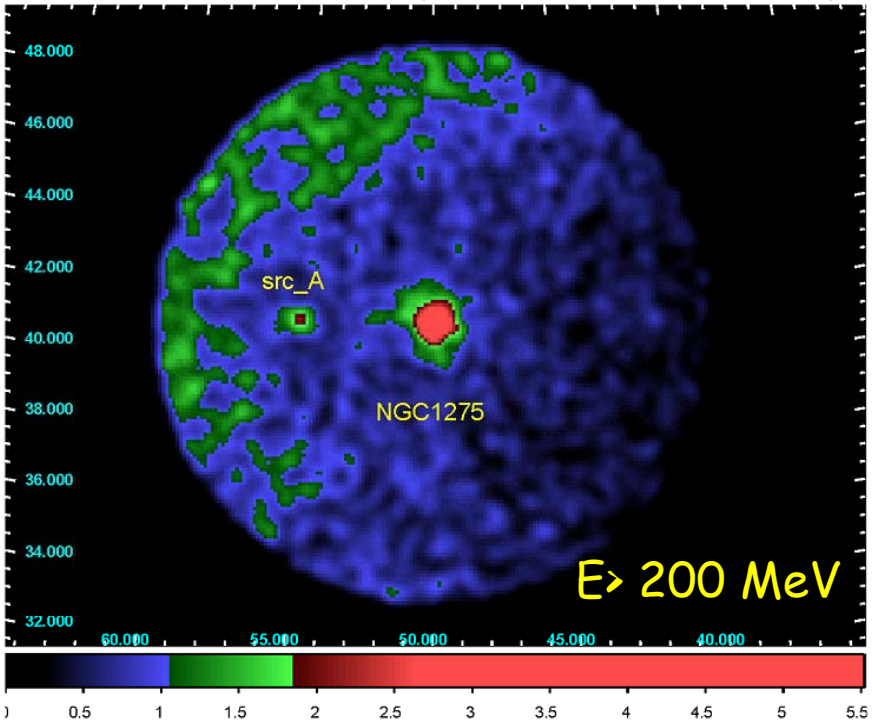


- 2 radio galaxies, NGC 1275 and Cen A have been detected in the first 3 month catalog (Abdo et al. 2009)
- Very recently, M 87 also detected at 10 σ level based on ten-months of all sky LAT data. (ApJ submitted)

NGC 1275: close-up

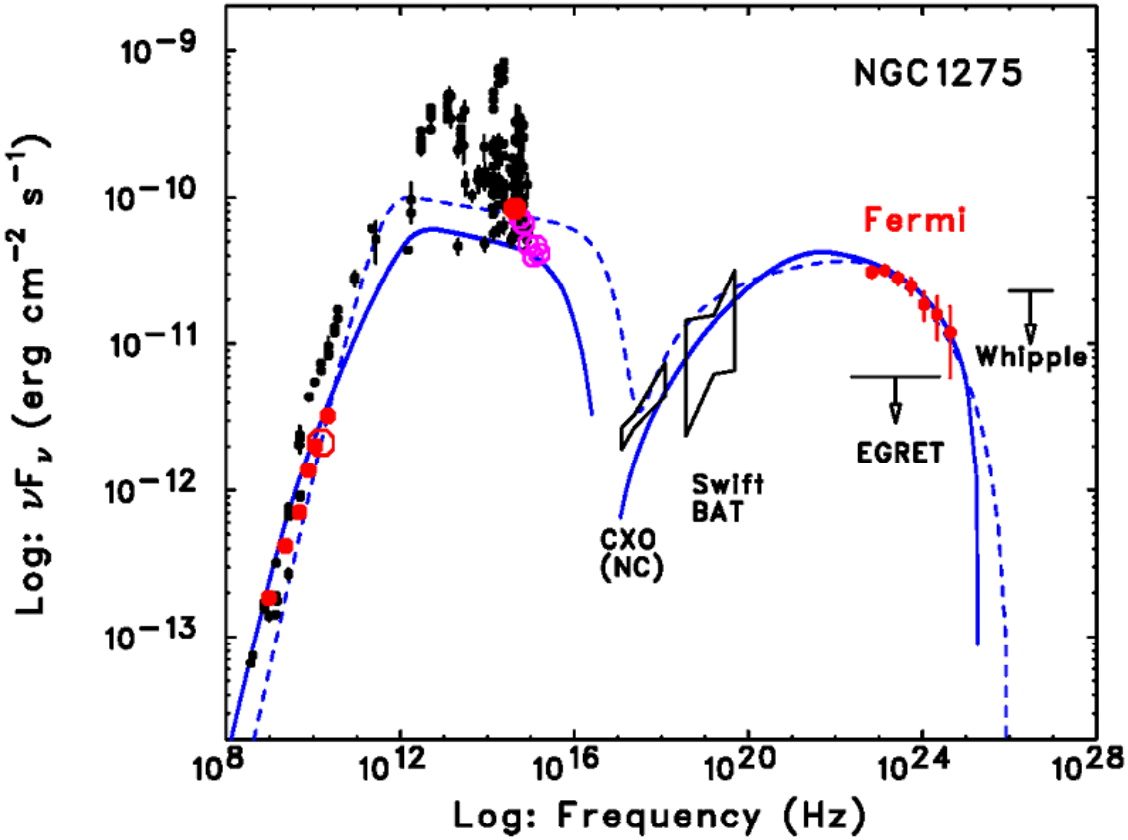
Abdo+ 2009 (contact: J.Kataoka)





- Clear excess at the position of Perseus/NGC 1275 complex .
- About an order of magnitude brighter than EGRET UL – significant brightening on decade time scale.
- The positional center of the γ-ray emission is only **2.3'** apart from the nucleus, 3C 84, well within the 95% LAT error circle.

NGC 1275: MW spectrum

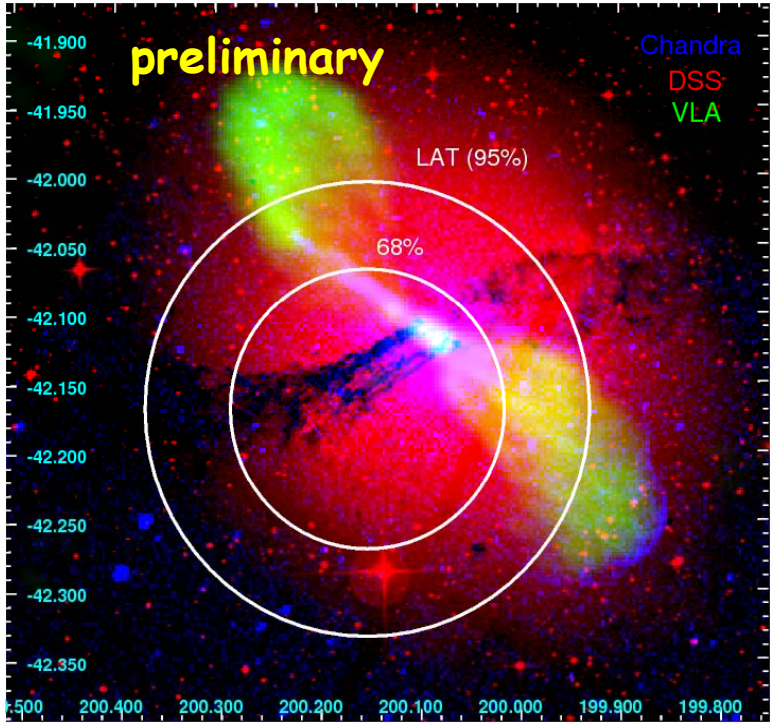


(1) one-zone SSC
B= 0.05 G
R= 0.7 pc
δ= 2.3, Γ = 1.8
L_{jet} = 2.3e45 erg/s

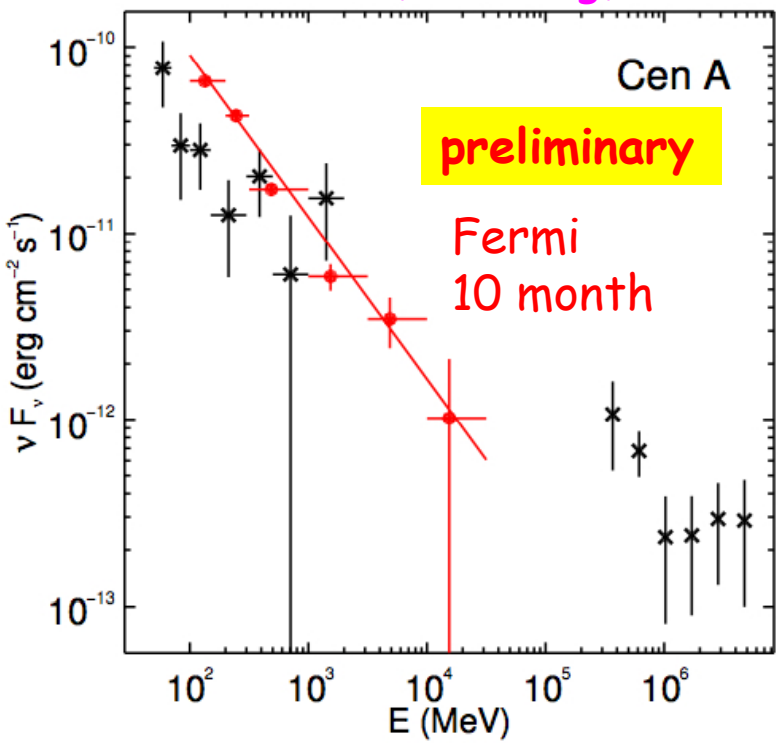
(2) Decelerating flow
B = 0.2 G
D = 0.2 pc
R = 0.01 pc
Γ = 10 -> 2
L_{jet} = 6.0e43 erg/s

- Possible unification of BL Lac and Radio Galaxies !
- Jet power close to the power required to inflate the lobes of 3C 84 against the pressure of the hot cluster gas.
  (0.3-1.2)x 10^{44} erg/s: Dunn & Fabian 2004

Centaurus A: Fermi Detection



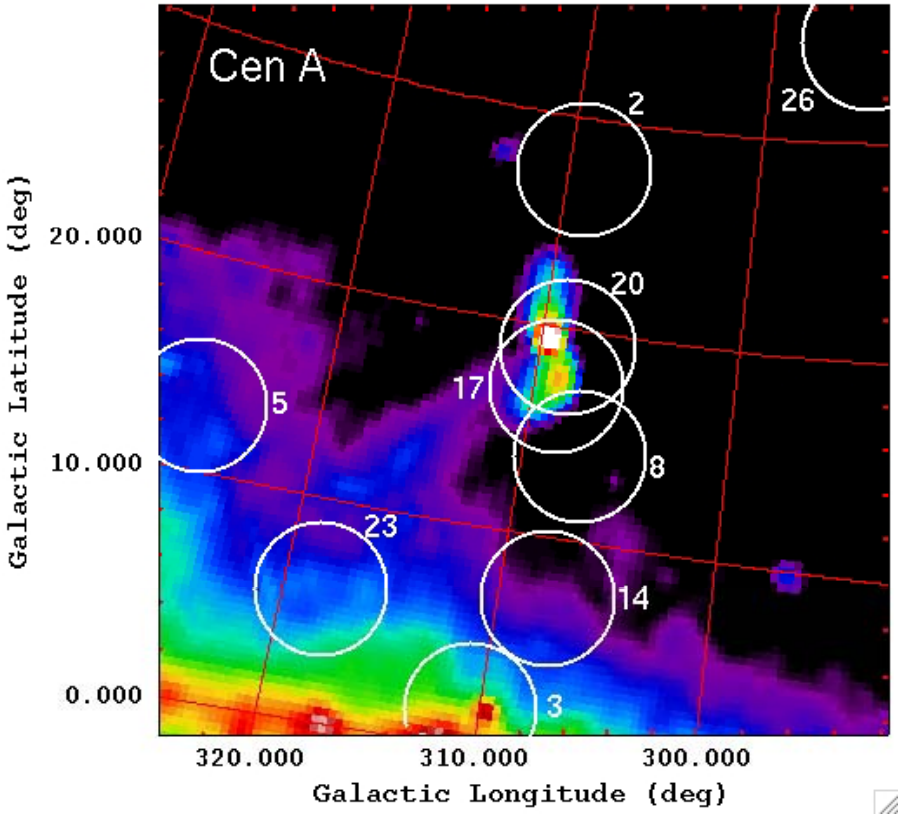
contact: F.Justin,C.Cheung,Y.Fukazawa

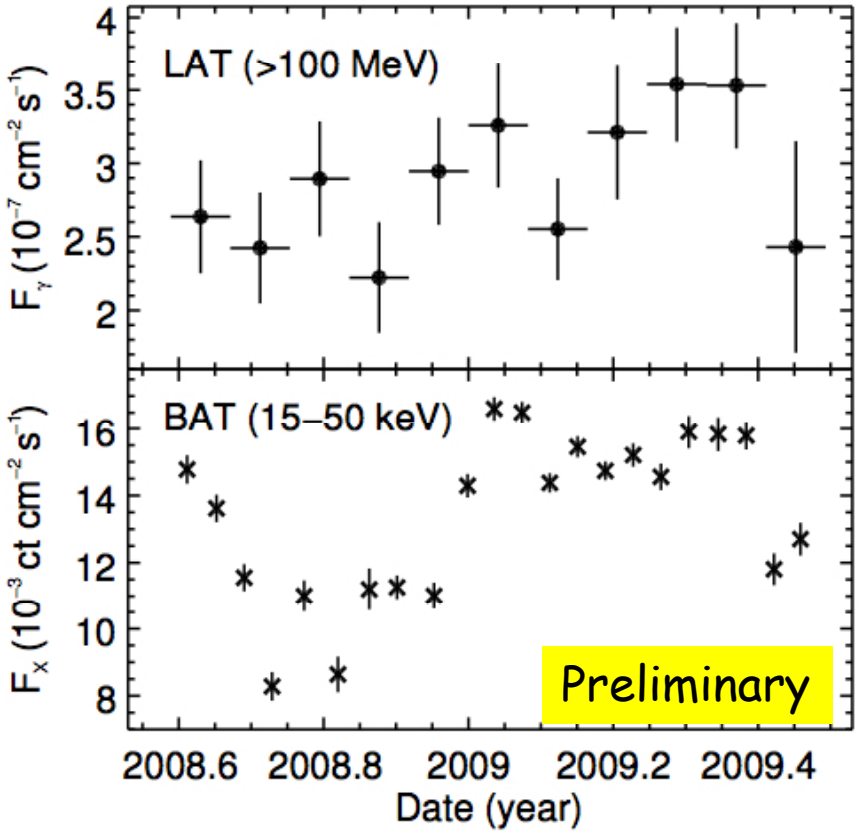


- Only clearly associated EGRET radio galaxy, but was limited to 2.1σ – 3.9σ detections on yr to sub-yr time-scale.
- Fermi error circle includes pc-scale core, jet, and the kpc-scale jet, but other sources like kpc-scale lobes may contribute.

Additional Challenges

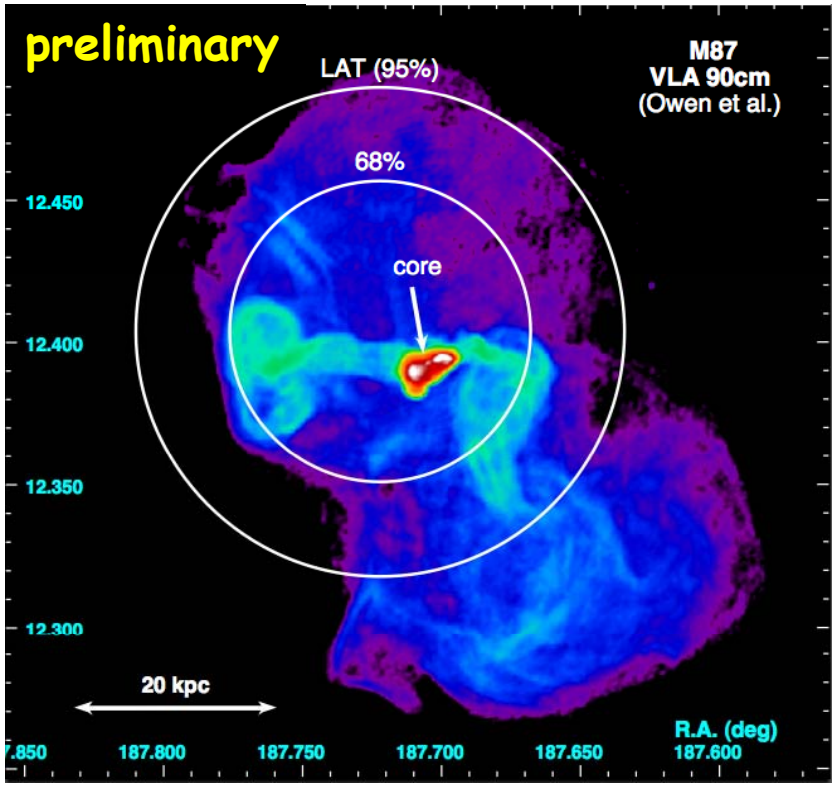
γ-ray signature of UHECRs?



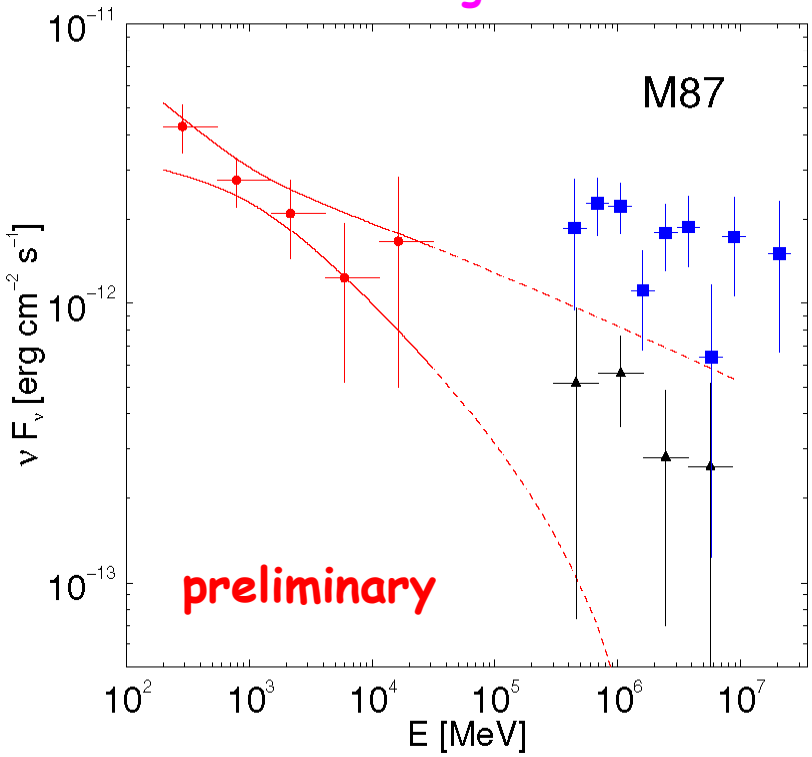


- Haslam image with directions of Auger UHECR events indicated (r=3.2d) (Moskalenko et al. 2009)
- Possible variability from NC emission detected.

M87: NEW Detection!

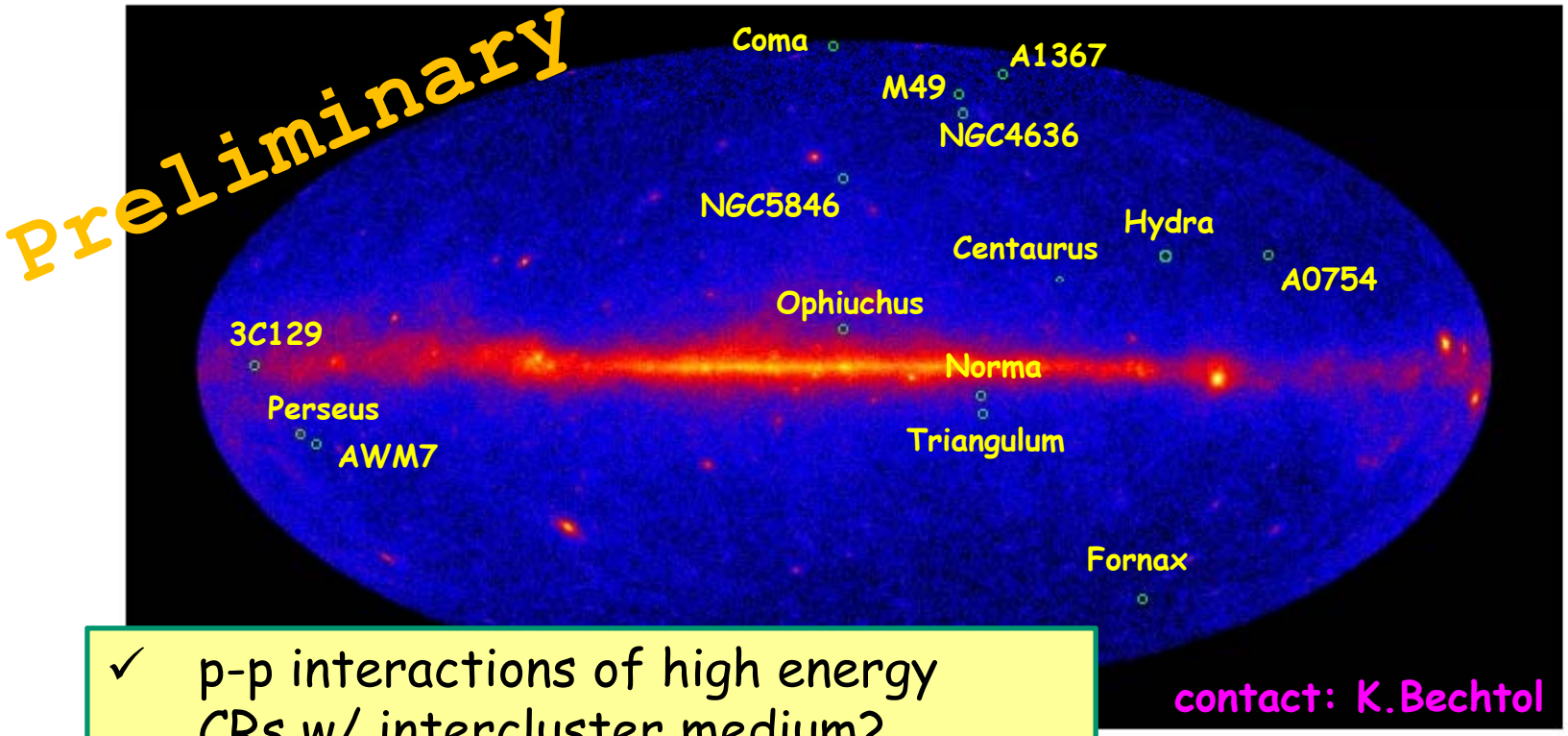


contact: C.C.Cheung & W.McConville



- Comparable w/ previous EGRET UL of 2.18×10^{-8} ph/cm^2/s – no significant variability on decade time scale?
- LAT spectrum smoothly connects w/ historical minimum TeV emission. (paper just submitted to ApJ!)

Future Challenges: Galaxy Clusters



- ✓ p-p interactions of high energy CRs w/ intercluster medium? (Berezinsky+97;Atoyan&Volk 00)
- ✓ Large scale shock in forming CG? (Totani & Kitayama 00)
- ✓ Dark matter annihilation? (Totani 04)

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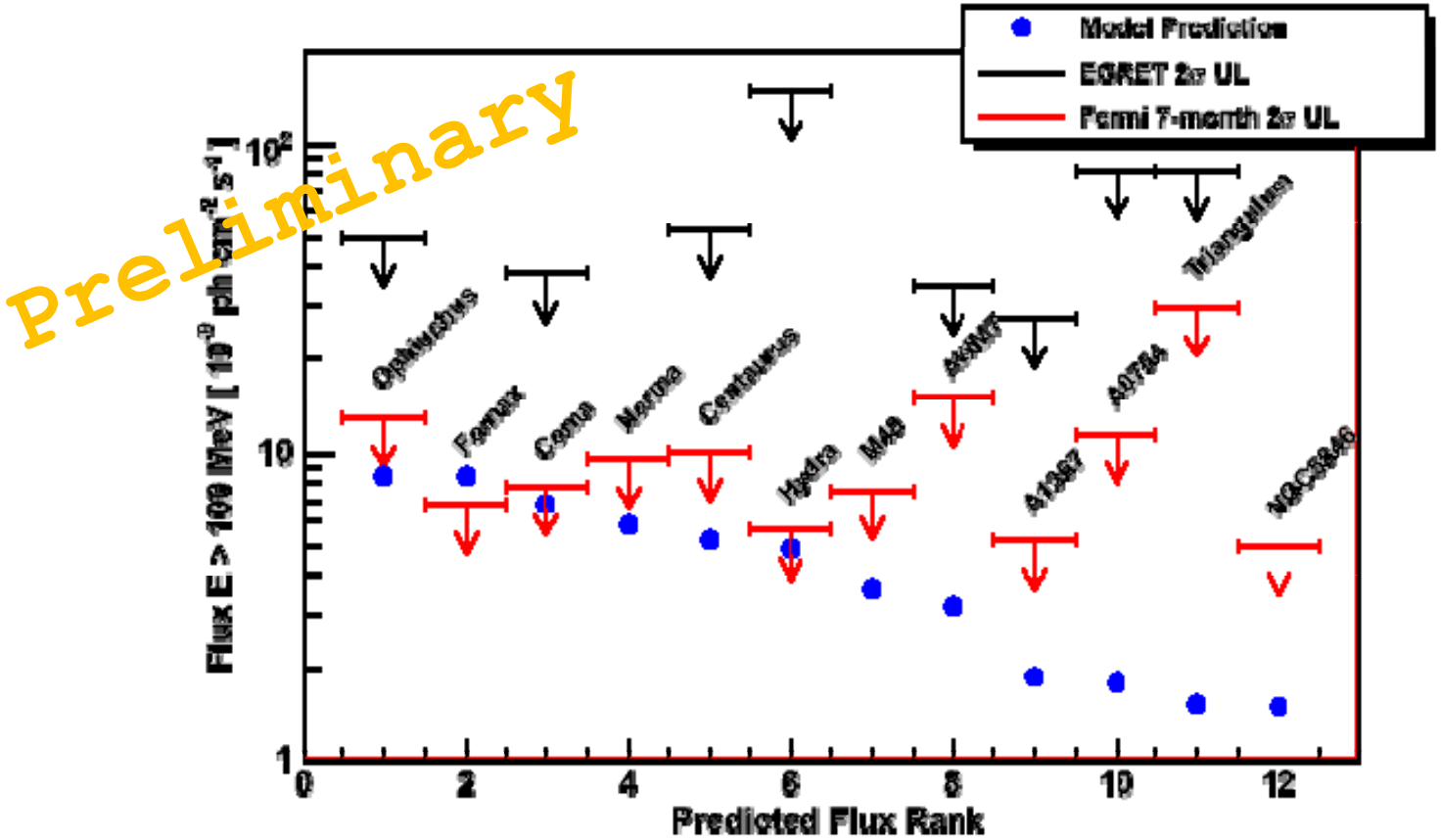
be paid, e.g.,

75
deg away … and so on!

UL from 7month Survey

Compare the Fermi 7-month flux UL to EGRET results and predicted flux



- Note, Fermi searches for extended GC emission becomes already deeper than EGRET UL, comparable to the theoretical prediction.

Summary

I have reported most recent highlights from Fermi observations of AGN jets, including future challenges to galaxy clusters.

- Excellent Fermi sensitivity and all sky monitor allow us "non-bias" survey of blazars, even in their quiescent states.
- Various MW campaigns are ongoing, providing for the first time multi MeV-TeV SED without any data gaps.
- Surprisingly, three radio galaxies and one NLSy1 have been detected so far, allowing new challenges for the unification theory of AGNs.
- Searches for diffuse and extended emission from CGs is an important challenge for future GeV gamma-ray astronomy.