VHE (> 100 GeV) emission from FSRQs
Its origin and emission mechanism

Bagmeet Behera
(*DESY, Zeuthen Germany*)
and
Anna Barnacka
(NCAC, Warsaw Poland; and CEA, Saclay France)

Granada, 12 June 2013

DESY

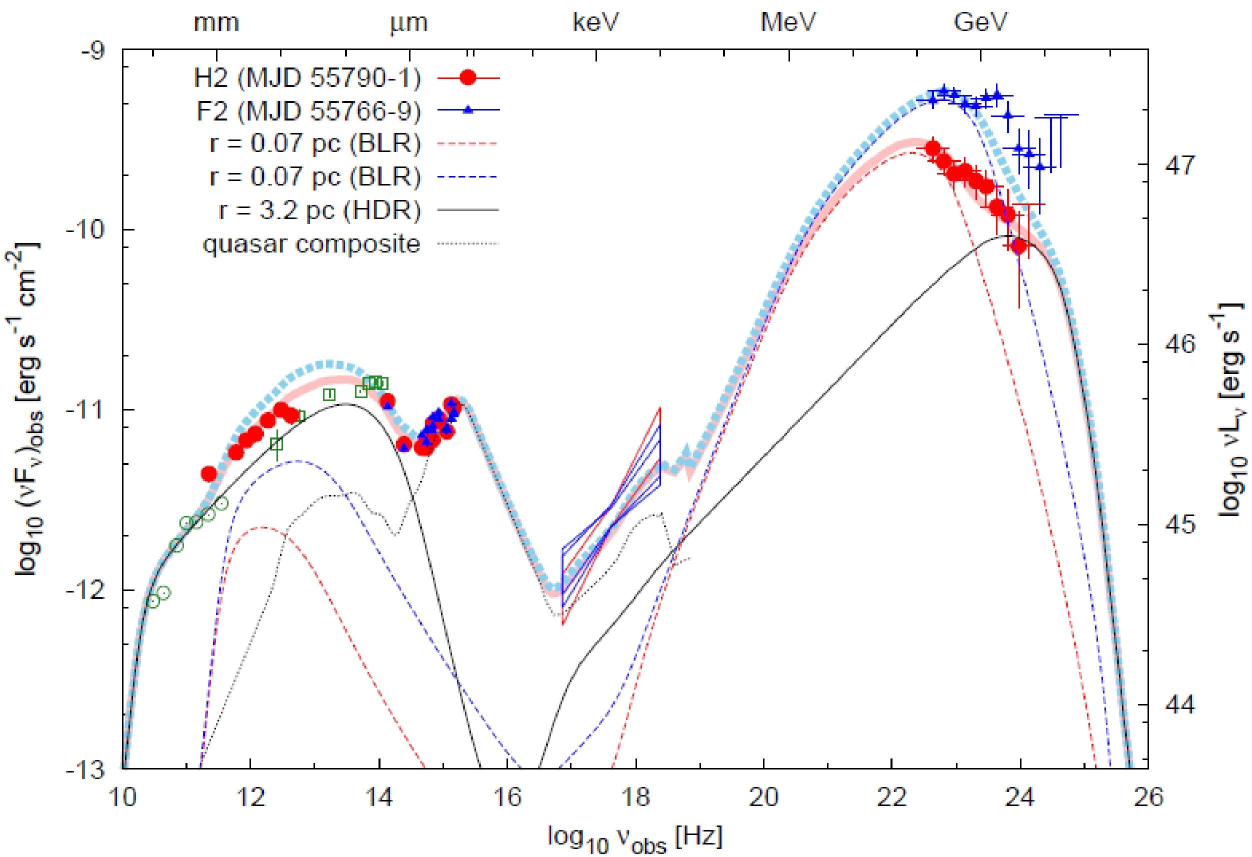
Outline

- *Introduction:* What we knew before about FSRQs.
- *Whats recent observations with Fermi-LAT, Cherenkov instruments, along with other MWL data tell us -*
  - *Fermi LAT findings*
  - *VHE detection of 3 FSRQs*
  - *A closer look at PKS 1510-089*
  - *What does radio sample studies reveal*
- *Where we go from here?*

Flat Spectrum Radio Quasar

If you asked a biased gamma-ray astronomer

- Observational definition → FSRQs are blazars that have
  - ◊ line emission,
  - ◊ low synchrotron-peak-frequency,
  - ◊ and steep gamma-ray spectra (100 MeV – 10s GeV

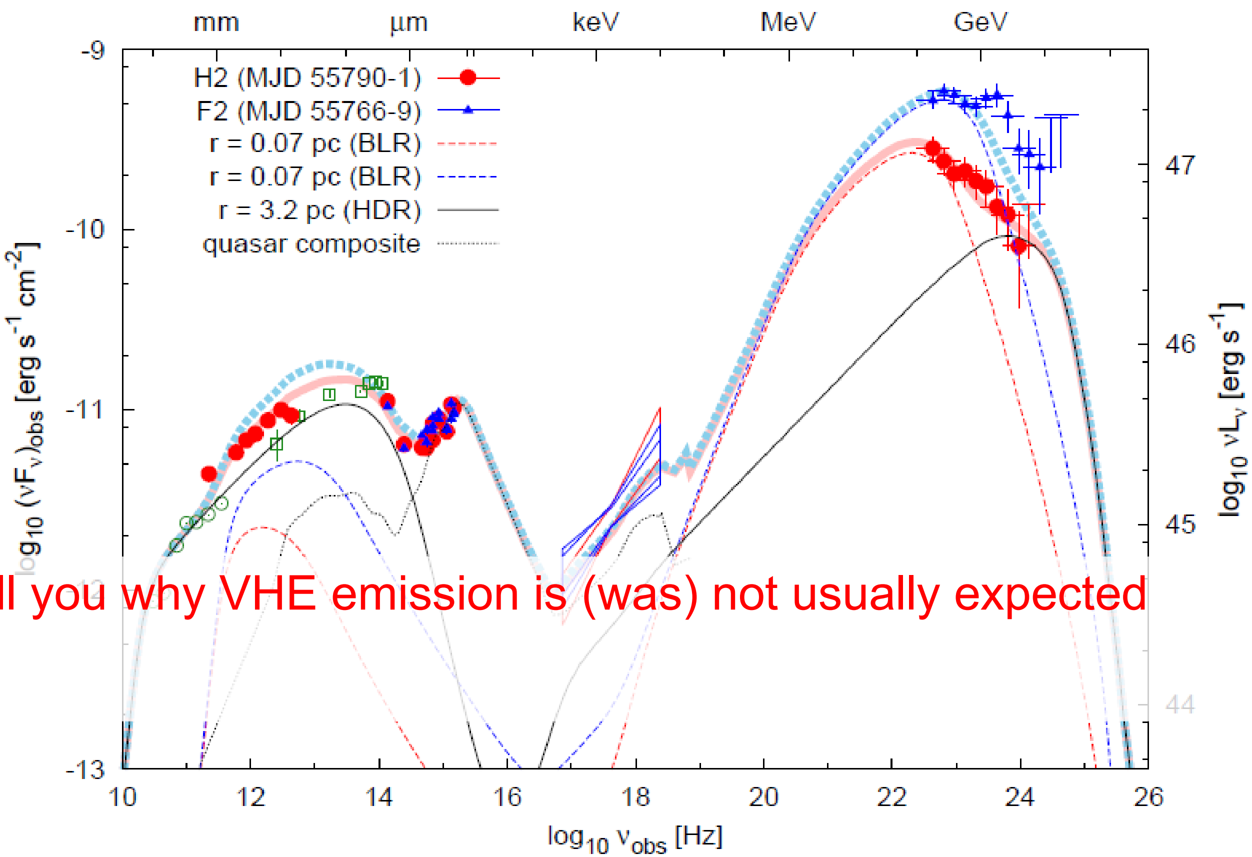


Nalewajko et al 2012, ApJ 760, 69

Flat Spectrum Radio Quasar

If you asked a biased gamma-ray astronomer

- Observational definition → FSRQs are blazars that have
  - line emission,
  - low synchrotron peak frequency,
  - and steep gamma-ray spectra (100 MeV – 10s GeV)



All these features also tell you why VHE emission is (was) not usually expected from FSRQs

Nalewajko et al 2012, ApJ 760, 69

Why are FSRQs hard to detect in VHE?

- Line emission and thermal components → Intense internal photon field in the IR-optical regime → In-situ absorption via $e^+ e^-$ pair production (*Internal absorption*)
- Low synchrotron peak → not enough high energy electron to up-scatter photons to VHE (means similarly *low frequency peak in the gamma-rays*)
- Steep *Fermi*-LAT spectrum means simple extrapolations → *VHE gamma-ray ray emission too low* to register
- FSRQs are relatively distant than Bl Lacs → *EBL absorption* is also limiting the detection possibility

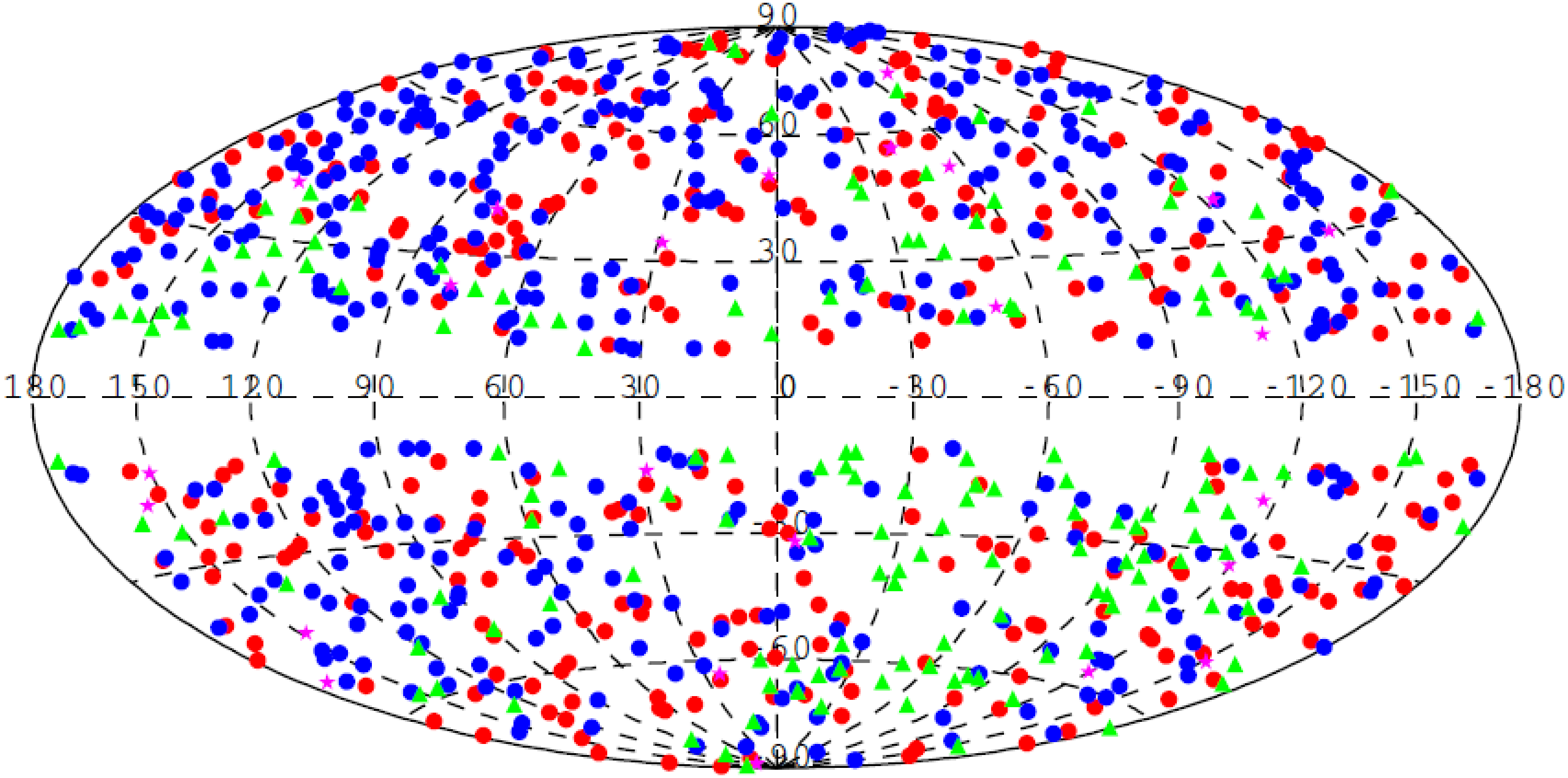
Why are FSRQs hard to detect in VHE?

- Line emission and thermal components → Intense internal photon field in the IR-optical regime → In-situ absorption via $e^+ e^-$ pair production (*Internal absorption*)
- Low synchrotron peak → not enough high energy electron to up-scatter photons to VHE (means similarly *low frequency peak in the gamma-rays*)
- Steep *Fermi*-LAT spectrum means simple extrapolations → *VHE gamma-ray ray emission too low* to register
- FSRQs are relatively distant than Bl Lacs → *EBL absorption* is also limiting the detection possibility

Nevertheless, 3 FSRQs have been detected at VHE (although not every time these were observed)

FSRQs detected in gamma-rays

- 353 FSRQs in the 2FGL *Fermi*-LAT catalog

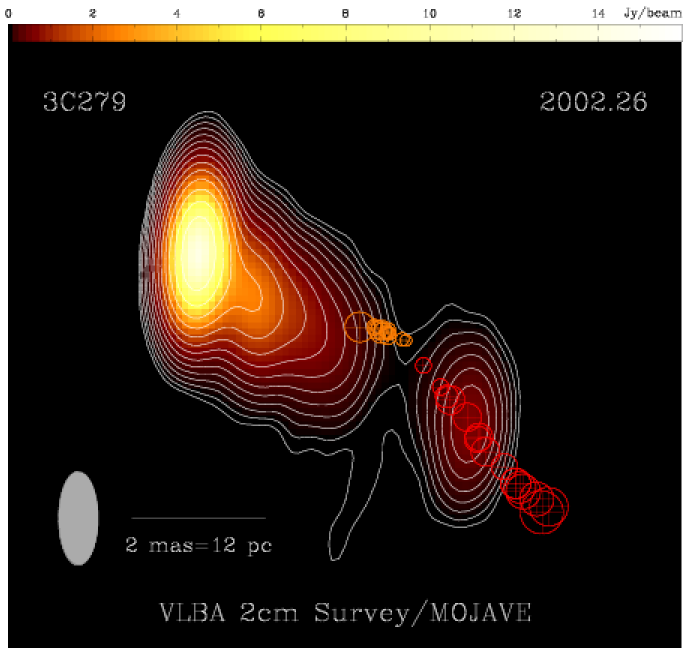


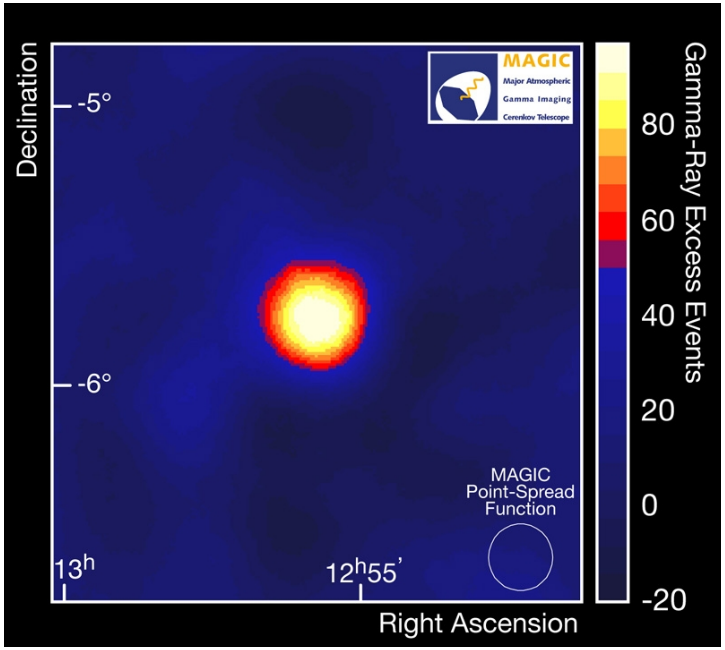
FSRQs detected in gamma-rays

- 353 FSRQs in the 2FGL *Fermi*-LAT catalog
- Just 3 in very high energies (**VHE**: *i.e. E* > *100 GeV*)

Number of FSRQs detected in gamma-rays

- 353 FSRQs in the 2FGL *Fermi*-LAT catalog
- 3 in very high energies (**VHE**: *i.e. E > 100 GeV*)
  - **3C 279** in 2006, seen with MAGIC

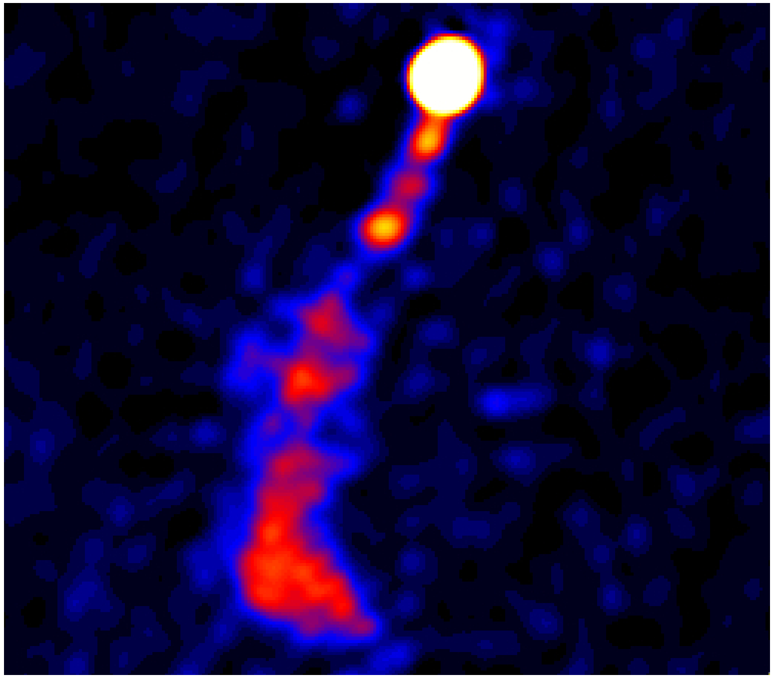




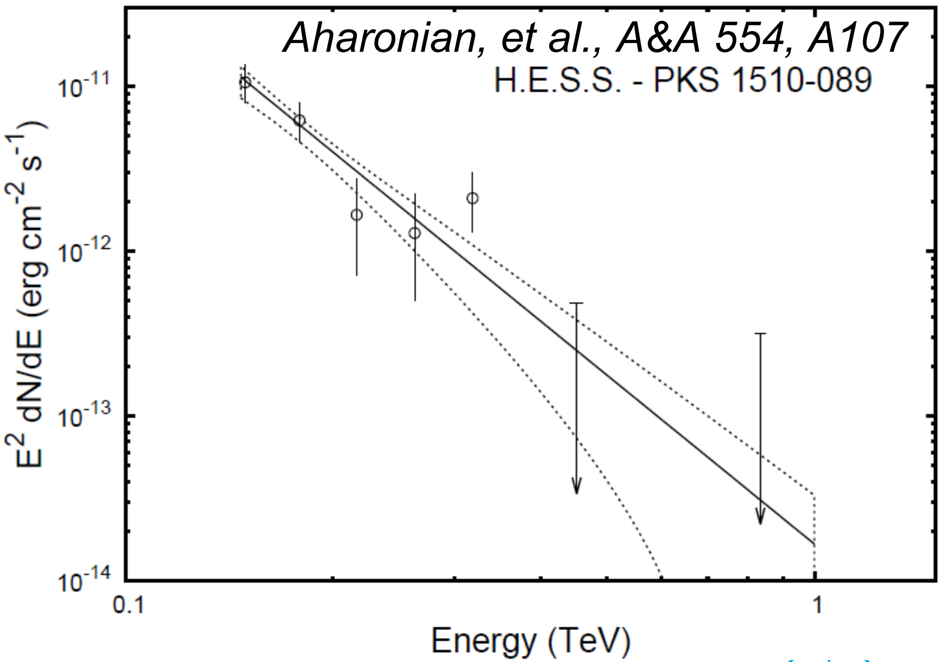
Kinematics of AGN Jets - Ros, Eduardo J.Phys.Conf.Ser. 131 (2008)

Number of FSRQs detected in gamma-rays

- 353 FSRQs in the 2FGL *Fermi*-LAT catalog
- 3 in very high energies (**VHE**: *i.e. E > 100 GeV*)
  - **3C 279** in 2006 by MAGIC
  - **PKS 1510-089** in 2009 by H.E.S.S.

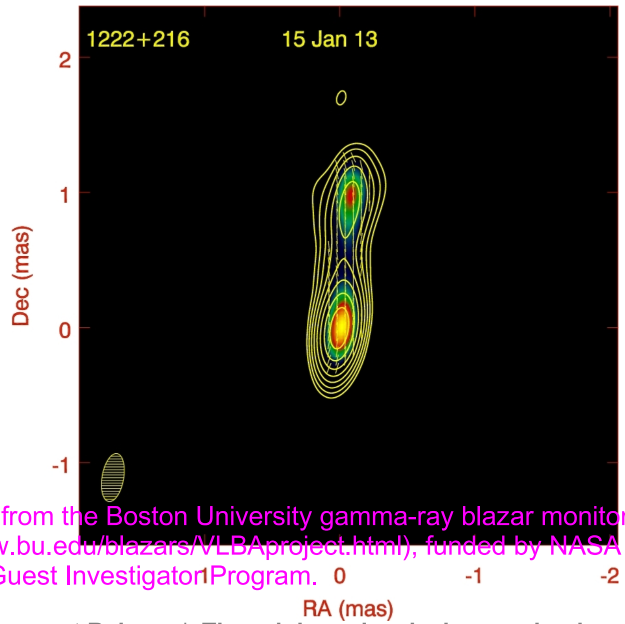


5 GHz VLA radio image (O'Dea et al. 1988, Sambruna et al. 2004)

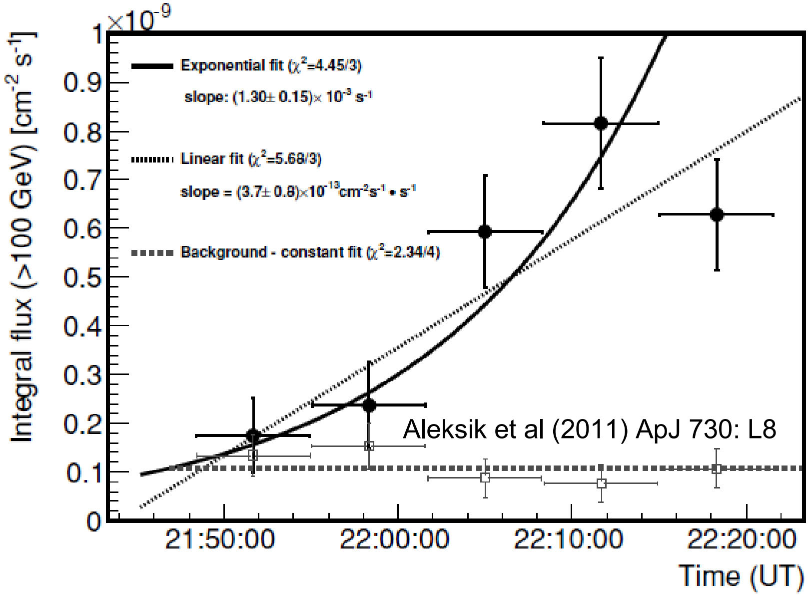


Number of FSRQs detected in gamma-rays

- 353 FSRQs in the 2FGL *Fermi*-LAT catalog
- 3 in very high energies (**VHE**: *i.e. E > 100 GeV*)
  - **3C 279** in 2006 by MAGIC
  - **PKS 1510-089** in 2009 by H.E.S.S.
  - **PKS 1222+21** (**4C 21.35**) in 2010 by MAGIC



43 GHz VLBA data from the Boston University gamma-ray blazar monitoring program (http://www.bu.edu/blazars/VLBAproject.html), funded by NASA through the Fermi Guest Investigator Program.



What have we learned about *gamma-ray bright* FSRQs?

- From MWL observations

(*a lot of interesting discussion in other talks*)

- Taking into account the VHE emission

Fermi-LAT

- Highly variability as some other bright FSRQs

D'Ammando, F., et al. 2009, A&A, 508, 181	PKS 1510-089 - *Agile*
Abdo, et al. 2010 ApJ 721, 1425-1447	PKS 1510-089 - *Fermi*-LAT
Marscher, at al. 2010 ApJ 710, L 126	PKS 1510-089 - *Fermi-LAT*
Hayasida, et al. 2010 Nature 463, 919	3C 279 *Fermi*-LAT

…. and a number of other sources as well e.g. 3C 454.3 etc.

◊ → size scale of emitting region

Fermi-LAT

- Highly variability as some other bright FSRQs

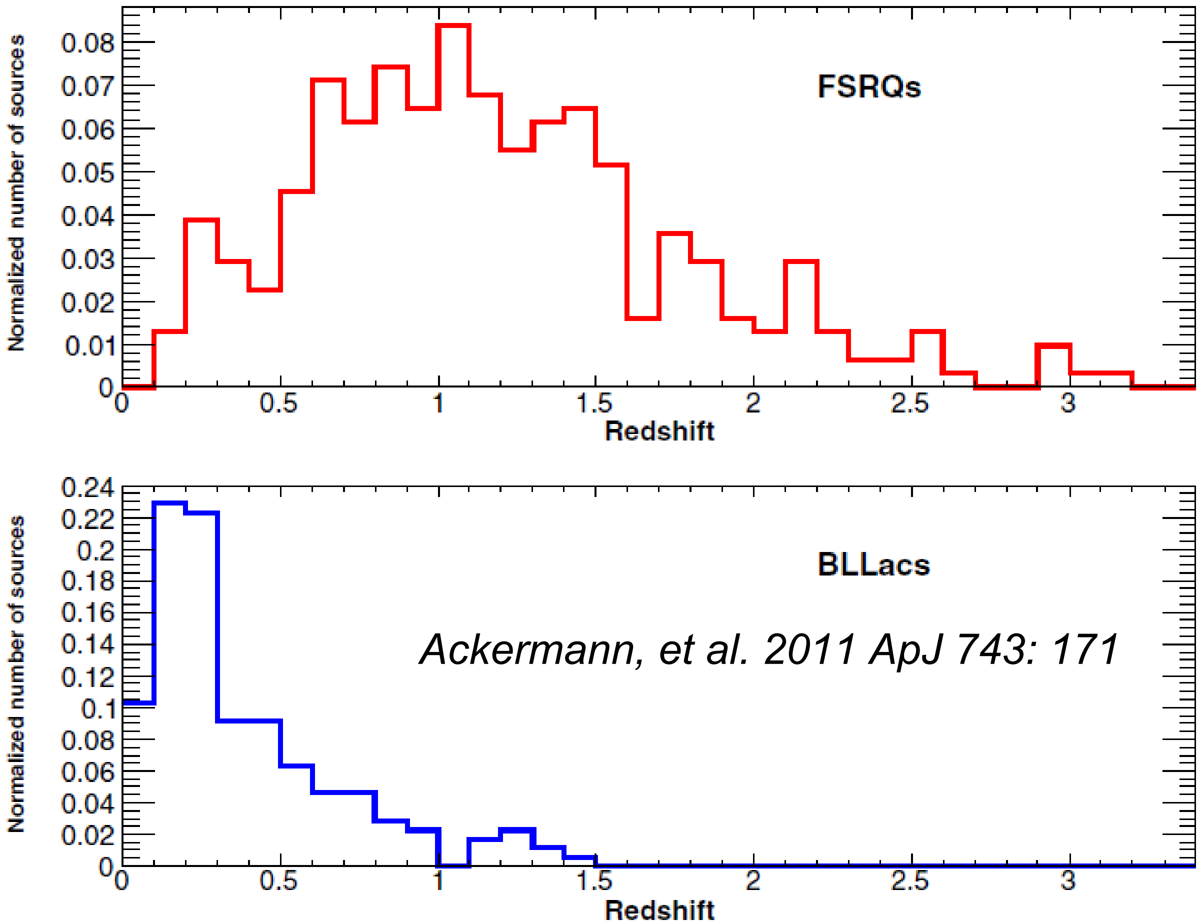
D'Ammando, F., et al. 2009, A&A, 508, 181	PKS 1510-089 - *Agile*
Abdo, et al. 2010 ApJ 721, 1425-1447	PKS 1510-089 - *Fermi*-LAT
Marscher, at al. 2010 ApJ 710, L 126	PKS 1510-089 - *Fermi-LAT*
Hayasida, et al. 2010 Nature 463, 919	3C 279 *Fermi*-LAT

…. and a number of other sources as well e.g. 3C 454.3 etc.

- ◊ → size scale of emitting region
- ◊ → size/variability scale of the external photon field (accounting for Doppler boosting)

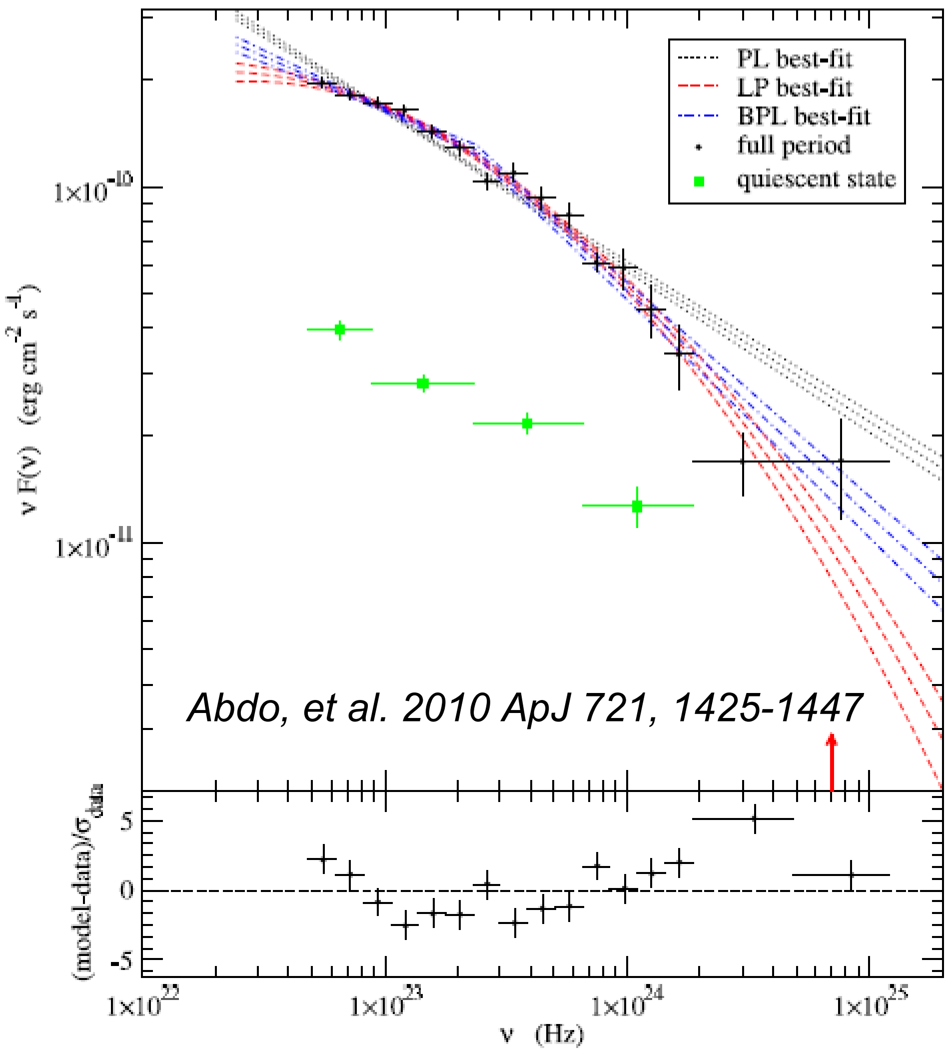
Fermi-LAT

- Higher 'z' compare to BL Lacs



Fermi-LAT

- Possible curvature (and breaks) in some → indicate internal absorption due to emission lines, at least in some cases

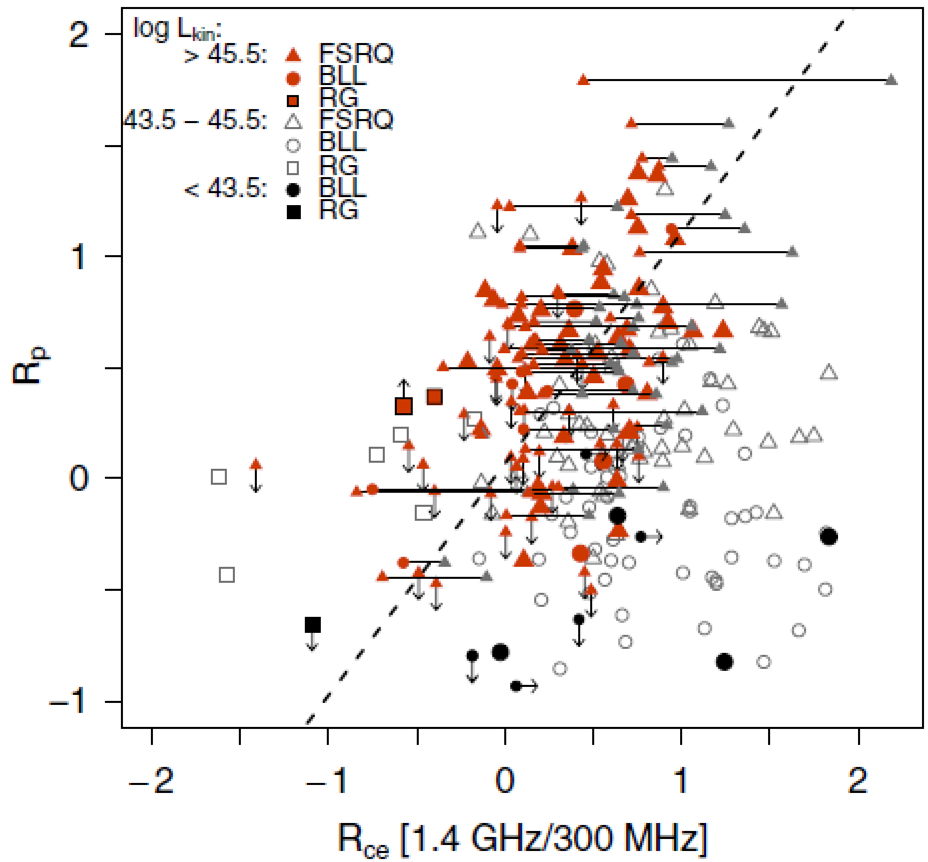


Abdo, et al. 2010 ApJ 721, 1425-1447

Radio VLBI

- *Meyer et al. 2011 and 2012*
  - More powerful jets in FSRQs
  - *Fermi*-LAT FSRQs have EC dominated emission

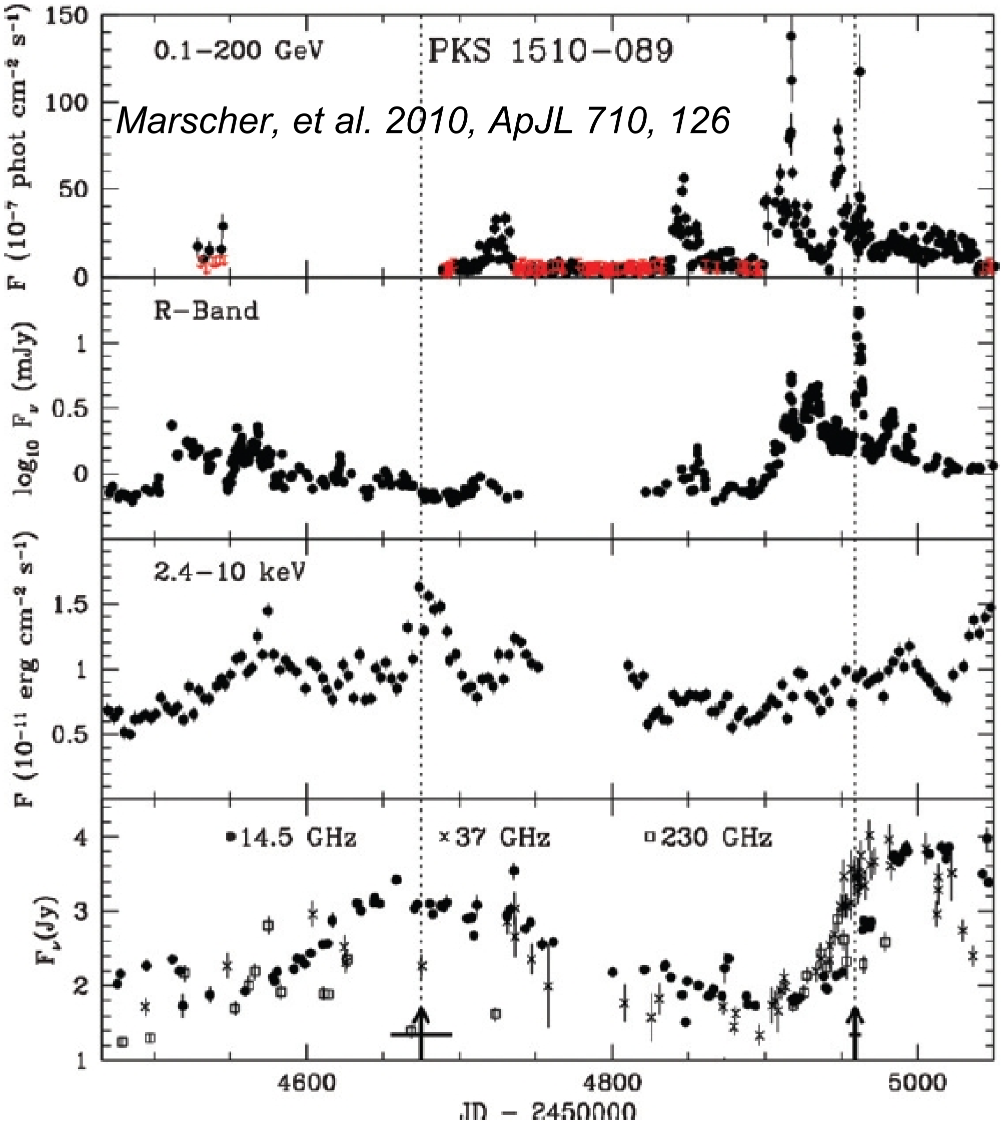
Compton dominance (Rp) vs. radio core dominance (Rce).



Meyer, et al. 2012 ApJ 752: L4

MWL variability

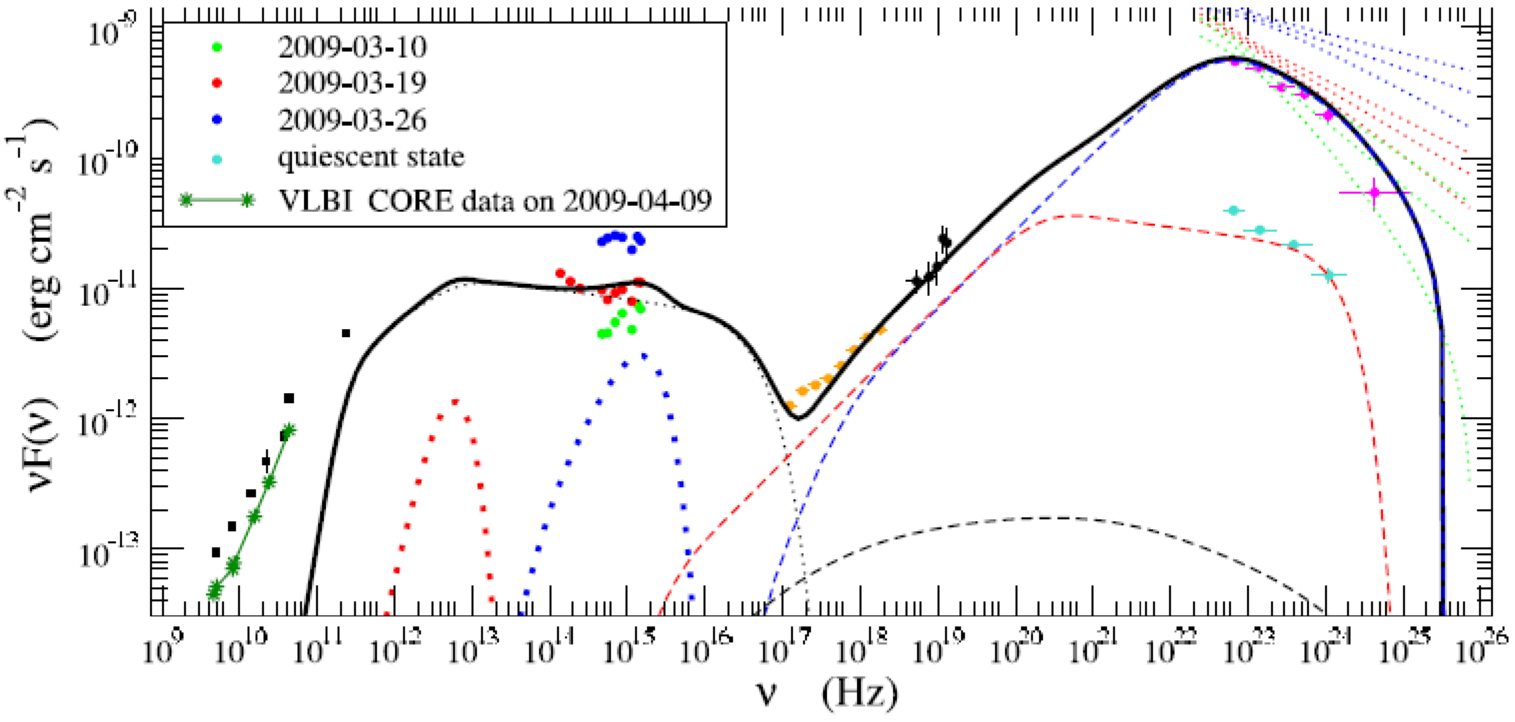
- PKS 1510-089 flares
  - ◊ Complex nature → multiple emission components, and multiple active zones
- Correlated gamma flux optical flux & polarization changes → co-spatial component for MWL flare
- Uncorrelated gamma / optical flares other mechanism



DESY

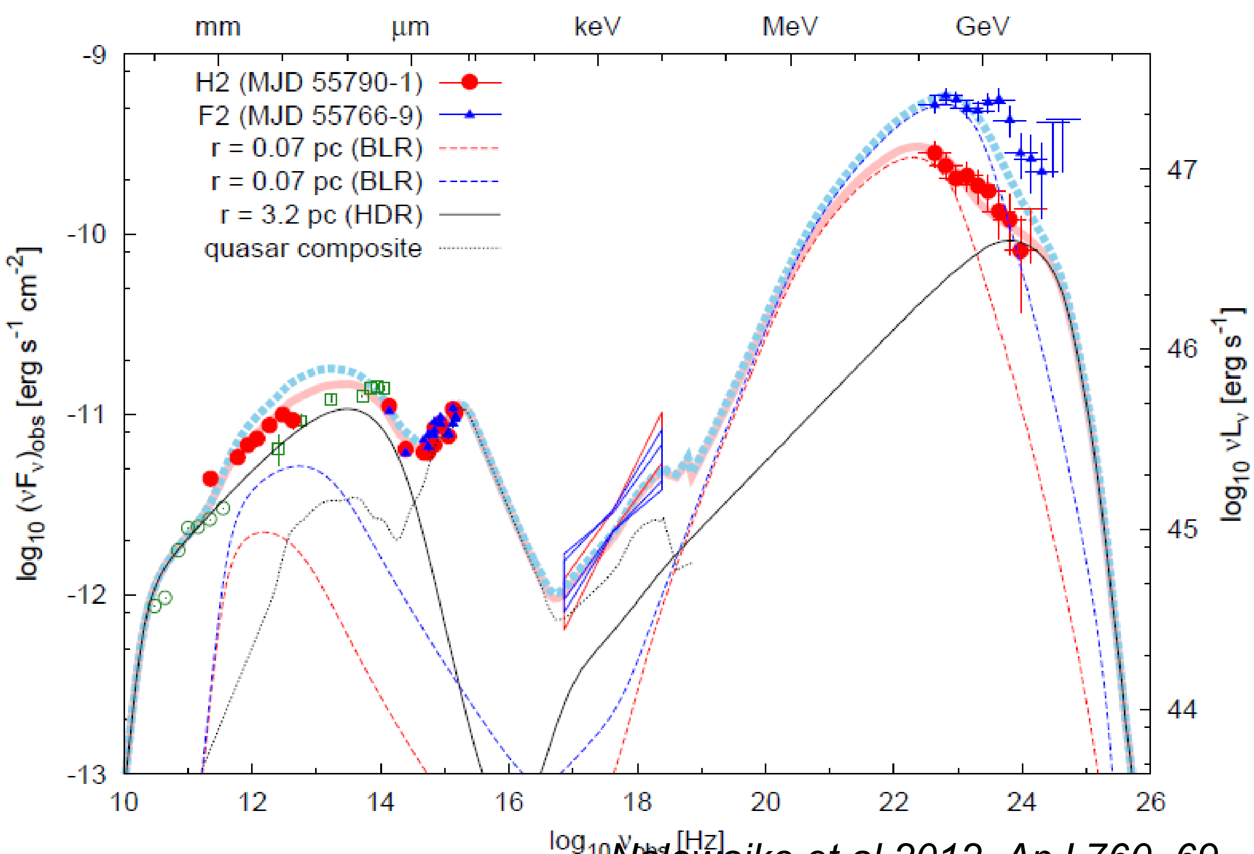
SED model for PKS 1510-089

- Abdo et al. 2009
  - KN suppressed BLR and DT EC



SED model for PKS 1510-089

- Nalewajko et al. 2012
- → requirement of multiple 'component'



Nalewajko et al 2012, ApJ 760, 69

A closer look at PKS 1510-089

What we learn for VHE emission from FSRQs

VHE emission: Internal absorption constrains

- Internal absorption due to thermal fields does not absorb (all) emission above 100 GeV
  - However, all 3 are detected below ~ 400 GeV

  → *Strong indication of internal absorption due to IR photons from the dusty-torus which causes cutoff*

Restricts the location of VHE emission to near (enough) the DT to be absorbed

Nature of IC emission: *Thomson or Klien Nishina*

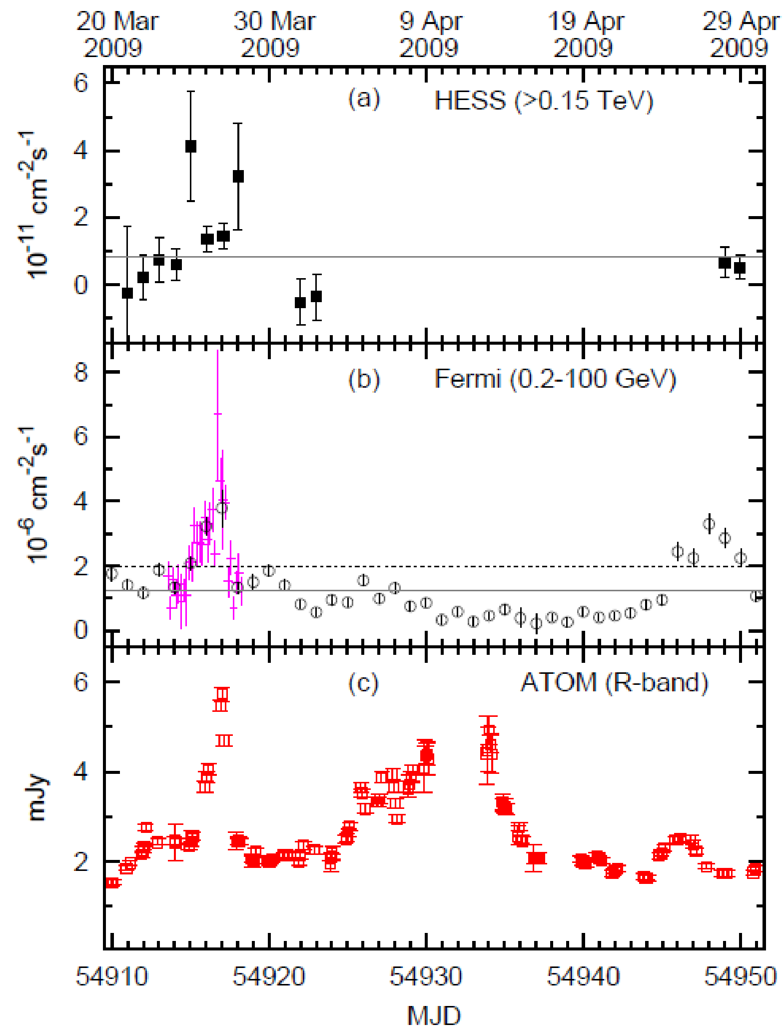
- Correlated variability in optical & *Fermi*-LAT → BLR EC should dominate 100 MeV to ~ GeV range
- Optical emission of BLR and low synchrotron peak → Klein Nishina suppression for BLR EC
- However, DT can still up-scatter from highest energy electrons to VHE gamma-rays in Thomson regime

Variability

- VHE flux consistent with constant

  → *Fermi*-LAT and H.E.S.S. could be seeing different emission-components

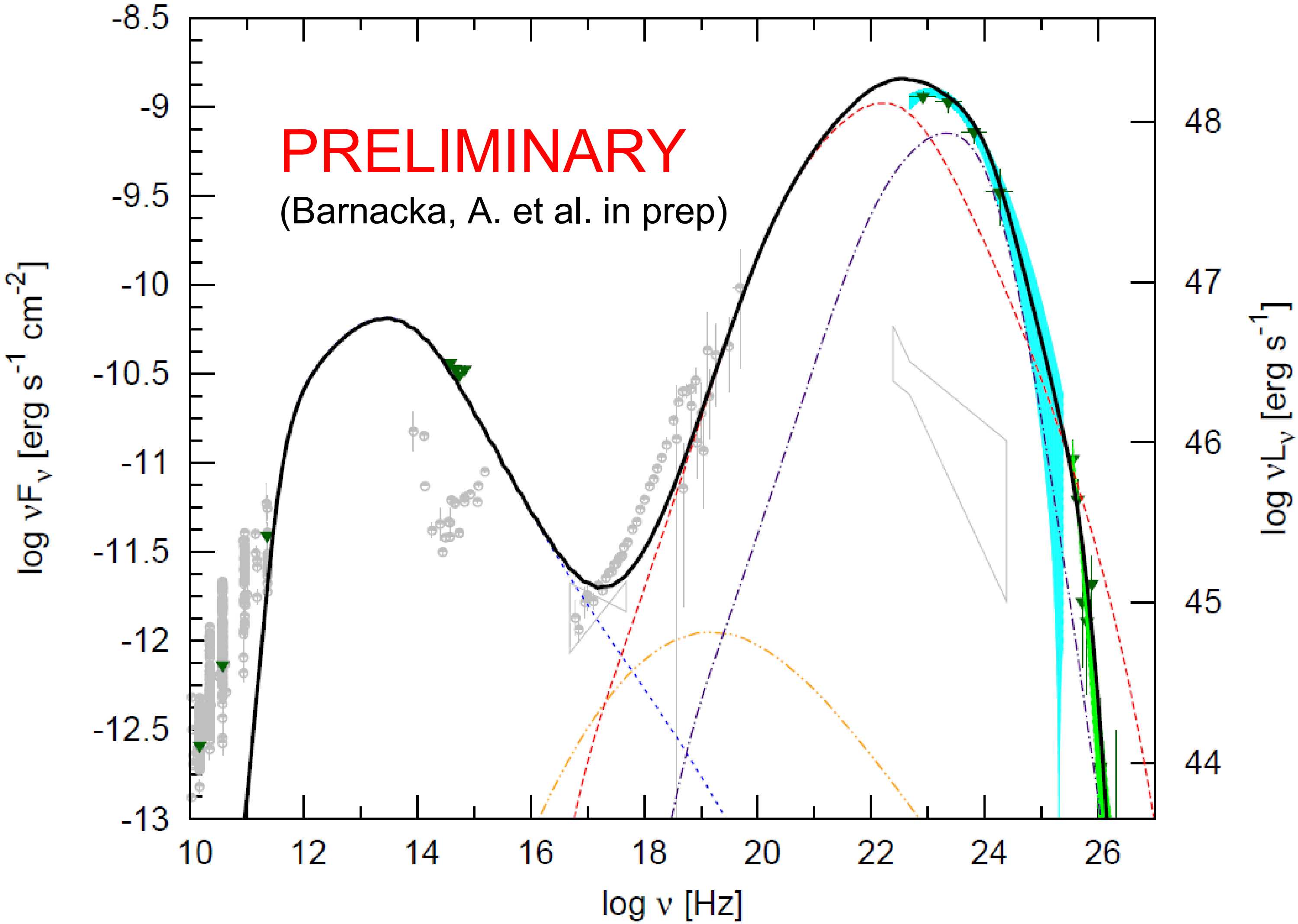
- Sometimes optical and *Fermi*-LAT fluxes correlate, at other times not



Aharonian, et al., A&A 554, A107

SED model for PKS 1510-089 (including VHE)

BLAZAR model code: *Moderski, et al. 2003, A&A 406, 855*



Consequences:

- If VHE emission is from EC on the DT field, it should be variable over long time scales, and could be present in many objects
- Location outside BLR but still within the influence of DT $\rightarrow$ VHE detection possible only in a narrow range
- Correlated variability could be seen in X-rays and VHE

Consequences:

- If VHE emission is from EC on the DT field, it should be variable over long time scales and could be present in many objects
- Location between BLR but still within the influence of DT → VHE detection possible only in a narrow range
- Correlated variability could be seen in X-rays and VHE
- 4C 21.35 also showed very small variability time scale ~30m (*during a GeV flare*)
  - VHE emitting blazar-zone or the change in external photon field (even after accounting for ~100) should be small <~ light days
  - Since the variability scales of the torus are expected ≳ month scale → BLR should provide the target photons with variability possibly driven by changing emission from the inner disk

Summary / Where do we go from here -

- It is difficult to detect FSRQs in VHE with current instruments
- Few new detections raise some interesting new questions
- Theoretical models should take in these complications into account
- *Fermi*-LAT flaring FSRQs do not guarantee bright VHE states
- MWL monitoring and correlating with low frequency observations in radio, IR, optical as well as higher energies, X-rays, could help understand the complicated behavior of gamma-ray bright FSRQs in general