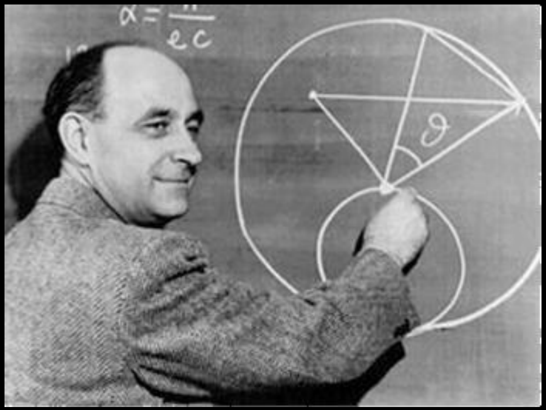


Tuomas Savolainen

Max-Planck-Institut für Radioastronomie

When Fermi met Jansky…

Max-Planck-Institut für Radioastronomie

MAX-PLANCK-GESELLSCHAFT

...A summary of the Bonn meeting

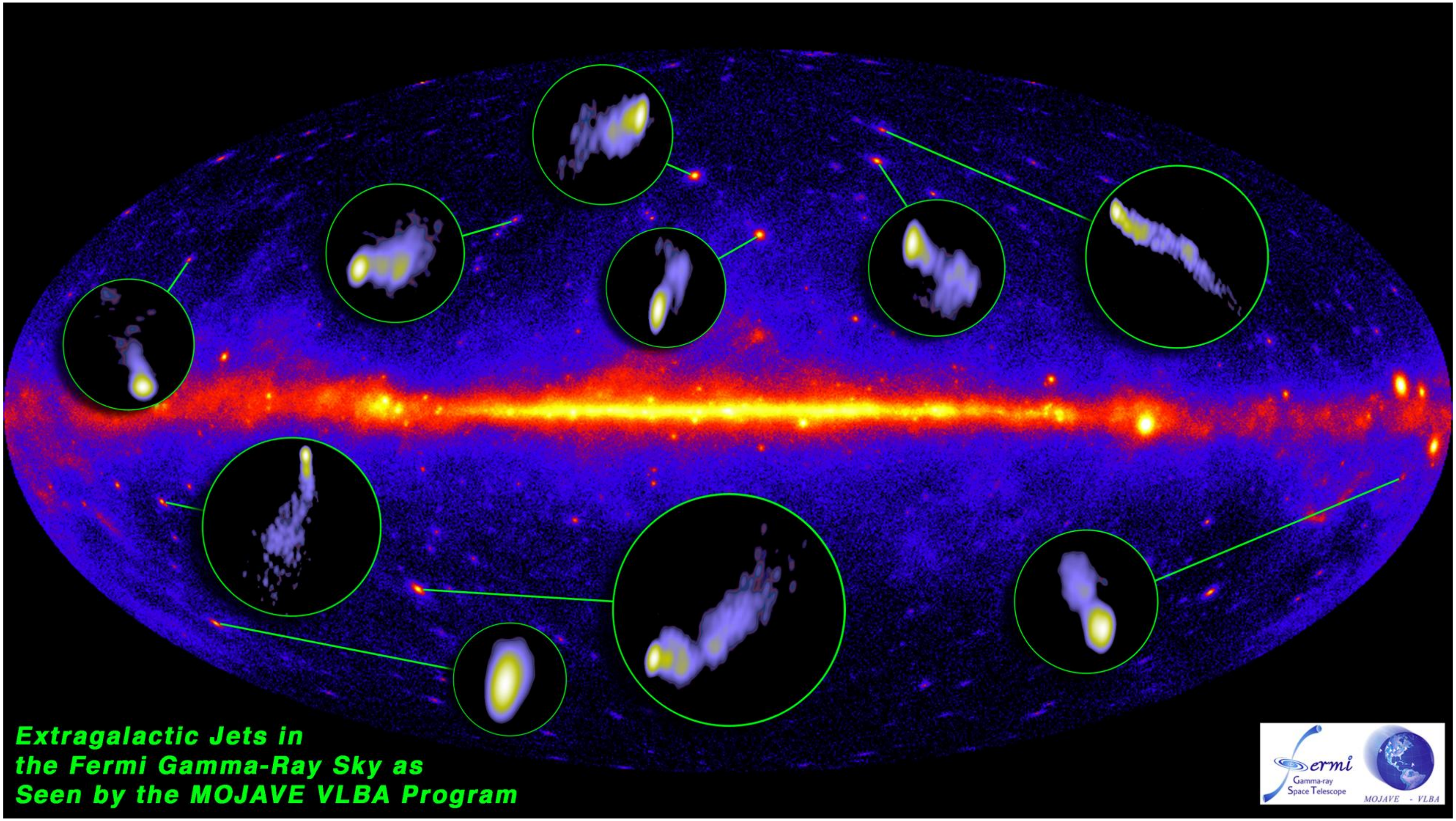
Fermi meets Jansky: AGN at radio and gamma-rays

MPIfR, Bonn, June 21-23, 2010

Let's give the credit where it's due.

Agudo Aller Aller Angelakis Arshakian Biermann Blandford Boeck Boettcher Britzen Chang Cheung D'Ammando Finke Fromm Fuhrmann Gabanyi Gasparrini Giovannini Giroletti Hardee Hovatta Hungwe Jorstad Kadler Kellermann Kino Kovalev Krichbaum Lähteenmäki Leon-Tavares Lister Lobanov Lott Lyutikov Mahony Mantovani Marscher Massi Max-Moerbeck McConville Mueller Nagai Nalewajko Nieppola Ojha Orienti Pearson Porcas Protheroe Pursimo Pushkarev Rachen Readhead Romano Ros Savolainen Scargle Schinzel Schlickeiser Sokolovsky Tornikoski Tosti Trippe Tzioumis Valtaoja Vercellone Vincent Wilms Zamaninasab Zensus Zhang

Fermi and Jansky. Why?



The Questions

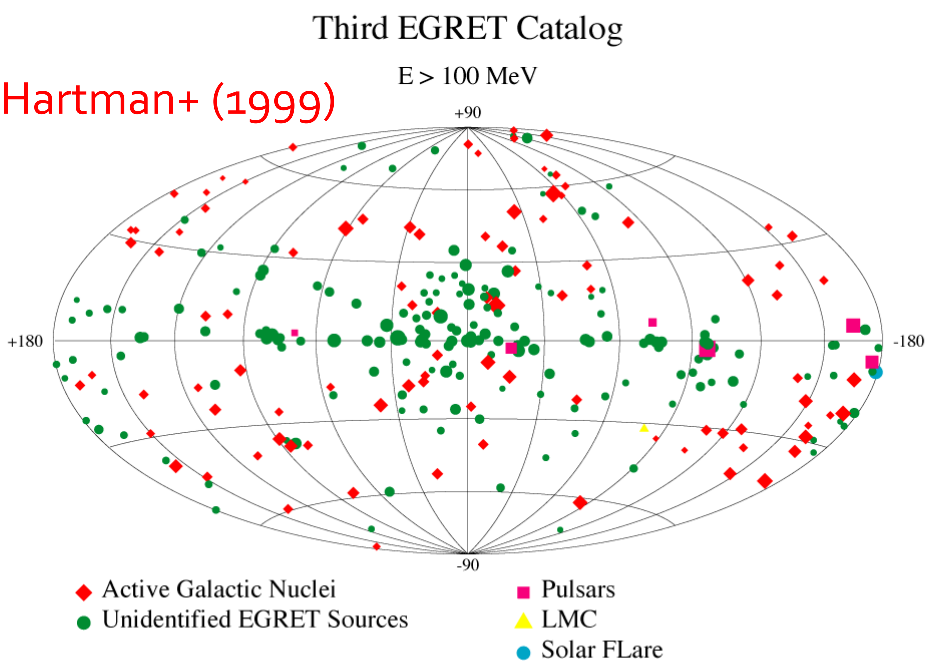
- From the EGRET era:
  - "What determines the gamma-ray brightness?"
  - "What mechanisms are responsible?"
  - "Where in the source do gamma-rays originate?"

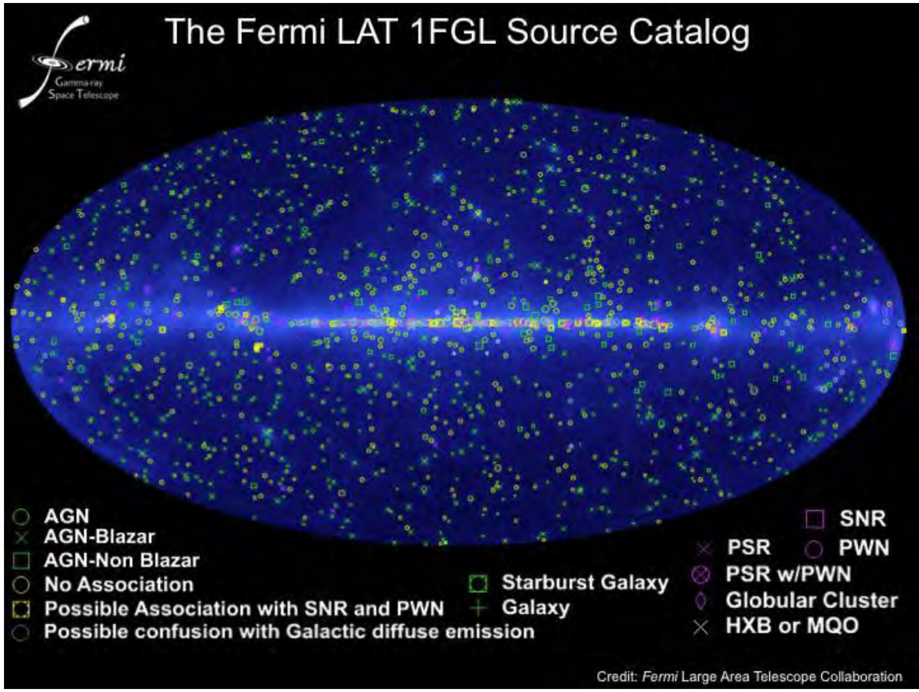
    (E. Valtaoja)
  - "What special conditions are present in the jet during broad band flaring?

    (M. Aller)
- From the preface of the FmJ proceedings:
  - " Are the radio–mm-wavelength properties and the -ray brightness correlated just because the radiation at both extremes of the spectrum is emitted from a relativistic jet? Or are the two emission processes more tightly knit with a possibly co-spatial production of both?"
  - "We hope that the workshop serves to converge the views about this and other open questions or at least helps to outline what observations are needed to settle the long-standing debates."

From 3EG to 1FGL

Hartman+ (1999)





Fermi collab. (2010)

3EG:

- 271 sources, including:
  - 66 high-confidence blazar identifications
  - 27 possible blazar identifications
  - 1 likely radio galaxy (Cen A)
  - 170 unidentified sources.

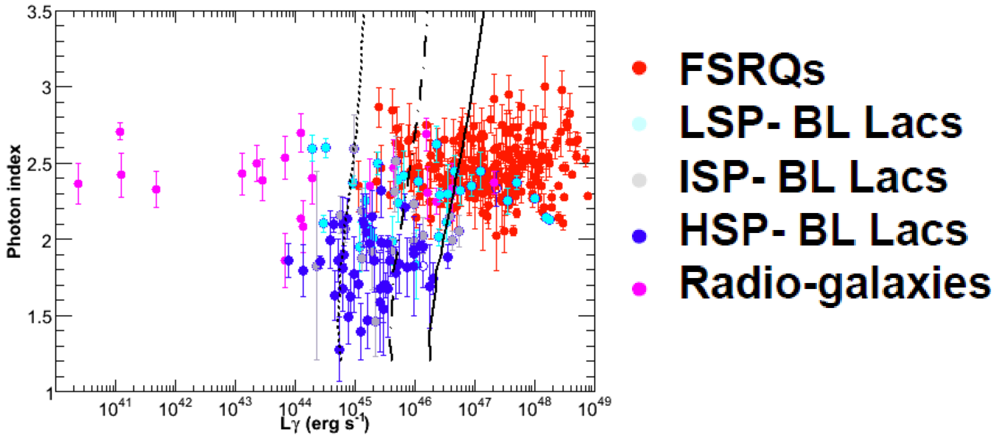
1FGL:

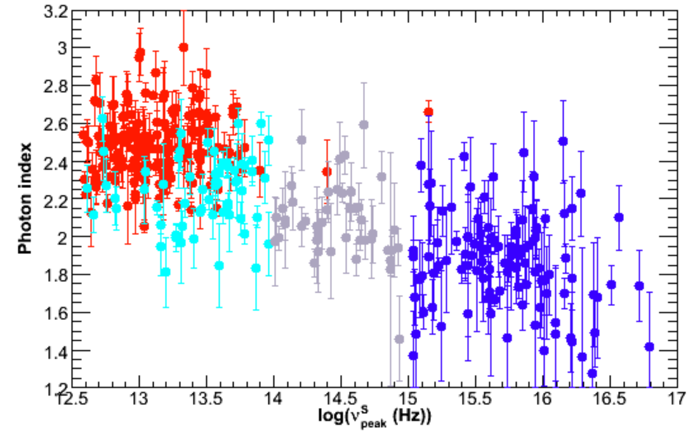
- 1451 sources, including:
  - 663 high-confidence blazar associations
    - 281 FSRQs
    - 291 BL Lacs
    - 61 of unknown type
    - 30 other AGN

1FGL – Properties of γ-ray AGN

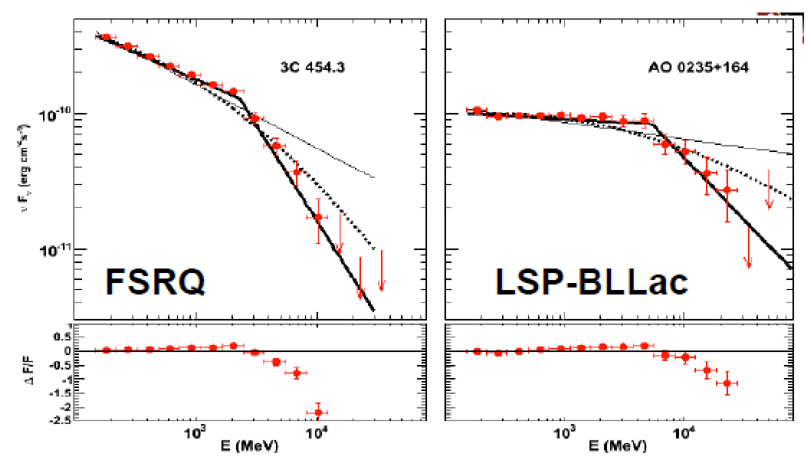
- Gamma-ray spectra:
  - Photon index correlates with blazar class

Lott+





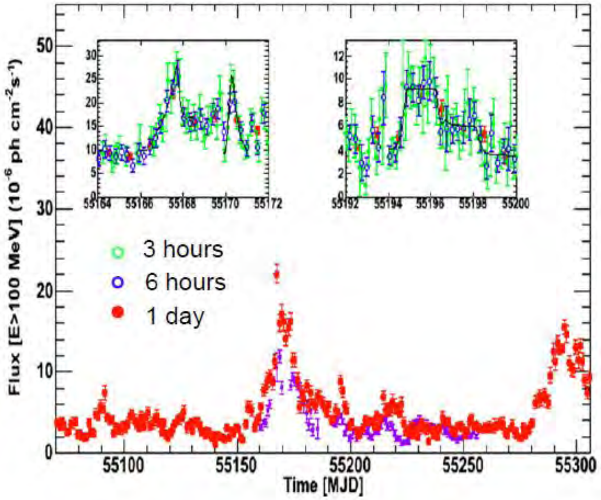
- Many FSRQs and LSP-BL Lacs show broken power-law spectra
  - $\Delta\Gamma \sim 1 \rightarrow$ not from radiative cooling
  - Due to a break in the underlying particle energy distribution?
  - KN-effect?
  - Photon-photon absorption: Intrinsic? Or on HeII Lyman recombination continuum + lines (Poutanen & Stern 2010) ?

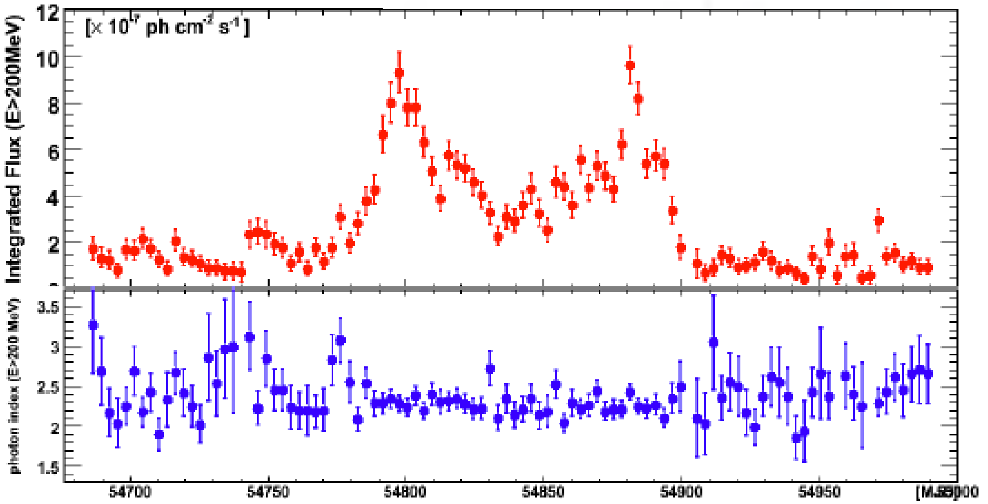


1FGL – Properties of γ-ray AGN

- Revolution in GeV variability studies – "All the sky (almost) all the time"
- Variability time scale range from months to hours
- Power-law PSD of slope -1..-2
- Relative constancy of photon index

3C454.3

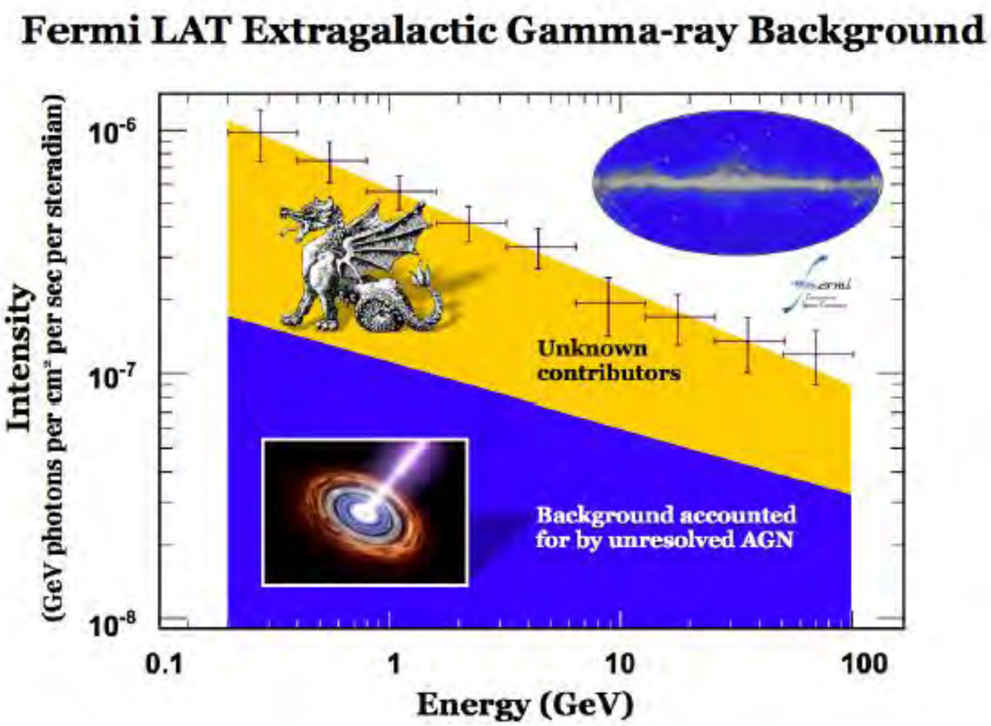




Lott+

Extragalactic γ-ray background

- Featureless EGB spectrum
- AGN account only <30%
- 70% from unknown sources (SF galaxies?) or truly diffuse (DM annihilation, intergalactic shocks?)



Tosti, Ajello+

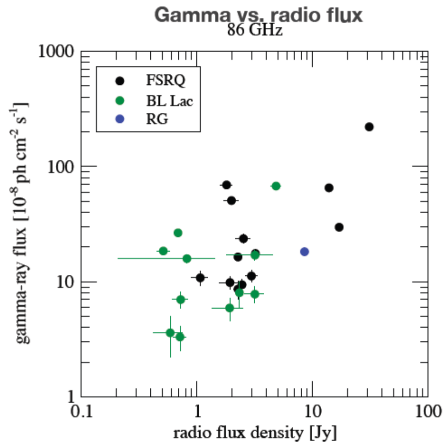
Enter Jansky (and friends)

Radio and gamma-ray correlations

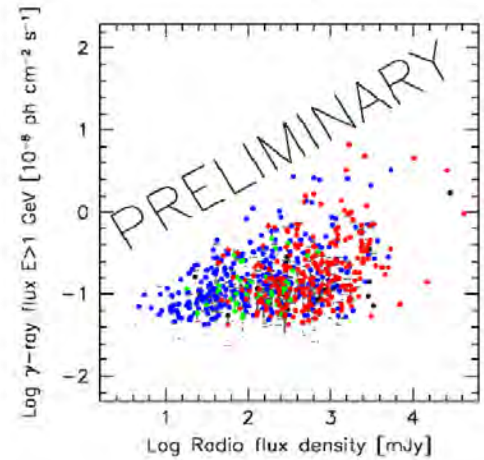
Images courtesy of NRAO/AUI, MPIfR, IRAM, Caltech, ATNF, U.Michigan, J. Wagner

F_{radio}-F_{γ} correlation

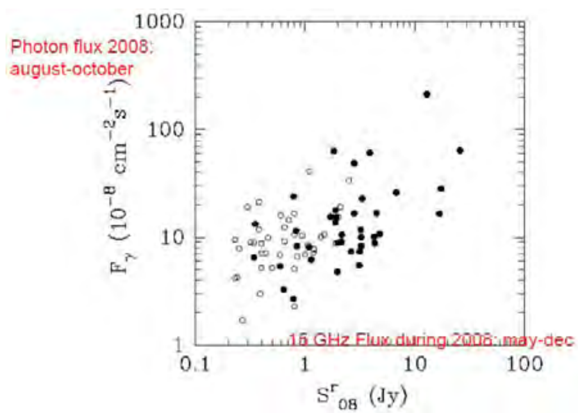
- Several studies in the EGRET era with inconclusive results
- In Bonn: several studies with different radio samples at different frequencies using non-simultaneous and quasi-simultaneous data – ALL except one (WMAP7 data; Gasparrini+) find a correlation
- MC simulation results confirm the intrinsic significance (Giroletti+, Max-Moerbeck+)



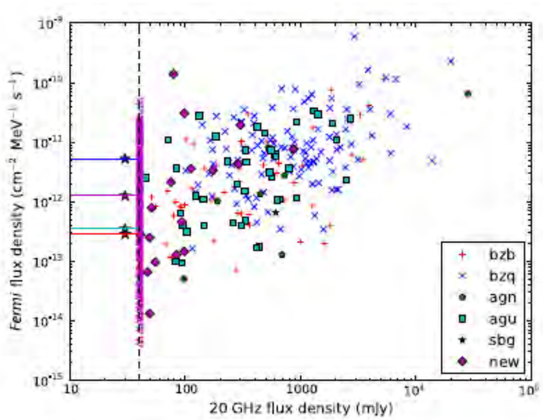
LBAS vs. 86 GHz radio: (Angelakis+)



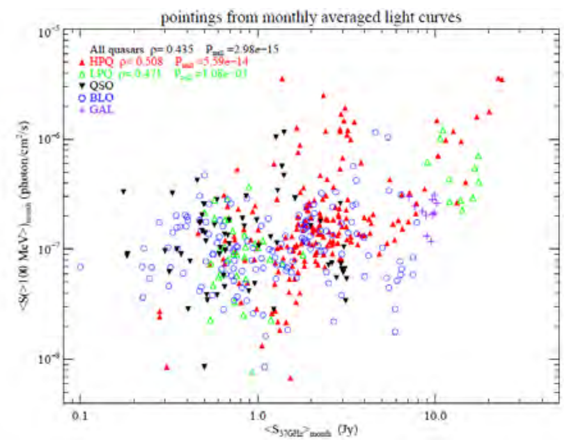
1FGL vs. 8 GHz radio: (Giroletti+)



LBAS vs. 15 GHz radio: (Kovalev+2009)



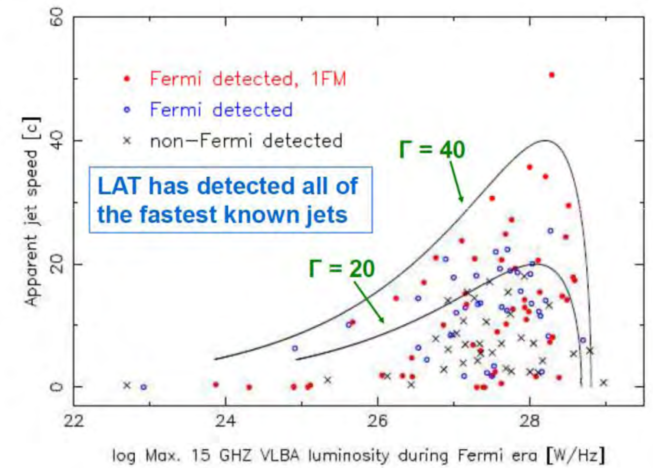
1FGL vs. 20 GHz radio: (Mahony+)

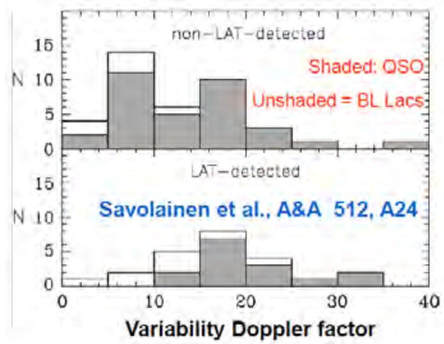


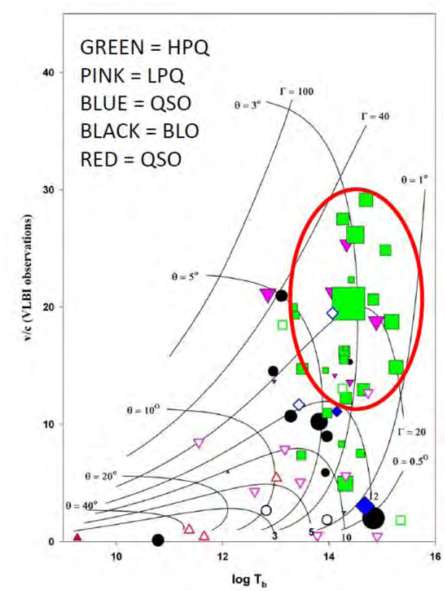
1FGL vs. 37 GHz radio: (Leon-Tavares+)

Infering jet properties of γ-ray sources

- Gamma-ray emission is directly connected with beamed relativistic jets
- Single-dish and VLBI monitoring surveys* provide measures of several key parameters of these jets (δ, θ, Γ, B)
- Gamma-ray brightest blazars tend to have (Lister+, Valtaoja+, Ojha+, Hovatta+):
  - Faster than average apparent jet speeds, high T_b, large apparent opening angles → higher than average Doppler factors, preferred (small) viewing angles, high Lorentz factors (?)
  - High activity state in radio
  - Lister: Unequal Doppler boosting in radio and gamma-rays destroys linear flux-flux correlation and produces an upper envelope
- Need Doppler factor measurements for larger samples!

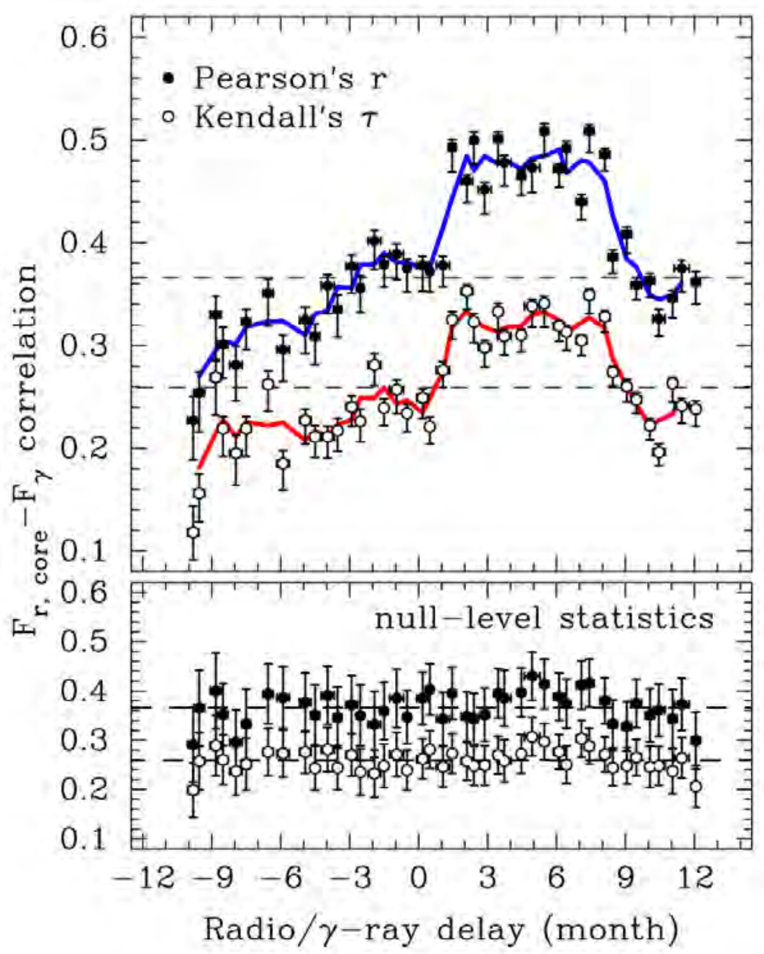






*) UMRAO, Metsähovi, OVRO, F-GAMMA, MOJAVE, TANAMI, Boston, VIPS…

Time-dependence in F_{radio}-F_{γ} correlation

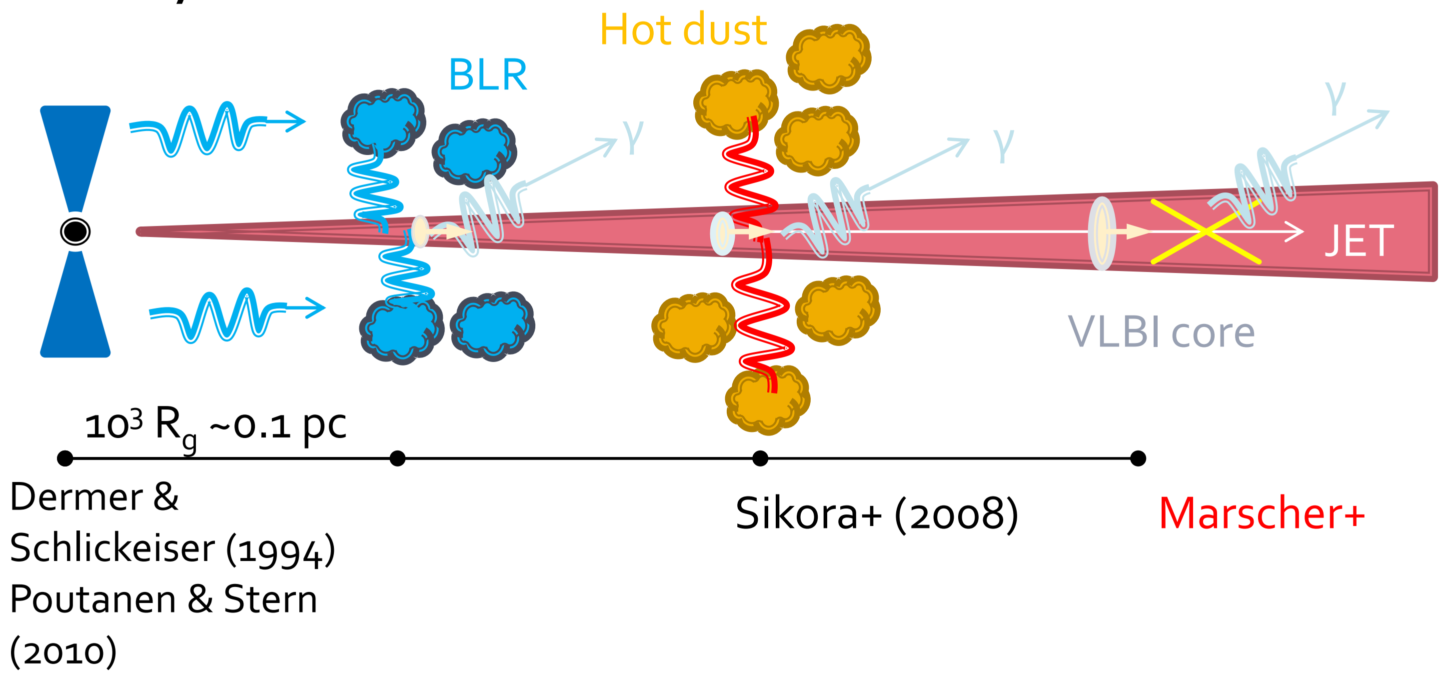


Pushkarev+

- Overall flux-flux correlation does not tell much about the physical connection between radio and gamma-ray emission – except that both occur in a jet and exhibit similar amount of Doppler beaming
- On the other hand, time-dependent correlation demonstrated between 15 GHz VLBA core flux and gamma-ray photon flux suggests that radio and gamma-ray events are connected (Pushkarev+)
- A delay of few months with 15 GHz flux lagging – most likely due to synchrotron opacity
- Shorter delays expected at higher frequencies → mm-wavelength data is important!

Localization of the Gamma-ray production site

- The central question of the FmJ workshop: where do they come from?

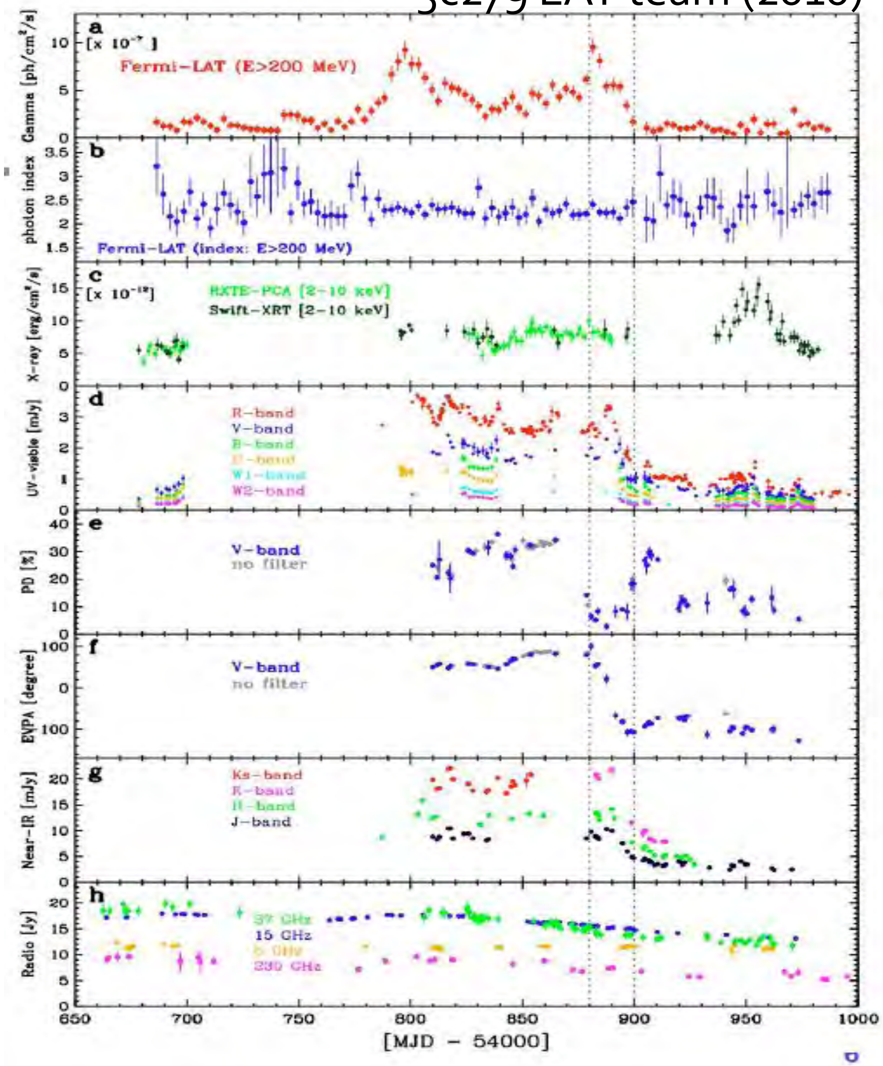


- Multiple sites in a single jet?
- Different regions for different source classes?

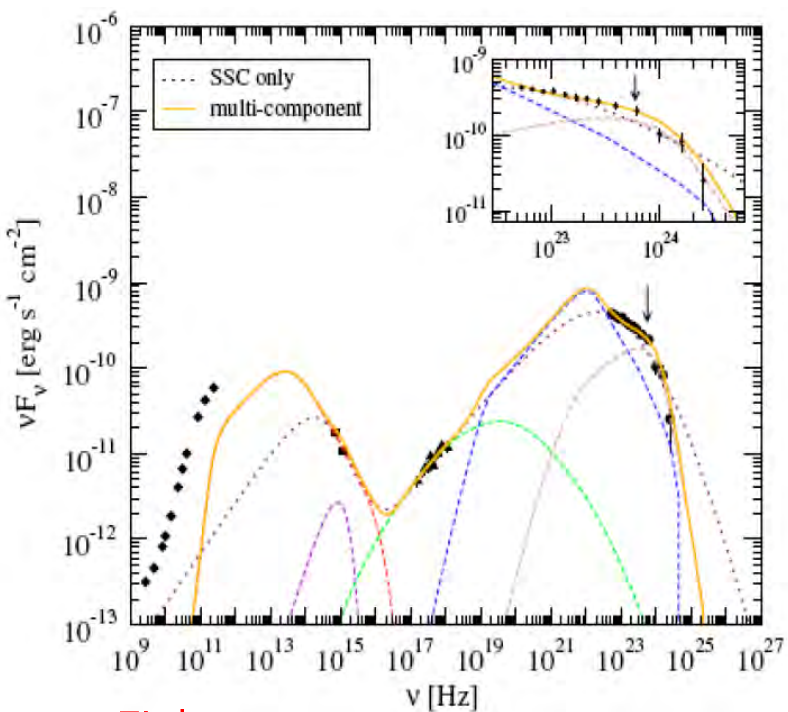
Need multi-wavelength data

- *Fermi* and AGILE missions serve as rallying points for large multi-wavelength efforts. Exactly what is needed!
- Unprecedented data sets for 3C279, 3C454.3, and many others (Fuhrmann+, D'Ammando+, Vercellone+)
- Data across the whole electromagnetic spectrum (far-IR and MeV still usually missing). A LOT of observatories participating.
- Includes total flux, polarization, and VLBI

3c279 LAT team (2010)



Localization…: SEDs and gamma-ray spectra

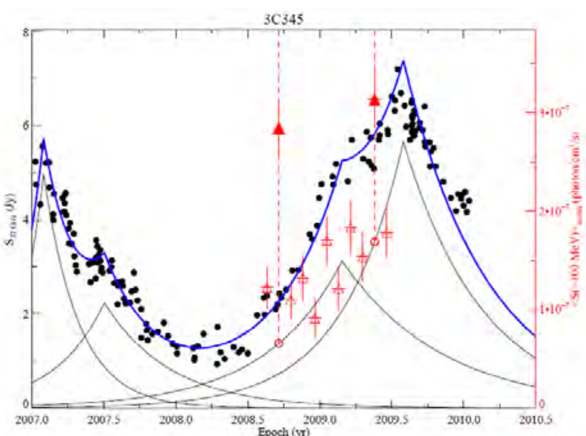


Finke+

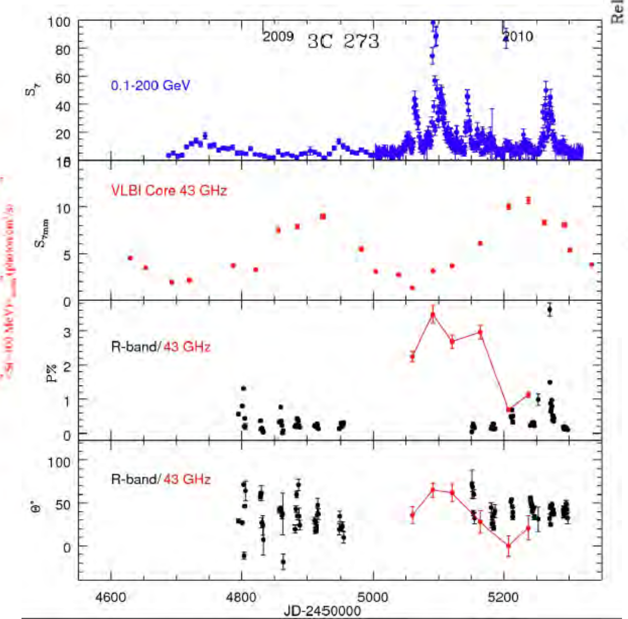
- Succesful modeling of FSRQ SEDs typically requires strong external photon fields which are present in the BLR
- Variability constrains the emission region size
- Most models are optically thick at radio frequencies
- The break in the gamma-ray spectrum at ~ a few GeV may be due to pair production on HeII recombination continuum and lines. This would place the emission region at ~0.1 pc from BH. (Poutanen & Stern 2010)

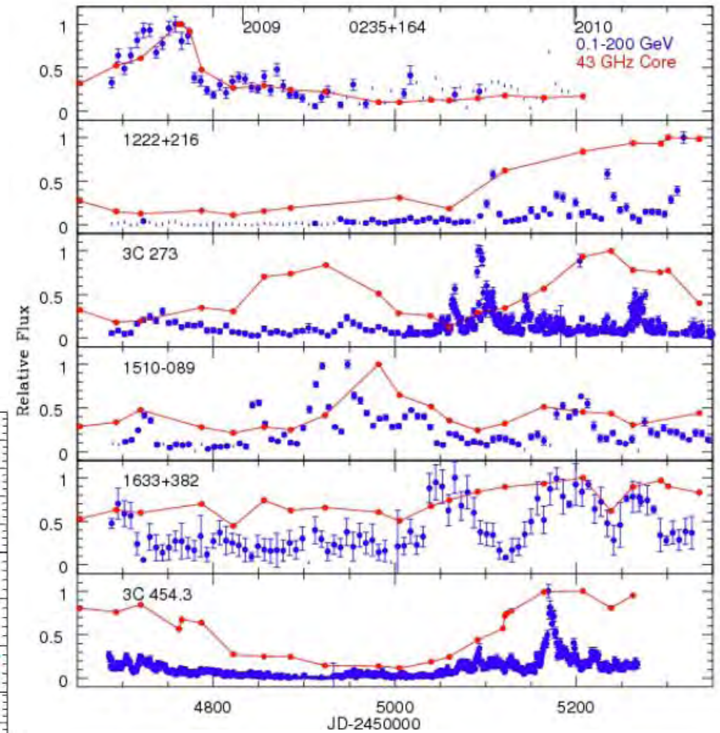
Localization…: mm – optical - gamma-ray connection

- Extended high gamma-ray states coincide with increase in mm-core flux (Jorstad+)
- Strongest gamma-ray flares typically during rise/peak of mm flare (Valtaoja+)
- Degree of linear polarization in mm-core increases during gamma-ray activity. Flare in degree of optical pol. at the time of a large gamma-ray flare (Jorstad+, Agudo+)



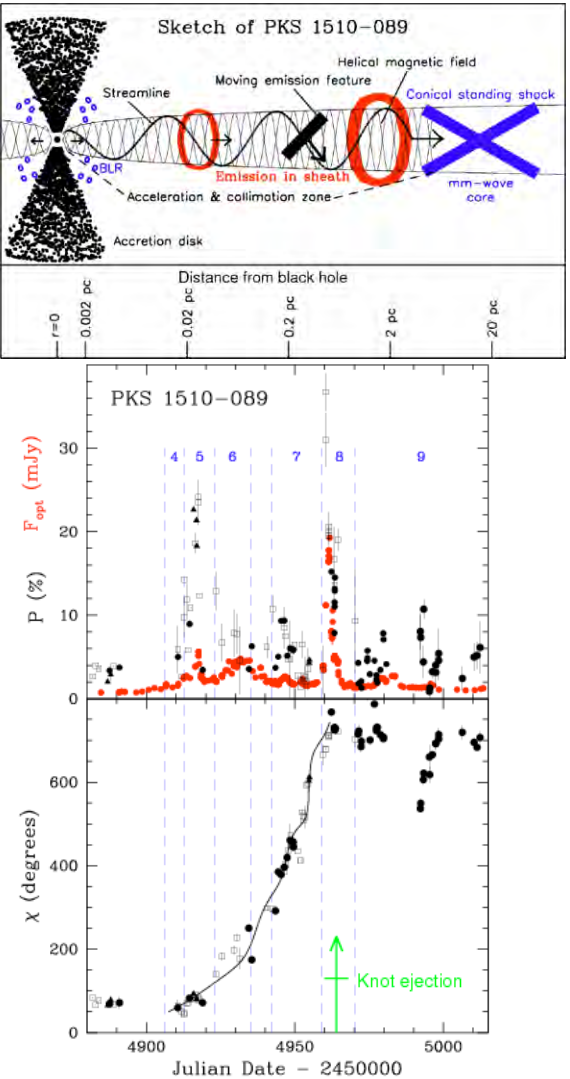
Leon-Tavares+



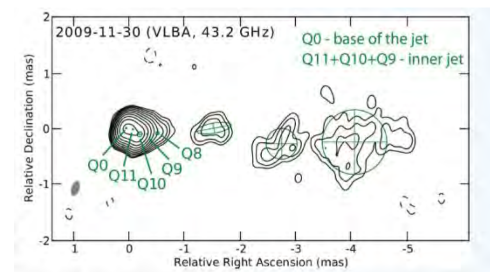


Jorstad+

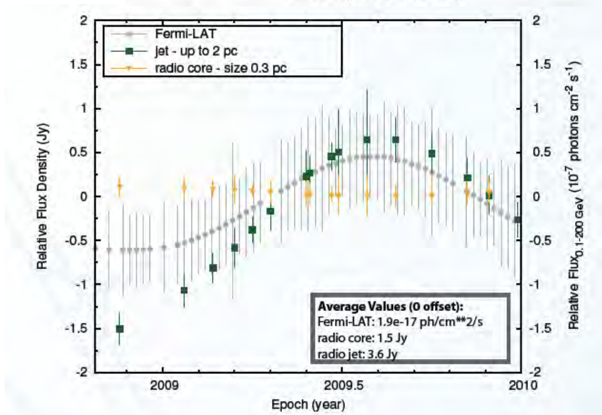
Localization…: mm – optical – gamma-ray connection



- PKS1510-089: >700 deg rotation in optical EVPA – ends at the time large gamma-ray flare. Simultaneously, a VLBI knot is ejected from the core. Single knot responsible for the outburst.
- Model: Emission feature following a spiral path through toroidal B field and finally colliding with a standing shock 17 pc from the BH.
- Disturbance sees different local seed photon fields during its propagation. (Marscher+)



- 3C345: Increasing trend in gamma-rays matches that of the inner jet at 43 GHz – not the core! Not a single emission region. (Schinzel+)

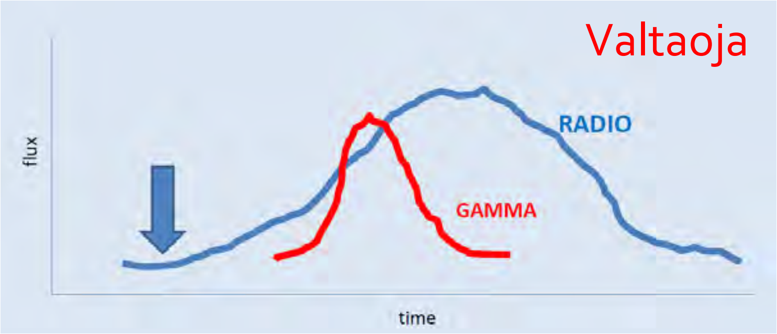


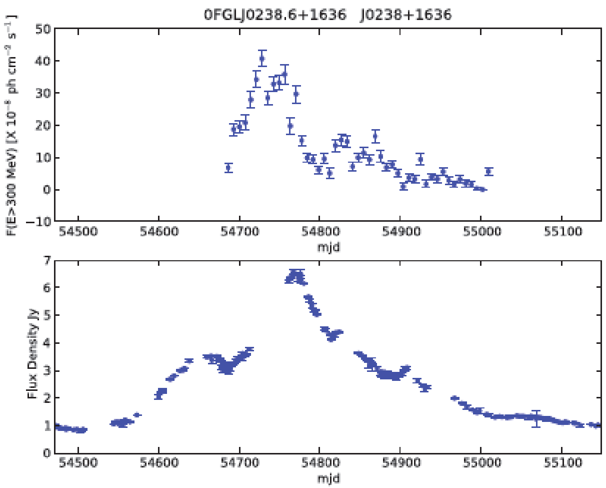
Did the views on γ-ray emission site converge during FmJ?

- Well, no.
  - "Fermi divorces Jansky" – M. Böttcher
- However, some agreement over the required future work:
  - Need test statistics on the connection between gamma-ray flares and VLBI core variability / component ejections / optical flares / EVPA changes
  - Get as complete simultaneous MW coverage as possible. Fill in the SED gaps in far-IR and MeV. Cover at least typical flare time scale.
  - Observations in radio/mm can constrain physical parameters of the jet. Use these as input for SED modeling. (Sokolovski+)
  - Challenge to modelers: Model random process time series!

What to correlate?

- Characteristic time scales are different in radio/mm and gamma-rays. Gamma-ray variability typically faster. (M. Aller, Valtaoja)
- Long-term light curves are needed (Readhead)
- Proper methods for radio-gamma-ray time series cross-analysis (Scargle)
- Are there "flares" at all? Or just random fluctuations?
- Radio total flux density may not be the best quantity to correlate with gamma-rays. Use instead polarization "events" and VLBI ejection epochs as time stamps (Marscher, Kovalev)



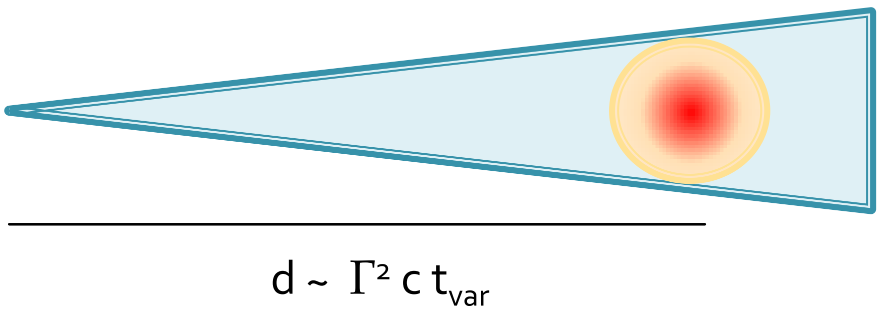


Max-Moerbeck+

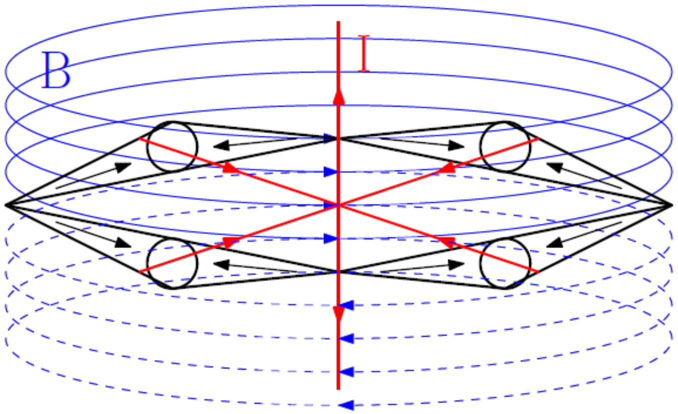
Theory, simulations & modeling

Models for blazar zone

- Blobs filling the jet
  - Fast γ-ray variability implies small emission region size and short distance from the central engine
  - Requires Lorentz factor > 50 to avoid photon-photon absorption in some TeV sources – contradiction with VLBI obs.

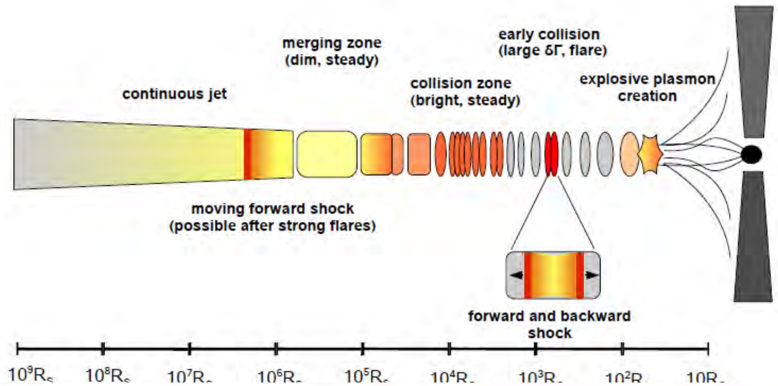


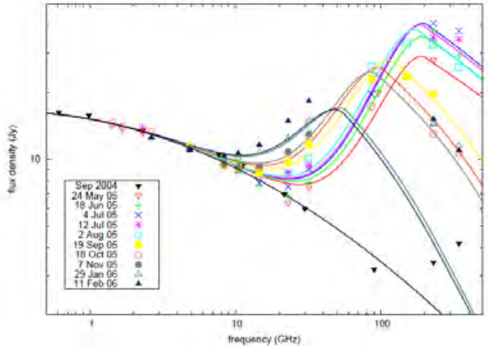
- Localized energy dissipation: jets-in-jet (Nalewajko)
  - Perpendicular flows within Poynting-flux dominated jet (Giannios+2009)
  - Emission region does not fill the jet
  - $\Gamma_{em} \sim \Gamma_j \Gamma_{co}$
  - Powered by magnetic reconnection



More models for blazar zone

- Colliding plasmons (Rachen+)
  - Dense series blobs with a distribution of velocities and masses (based on Spada+01)
  - Fitted flare evolution in 3C454.3 – no synchrotron losses dominated stage

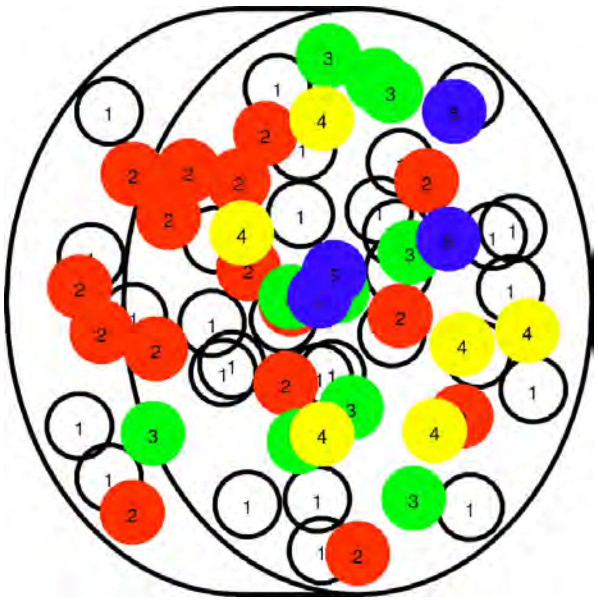




$$r_{\rm col} \sim \frac{\Gamma_{\rm jet}^2 c}{f_*(\delta\Gamma/\Gamma)}$$

$$L_{\rm syn} \propto (\delta\Gamma/\Gamma)^{5\ldots8}$$

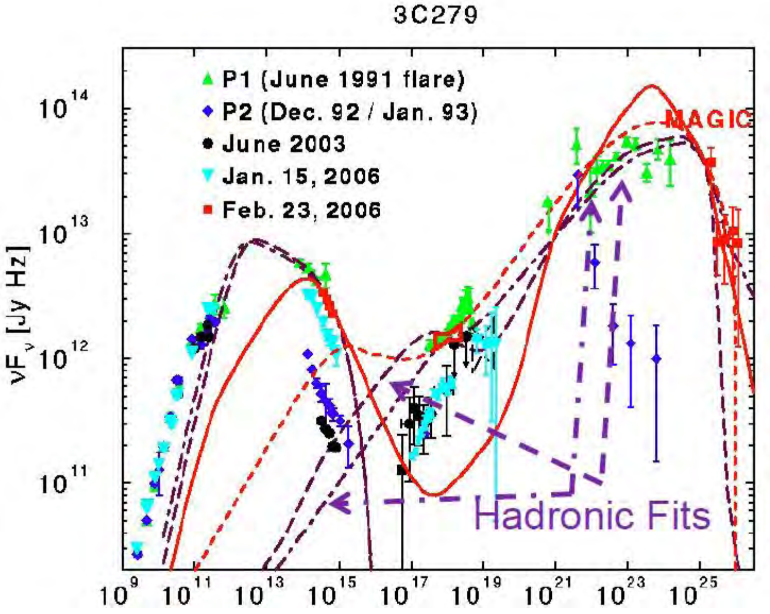
- Turbulent cells (Marscher+)
  - Standing shock energizes turbulent flow; maximum energy varies from cell to cell
  - Number of emitting cells depends on frequency; shorter variability time scales at higher frequencies
  - Higher and more variable linear polarization at high frequencies (as observed)

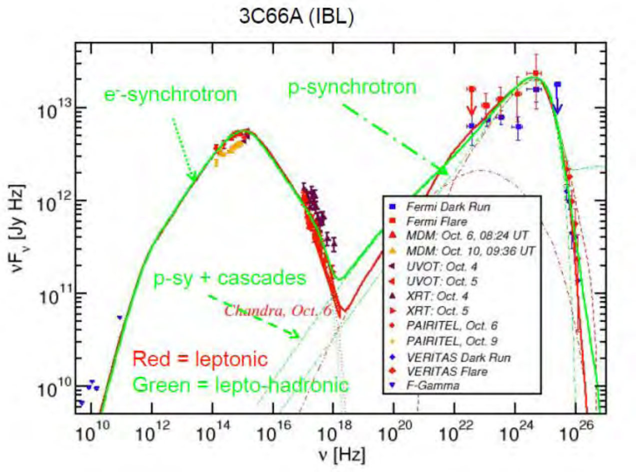


SED modeling with lepto-hadronic models

- Recent VHE detection of FSRQ 3C279 makes its SED difficult to model with purely leptonic models
- Lepto-hadronic models provide successful fit to 3C279 and many others
- Downside: requires very high jet luminosity and has problems in explaining fast variability

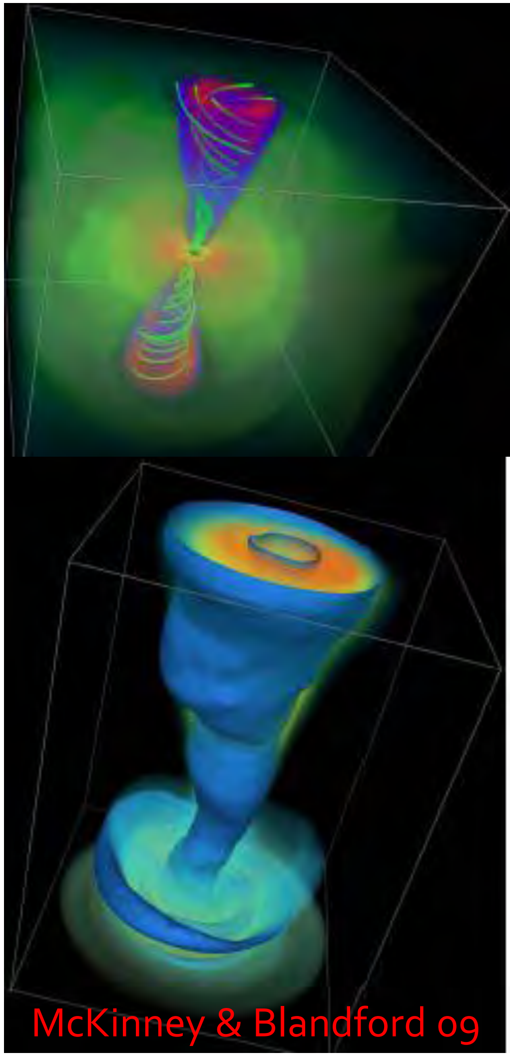
(Böttcher)





Simulations and "observing" them

- Great progress in 3D GRMHD simulations (Blandford)
  - Can produce Γ~10 dipolar jets that are stable up to 10^3 R_g
  - Mild substructure due to m=1 mode
  - Simulations give p′, B′, n′, V. Use simple emissivity models to calculate I,Q,U. Work in jet frame and take into account light travel delays
  - To be done: suite of RMHD simulations, produce blind tests for observers, compare with simple models…
- Similar progress expected in simulating shock microphysics with RPIC codes ⟶ Firm physical basis for particle acceleration inputs into existing blazar shock models (Hardee)



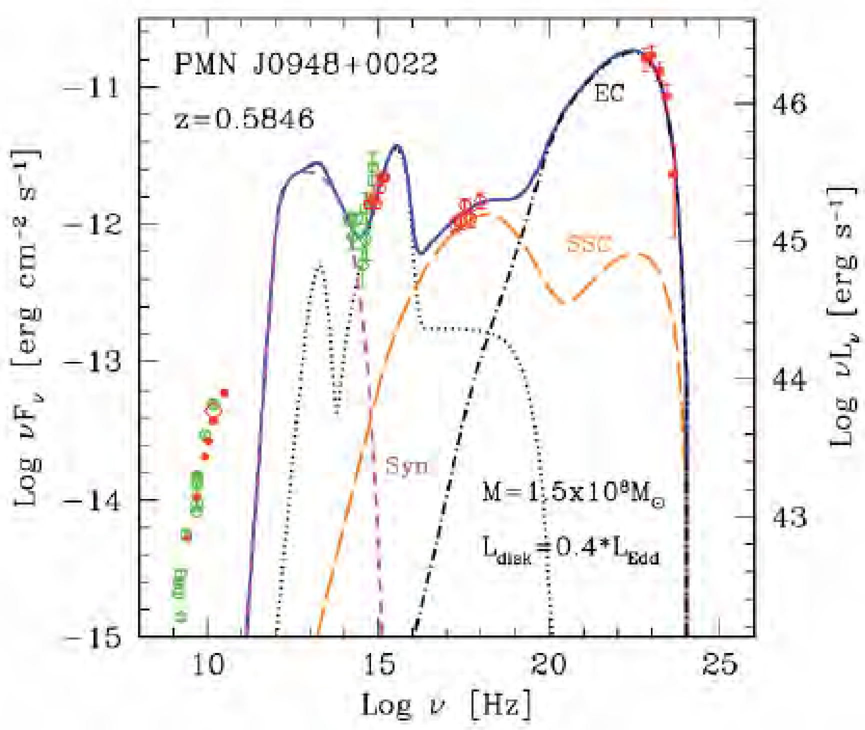
McKinney & Blandford 09

Non-blazar gamma-ray AGN

Narrow-line Sy 1s

- NLS1s – a new class of gamma-ray AGN (4 det. @FmJ meeting)
- Small black hole masses and ~Eddington rate accretion
- SEDs similar to blazars; jet power between BL Lacs and FSRQs; VLBI shows high T_b
- Relativistic jets from spiral galaxies

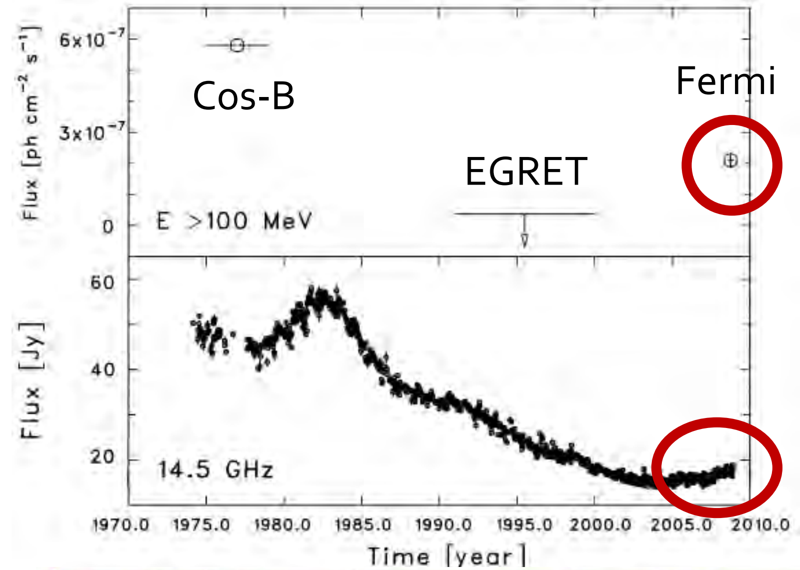
(Fuhrmann+, Cheung+)

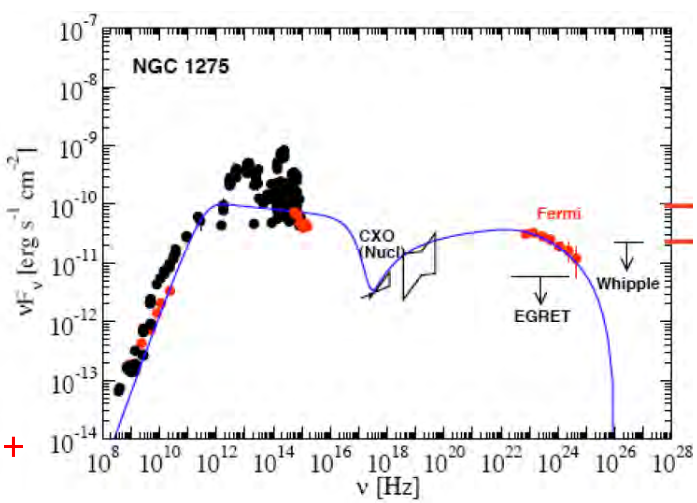


Radio galaxies: NGC 1275

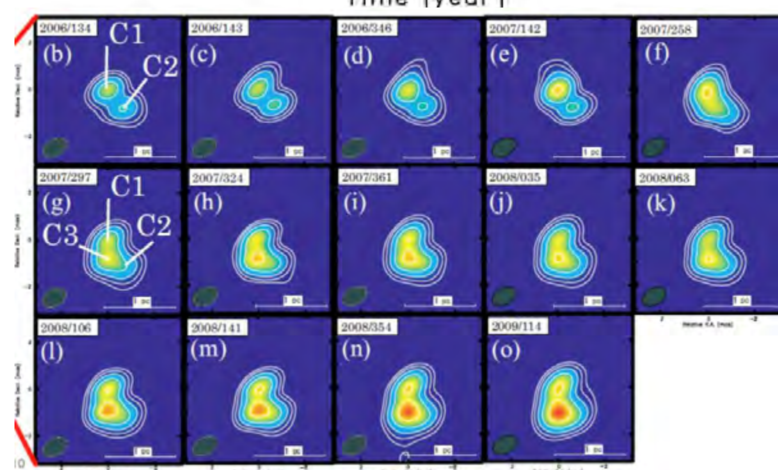
LAT-detected RGs @FmJ: Cen A, NGC6251, 3C111, NGC1275, M87, 3C78, 3C120
→ larger range of viewing angles to study!

- Long-term γ-ray variability in NGC1275: possible det. by COS-B, no det. by EGRET, det. by Fermi – seems to follow the radio trend (Cheung+). Radio flare coincides with a VLBI ejection (Nagai+).
- SED-modeling with 1-zone SSC assuming 1-month variability time scale requires D~9 and viewing angle < 6.6 deg (Finke+).
- However, VLBI-monitoring shows only mildly relativistic jet, D~1.7 (Kellermann+, Nagai+).





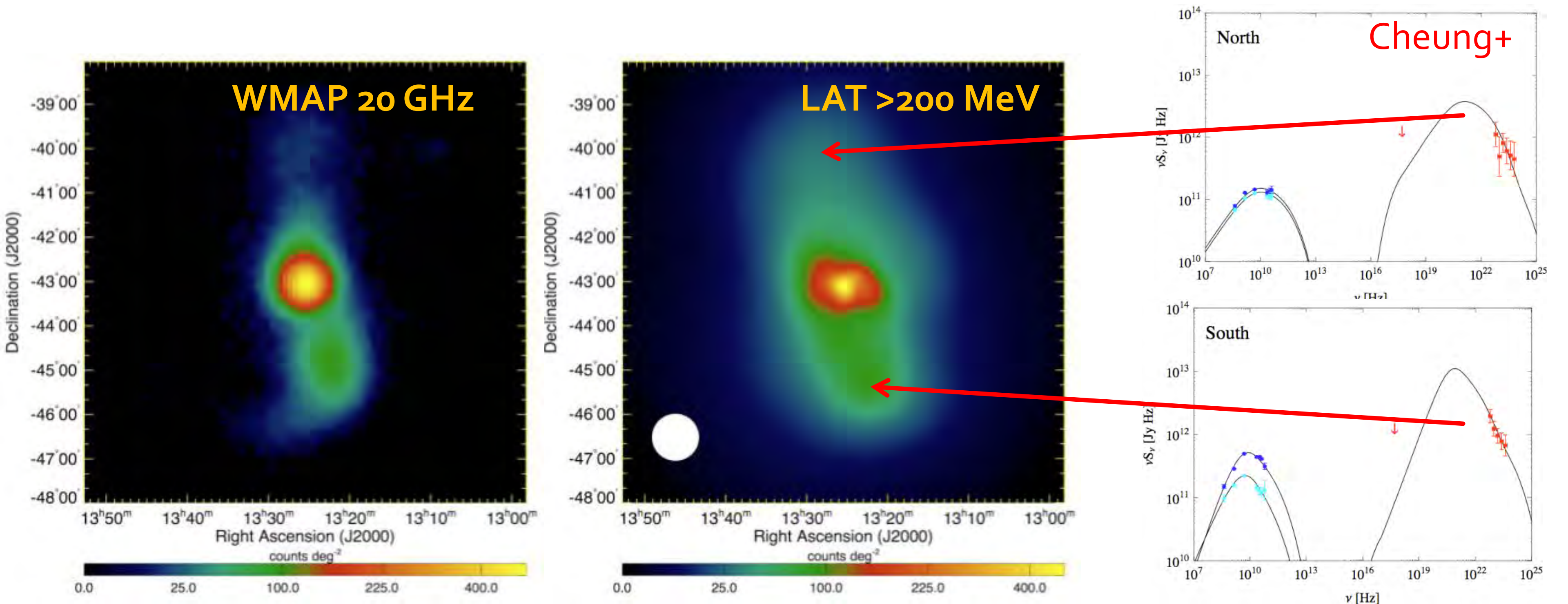
Finke+



Nagai+

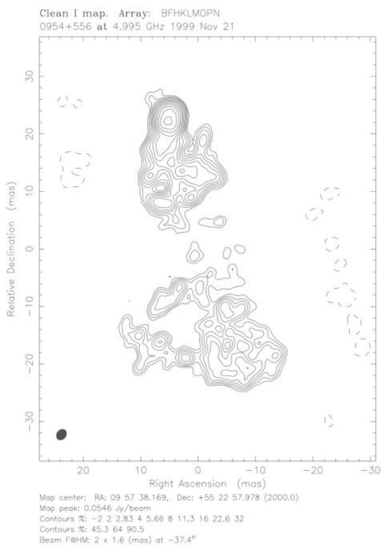
Radio galaxies: Cen A

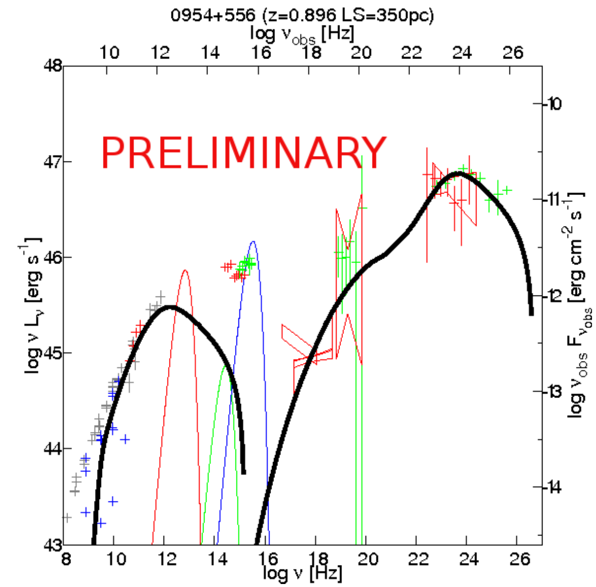
- At 3.8 Mpc Cen A is the nearest radio-loud AGN
- Possible source of UHECRs (Protheroe)
- First gamma-ray images of radio lobes by Fermi: over half of the total >100 MeV LAT flux in the lobes. Confirms the expectation that radio lobes can produce inverse Compton gamma-rays from CMB+EBL. (Cheung+)

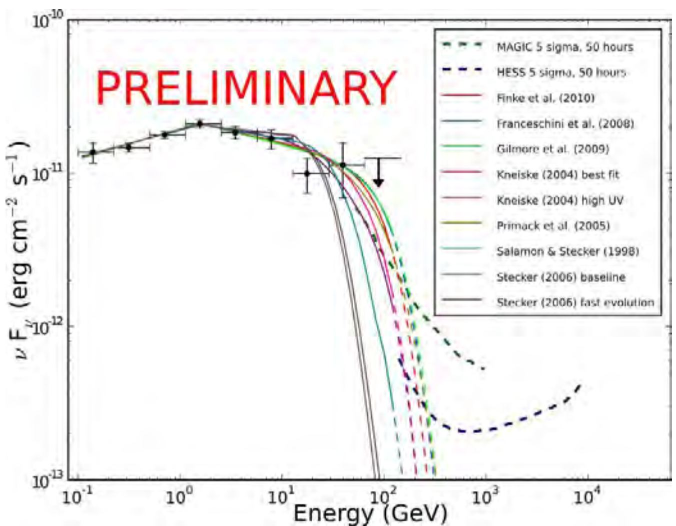


4C +55.17 – gamma-rays from young radio source?

- Classified as FSRQ, but no clear evidence for relativistic beaming: symmetric extended morphology, no variability, maximum $T_b \sim 10^8$ K $\rightarrow$ Young radio source?
- Fermi observes constant gamma-ray flux, hard photon index. SED can be modeled without resorting to relativistic beaming.
- Interesting candidate for Cherenkov telescopes and for EBL studies. (McConville+)







Thank you!

Download the proceedings at http://www.mpifr-bonn.mpg.de/div/vlbi/agn2010/PdfFiles/fmj2010_complete.pdf

Gamma-ray source identification

- Worries:
  - Are we selecting "out" new source types by classifying them as blazars?

Fermi LAT Detection of a New Galactic Plane Gamma-ray Transient in the Cygnus Region: Fermi J2102+4542, and its Possible Association with V407 Cyg

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on ***18 Mar 2010; 16:52 UT***
Distributed as an Instant Email Notice (Request for Observations)
Password Certification: Julie McEnery (julie.mcenery@nasa.gov)

Subjects: Gamma Ray, >GeV, Transients
Referred to by ATel #: 2498, 2506, 2511, 2529, 2536, 2546

The Large Area Telescope (LAT), on board the Fermi Gamma-ray Space Telescope, has detected a transient gamma-ray source in the Galactic Plane: Fermi J2102+4542. Preliminary analysis of the Fermi-LAT data indicates that on the 13th and 14th of March 2010, the source was detected with a >100 MeV flux of (1.0 +/- 0.3) x 10^-6 ph cm^-2 s^-1 and (1.4 +/- 0.4) x 10^-6 ph cm^-2 s^-1, respectively (statistical only) -- corresponding significances on these days are 8 sigma and 6 sigma. A systematic uncertainty of 30% should be added to this number. There is no previously reported gamma-ray source at this location.

Combining data for the period from Mar 12 0:0:0 UTC and ending Mar 16 ~8:30 UTC, the preliminary LAT position is (J2000.0): RA = 315.60 deg., Dec = 45.71 deg. (l, b = 86.96 deg, -0.55