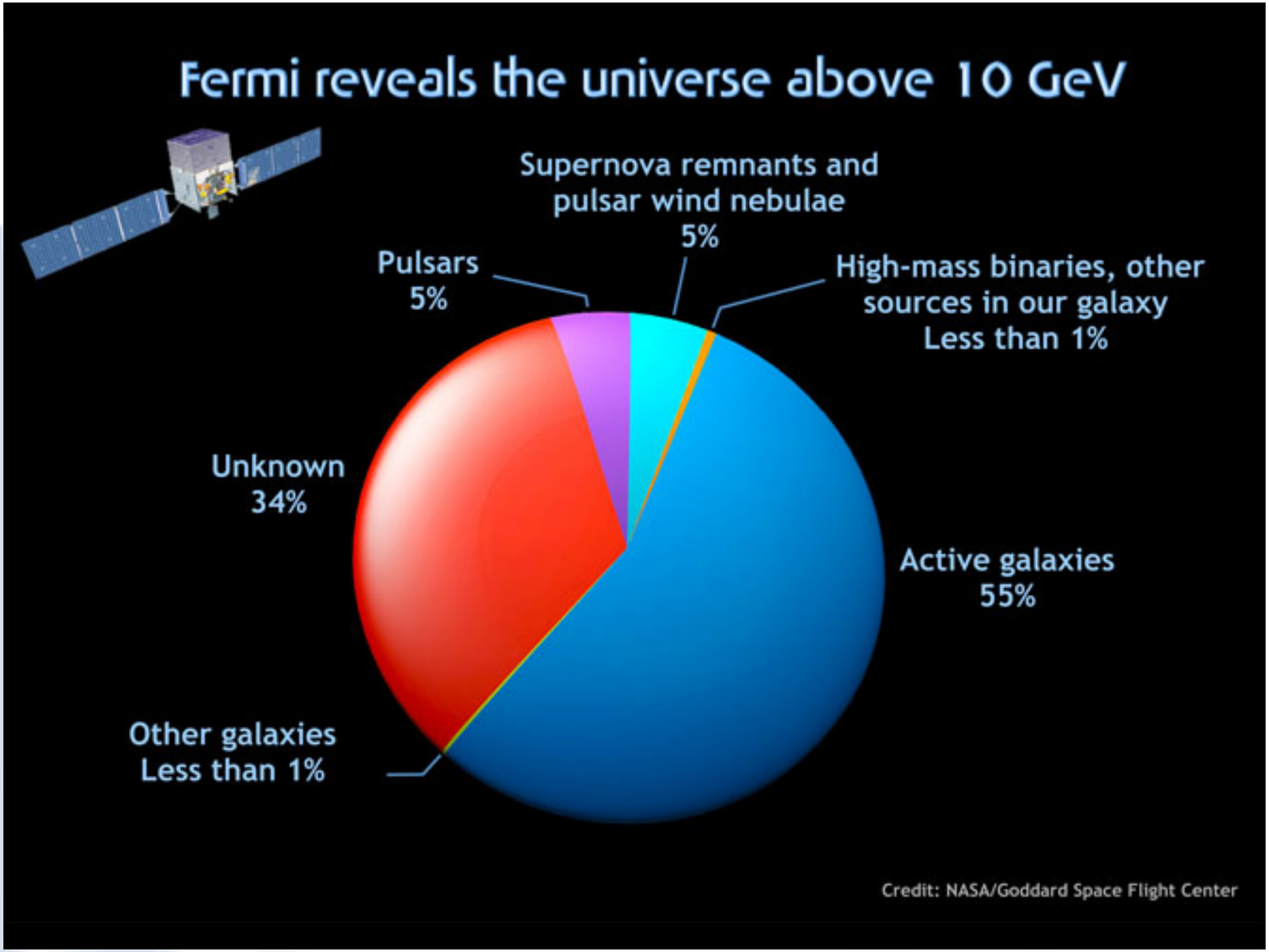
Very High Energy Gamma-Rays from Flat Spectrum Radio Quasars

Elina Lindfors,

ICRR Tokyo and Tuorla Observatory, University of Turku, Finland

Collaborators: J.Sitarek, J. Becerra Gonzalez, F.Tavecchio et al.
MWL Collaborators: S. Jorstad, T. Hovatta, A. Lähteenmäki, M. Tornikoski, S.Buson, F. D’Ammando, V. Fallah Ramazani, C. Raiteri
...and many more....

Gamma-ray sky



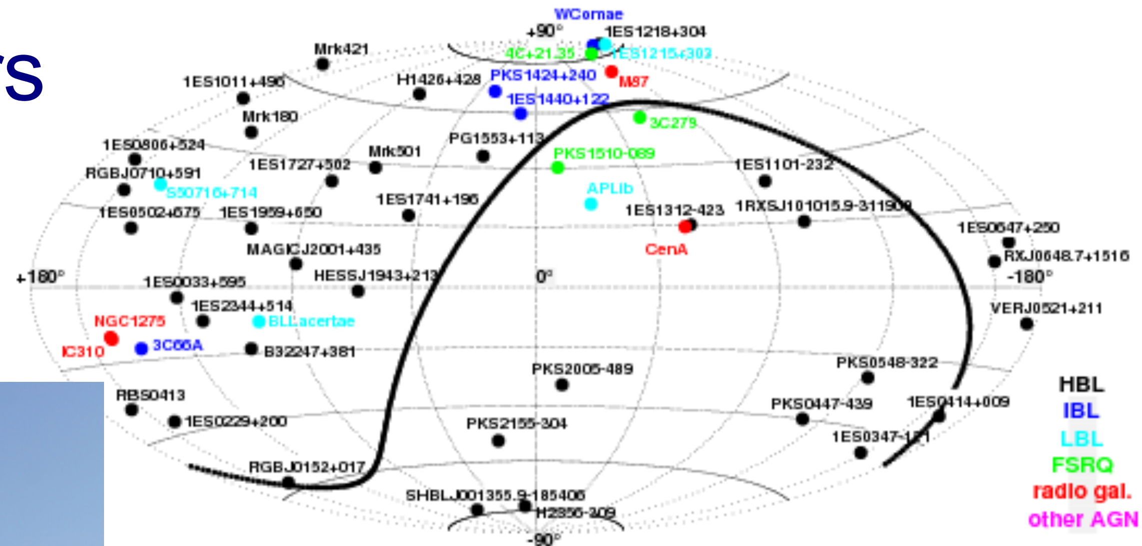
Blazars

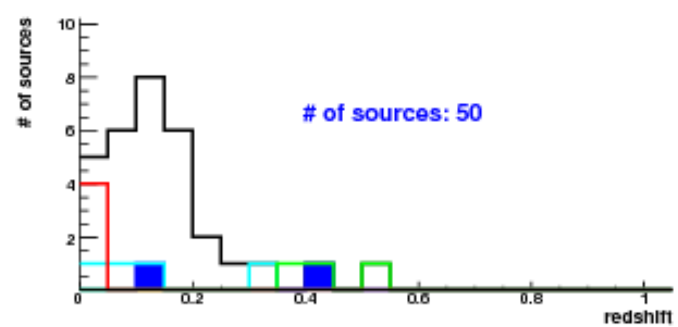
The most numerous objects in the gamma-ray sky

Extragalactic VHE sky

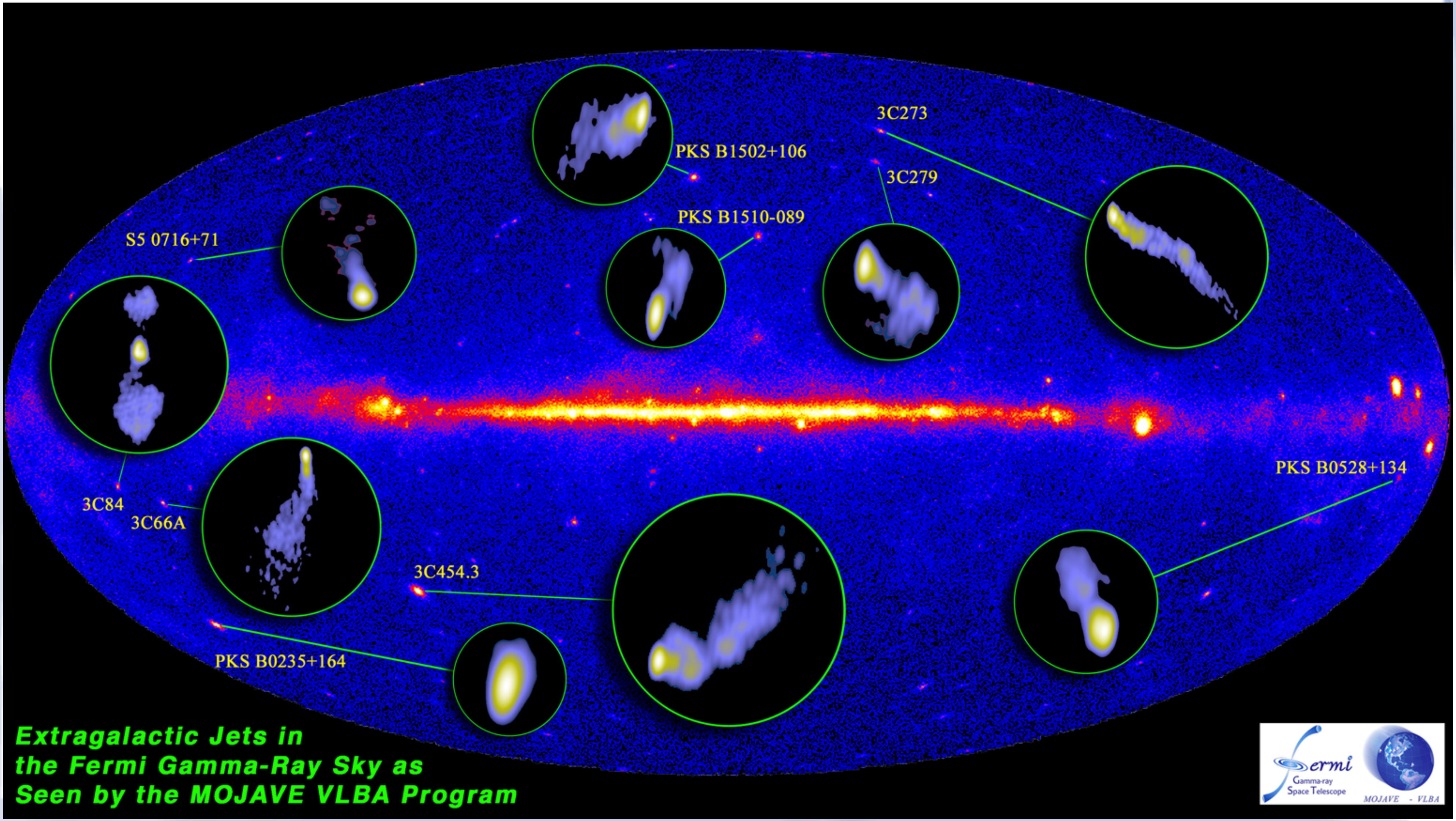
More than 60 sources

Dominated by blazars





Blazars - hosting relativistic jets



Blazar model

BL Lacs: no accretion disk, no Broad Line Region, no IR Torus
FSRQs: accretion disk, Broad Line Region Clouds, IR torus

(e.g. Giommi, Padovani et al. 2012)

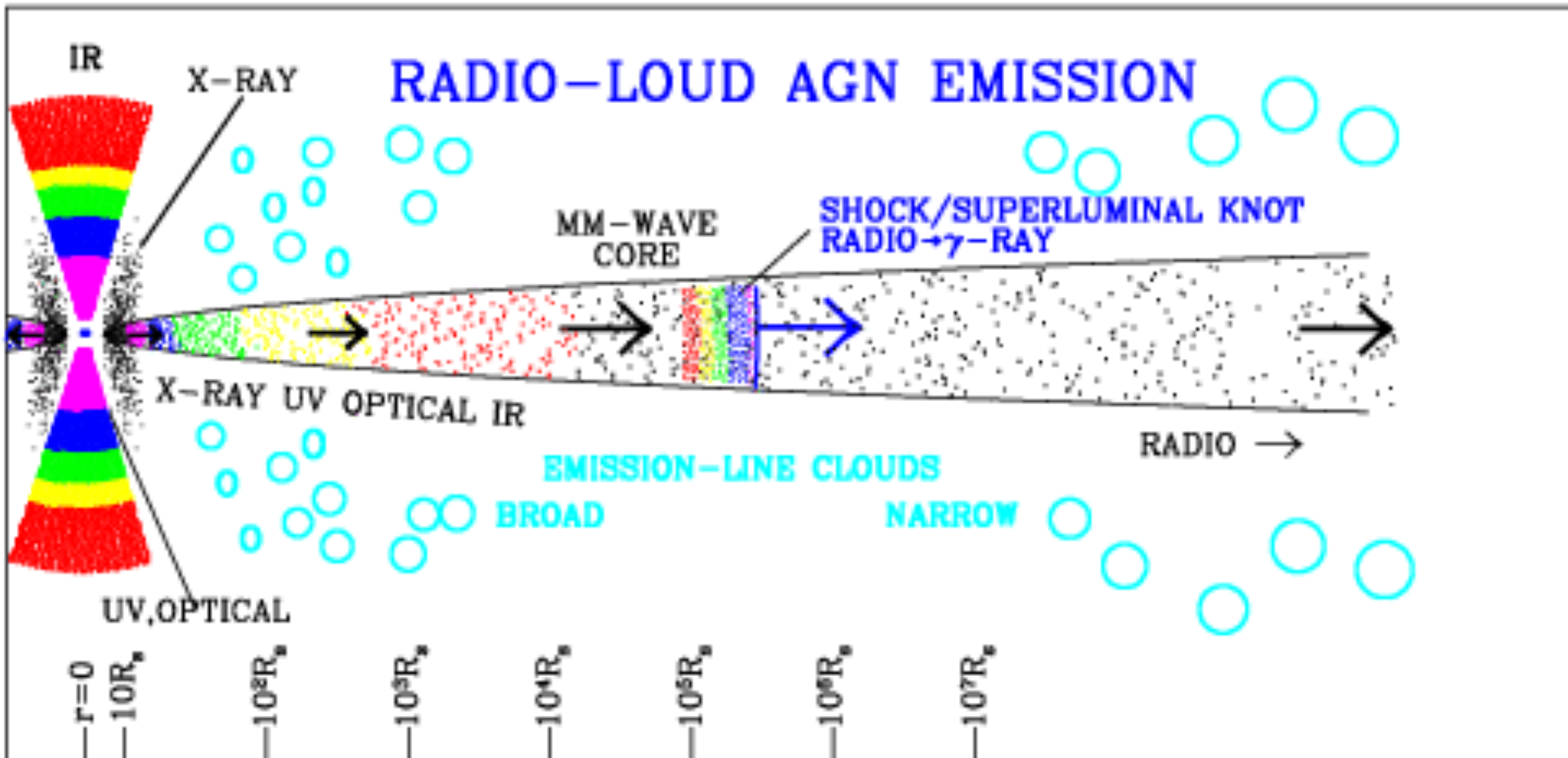


Figure: Alan Marscher

Flat Spectrum Radio Quasars

- The most luminous sources within gamma-ray emitting AGN class
- Multiwavelength characteristics:

-the VLBA jets with high Doppler factors, “knots” in the jet

-optical spectrum shows broad emission lines

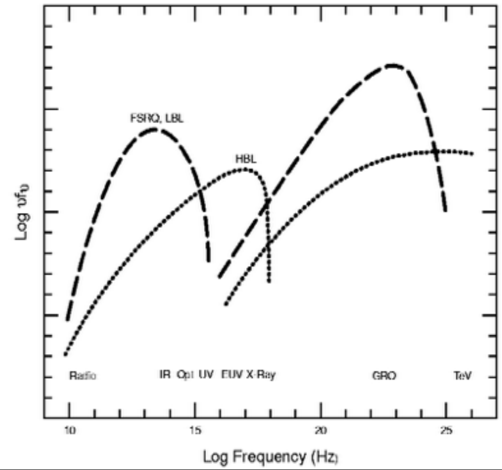
-SED: low synchrotron peak frequencies (infrared)

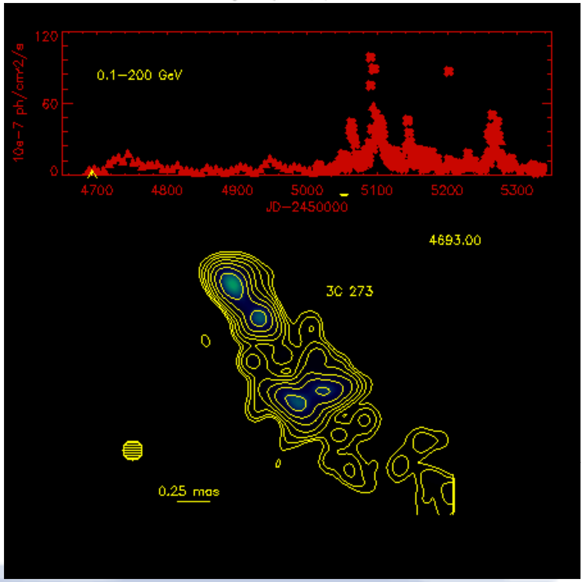
- In VHE (>100GeV) gamma-rays 7(?) known: 3C279, PKS1510-089, PKS1222+216

-PKS1441+25 and B0218+357 the newbies

-S4 0954+65 and BL Lac disputed classifications

- In Fermi >10GeV catalog 70 FSRQs

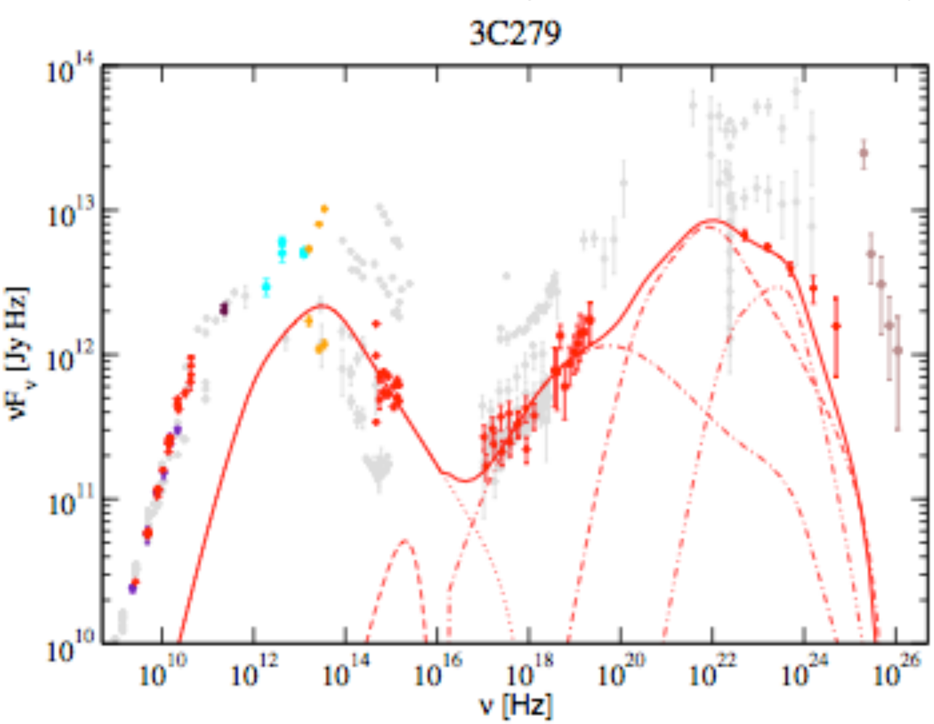




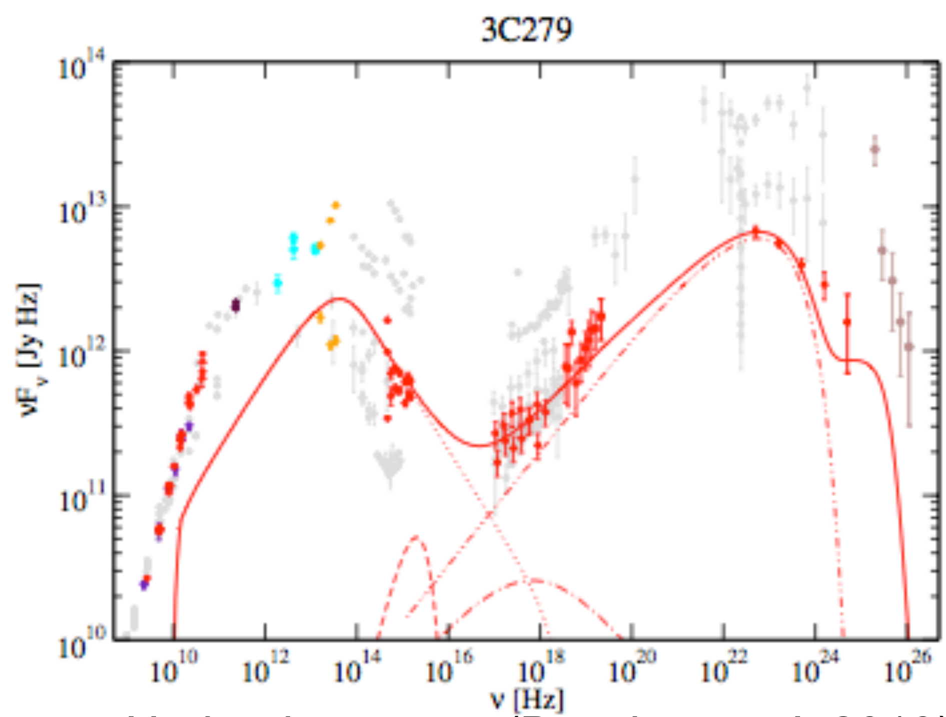
Emission mechanism?

Leptonic: synchrotron + inverse Compton scattering
Hadronic: photo-pair and photo- pion production, the cascades initiated by γ γ absorption of ultrahigh energy (UHE; E ≫ 1 TeV) photons produced through π0 decay and synchrotron emission of pions and their decay products.

Both can fit the SEDs, but: “The hadronic model presented here has difficulty describing the **GeV break** in the SEDs of two FSRQs, but provides appropriate fits for all other blazars in our sample.
However, the **fits require very large powers in relativistic protons**, of LP ~ 1047 –1049 erg s−1 , in most cases dominating the total power in the jet.



Leptonic



Hadronic (Bottcher et al. 2013)

Emission scenarios: "Close to the central engine"

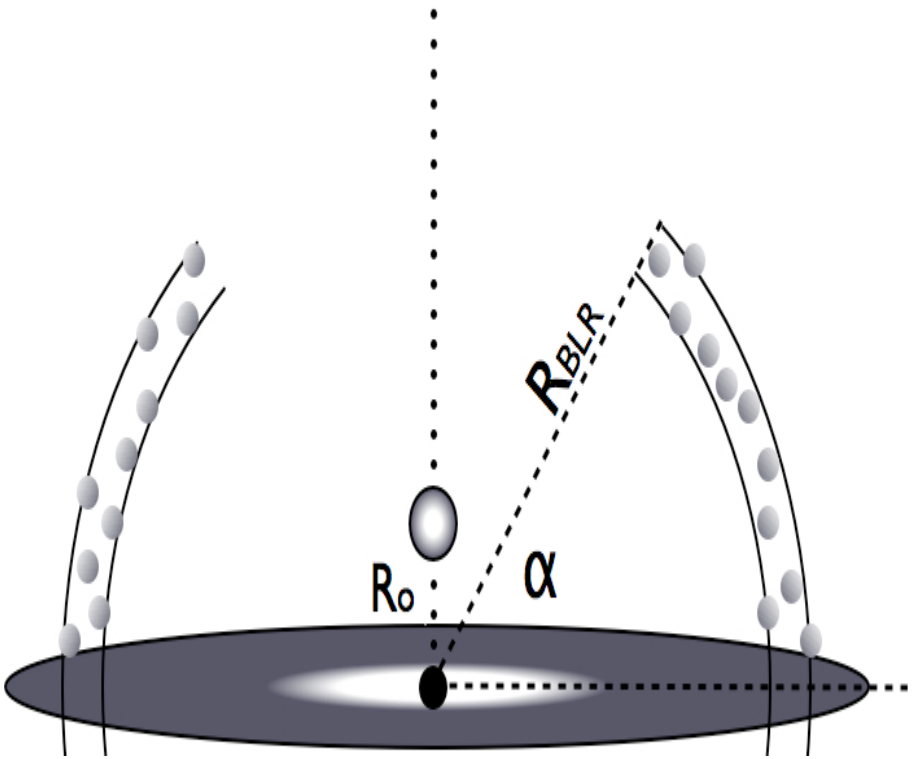


Image credit: Tavecchio & Ghisellini 2012

- Emission region close to central engine is the most economic way to produce the high luminosity (e.g. work by G. Ghisellini)
- And the most natural way to accommodate the short time scale variability (e.g. Tavecchio et al. 2010, MNRAS,405,94)
- A strong depression above ~20 GeV due to absorption (Donea & Protheroe 2003; Sitarek & Bednarek 2008; Tavecchio & Mazin 2009; Poutanen & Stern 2010). Scenario excluded if VHE emission observed (e.g. Tavecchio& Ghisellini 2012), however ongoing debate (e.g. Stern & Poutanen 2014)

Emission scenarios: “Far out emission region”

- Coincident timing of the radio (mm-flares, ejection of new components from VLBA core) and gamma events: Main part of the emission originates close to the 43GHz VLBA core (suggested already in EGRET era by Valtaoja et al. 1996, Jorstad et al. 2001)
- What is the source of the seed photons for the IC scattering (an infrared torus, a sheath, a standing shock?)
- What mechanism produces the fast gamma-ray variability (mini-jets? Magnetic reconnection? Turbulence caused by recollimation?)

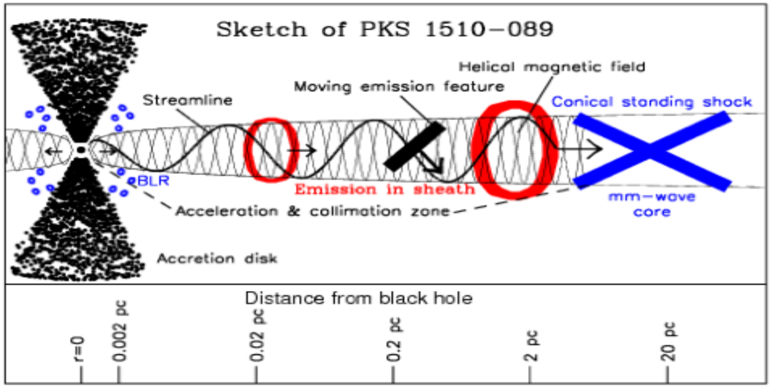


Image credit: Marscher et al. (2010): Moving emission feature on helical path, hits the conical standing shock=> gamma-ray flare, ejection of new component from the VLBA core

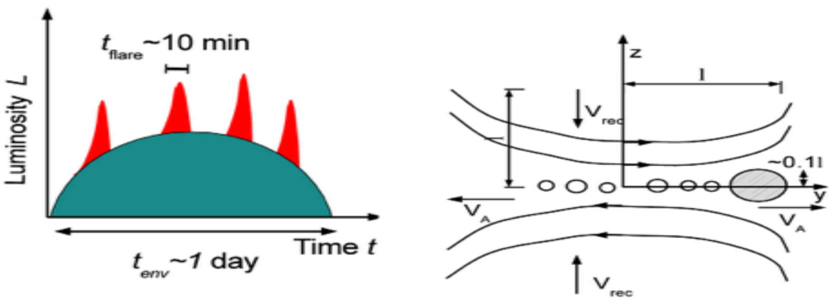


Image credit: Giannios (2012): Re-connection driven plasmoids

What can we learn by observing VHE emission?

Absorption: very severe, if the emission region inside BLR

=> If we see VHE, the emission region is outside BLR

Rapid variability: very small emission region

=>Very challenging to produce such emission region

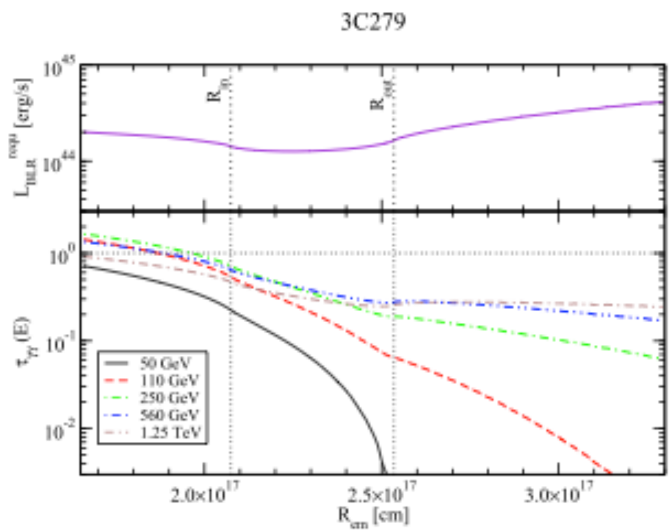
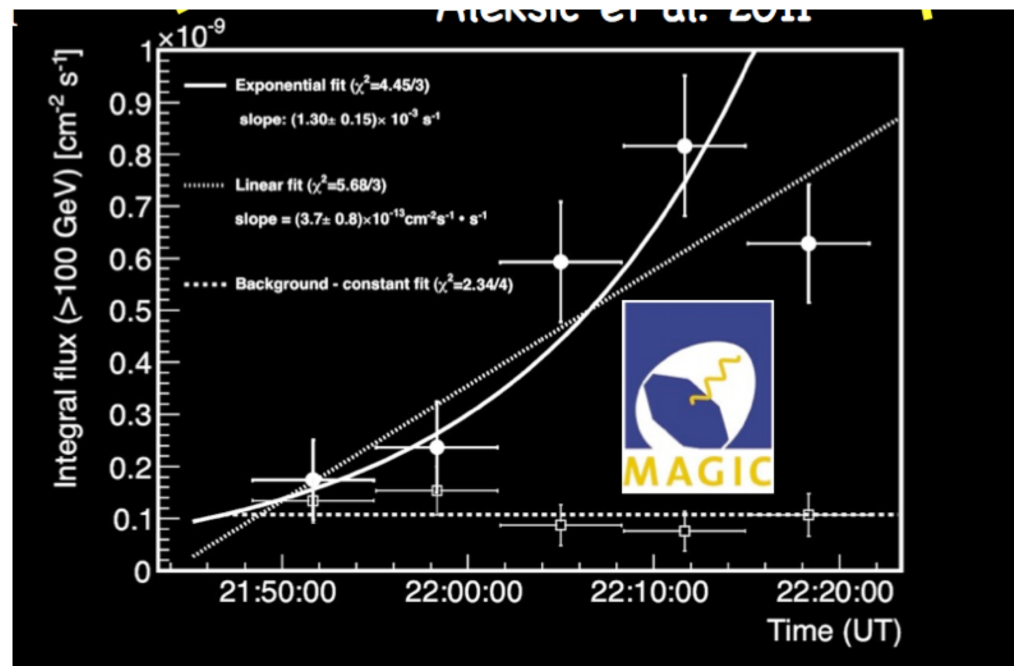


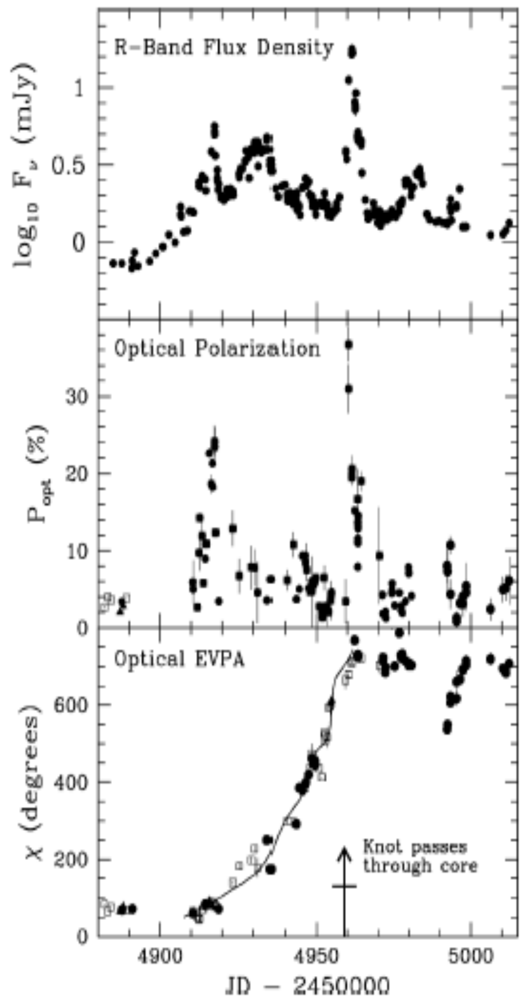
Figure 2. Results for 3C279. Lower panel: $\gamma\gamma$ absorption optical depth as a function of location of the emission region, R_{em}, for a fixed value of u_{BLR} as encountered by the emission region at the respective location (see the text), for several γ-ray photon energies. Upper panel: required luminosity of the BLR, according to the re-normalization of the local BLR emissivity (Equation (8)).



Bottcher et al. 2016

Aleksic et al. (MAGIC Collaboration), 2011

What can we learn from optical polarisation?

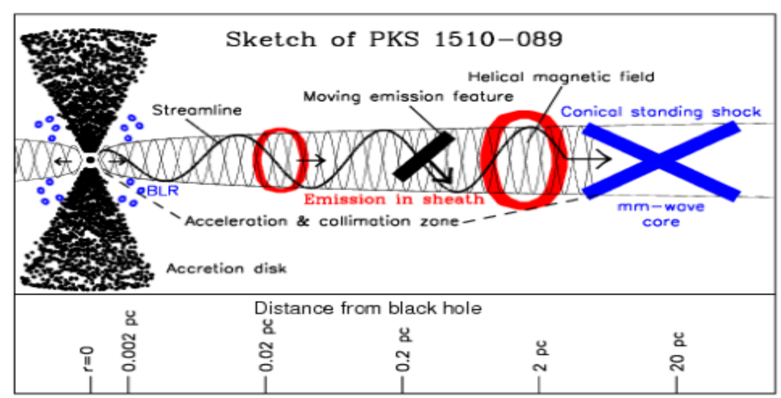


Marscher et al. 2010

Rotations of EVPA seen in many sources

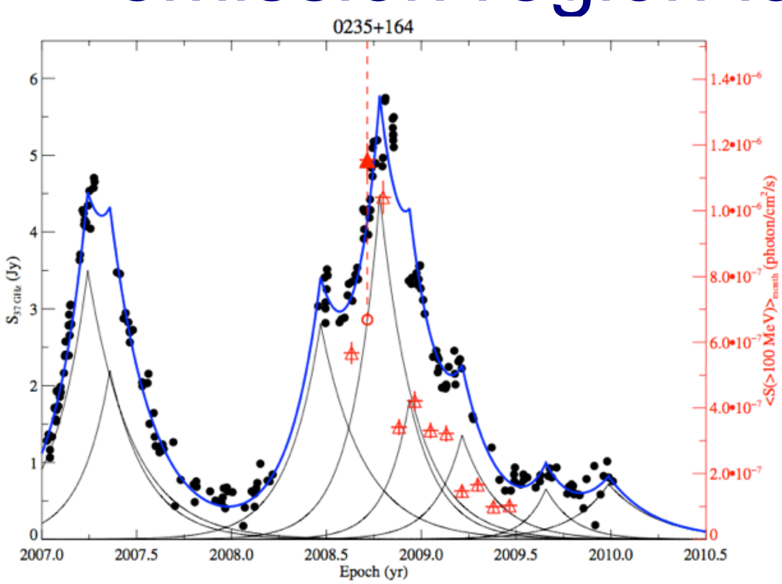
(BL Lac, PKS 1510-089, 3C279…)

- -Geometrical effect (bend in the jet?)
- -Emission feature moving along the
- streamline in acceleration and
- collimation region?

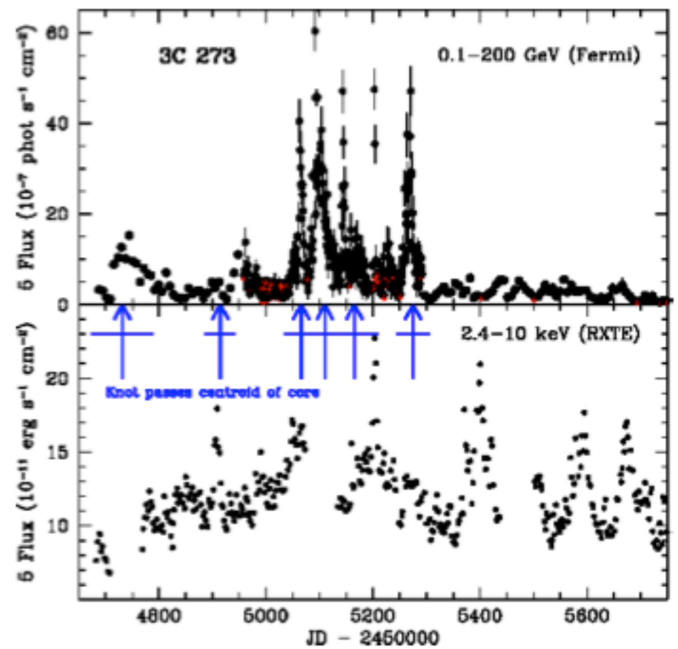


What can we learn from radio observations?

- Synchrotron self absorption; radio emission cannot originate very close to the central engine (~5-15pc from central engine)
- Flares in radio, ejection of knots in VLBA => emission region far from the central engine

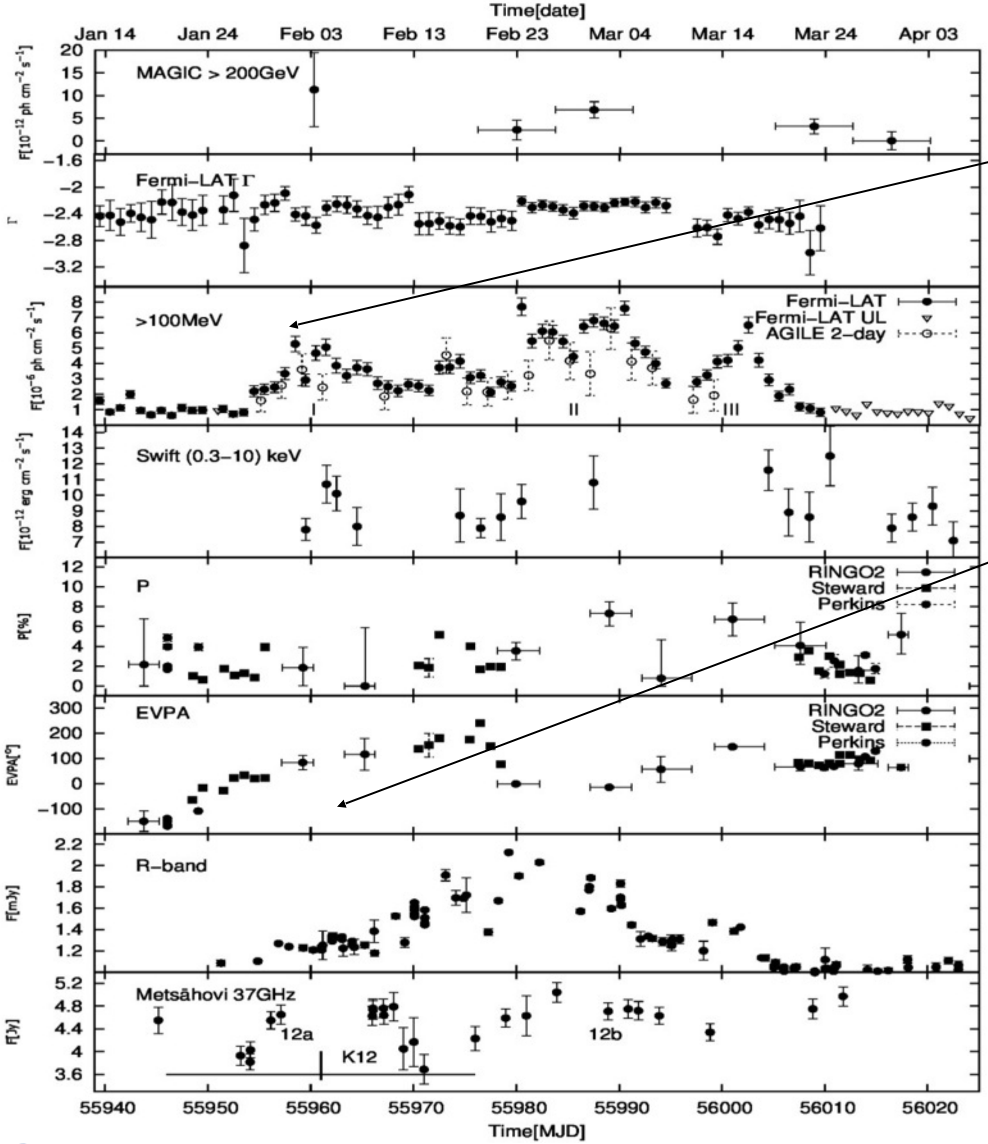


Leon-Tavares et al. 2011

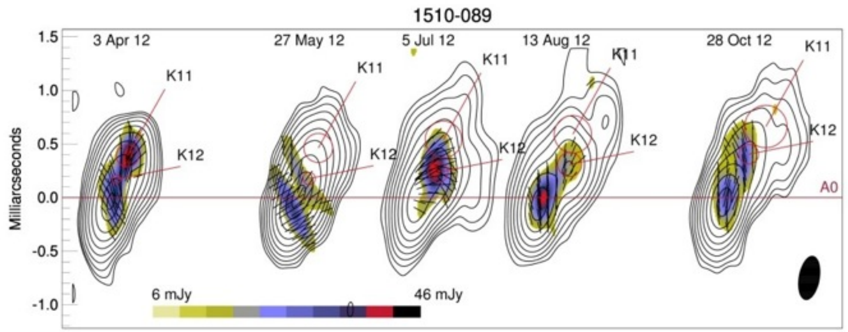


Marscher et al. 2012

PKS 1510-089 in 2012



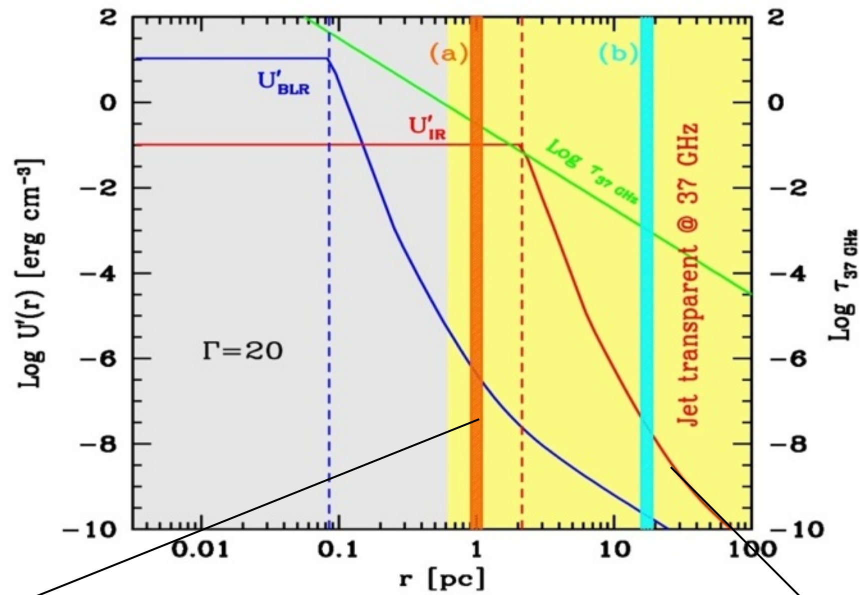
- MAGIC observations were triggered by the high state in HE gamma-ray band
- Simultaneous variability at 37GHz and HE gamma-rays
- Rotation of the optical polarization angle >180 degrees
- Ejection of new VLBA component



Aleksic et al (the MAGIC Collaboration). 2014, A&A

Far-out emission region SED modelling

Energy density of the photon field as function of the distance from the central engine

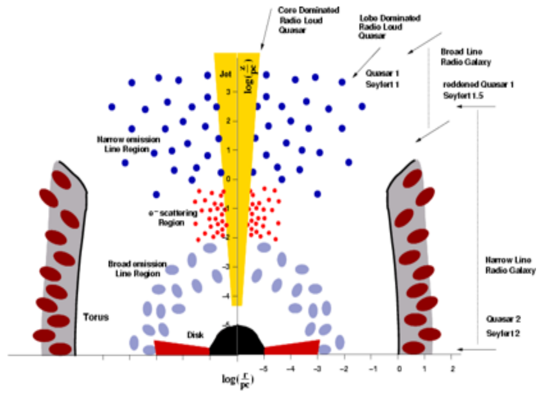


Blue: BLR

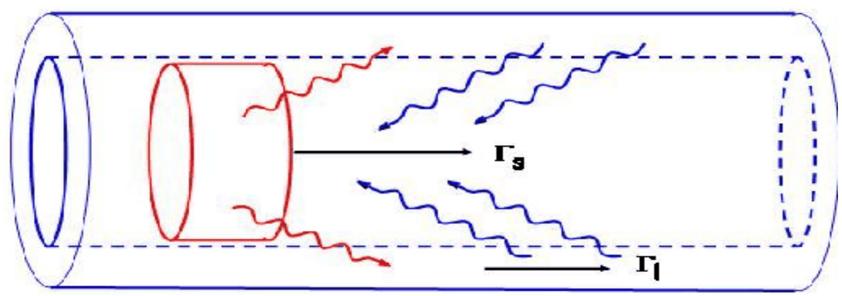
Red: IR torus

Aleksic et al. 2014, A&A

Seed photons from torus



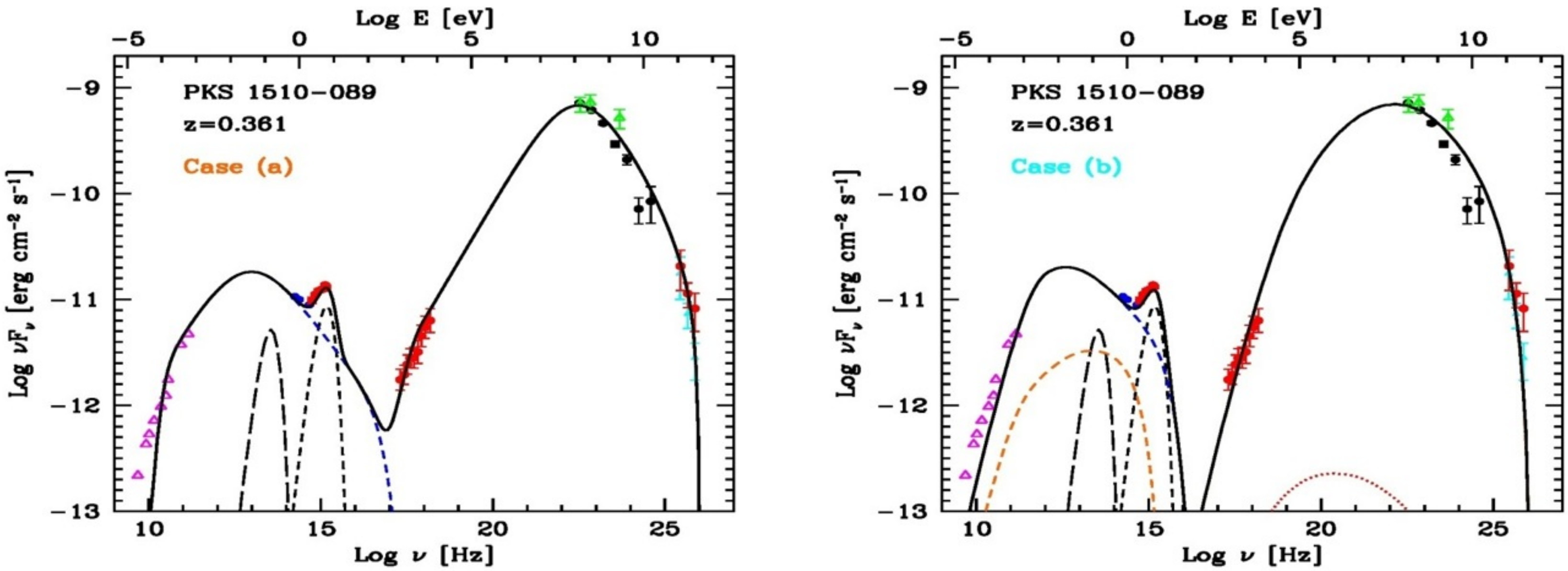
Seed photons from slow sheath



Ghisellini et al. 2005, observational evidence for PKS1510-089 in MacDonald, Marscher et al. 2015

Far out SED modelling: PKS 1510-089 in 2012

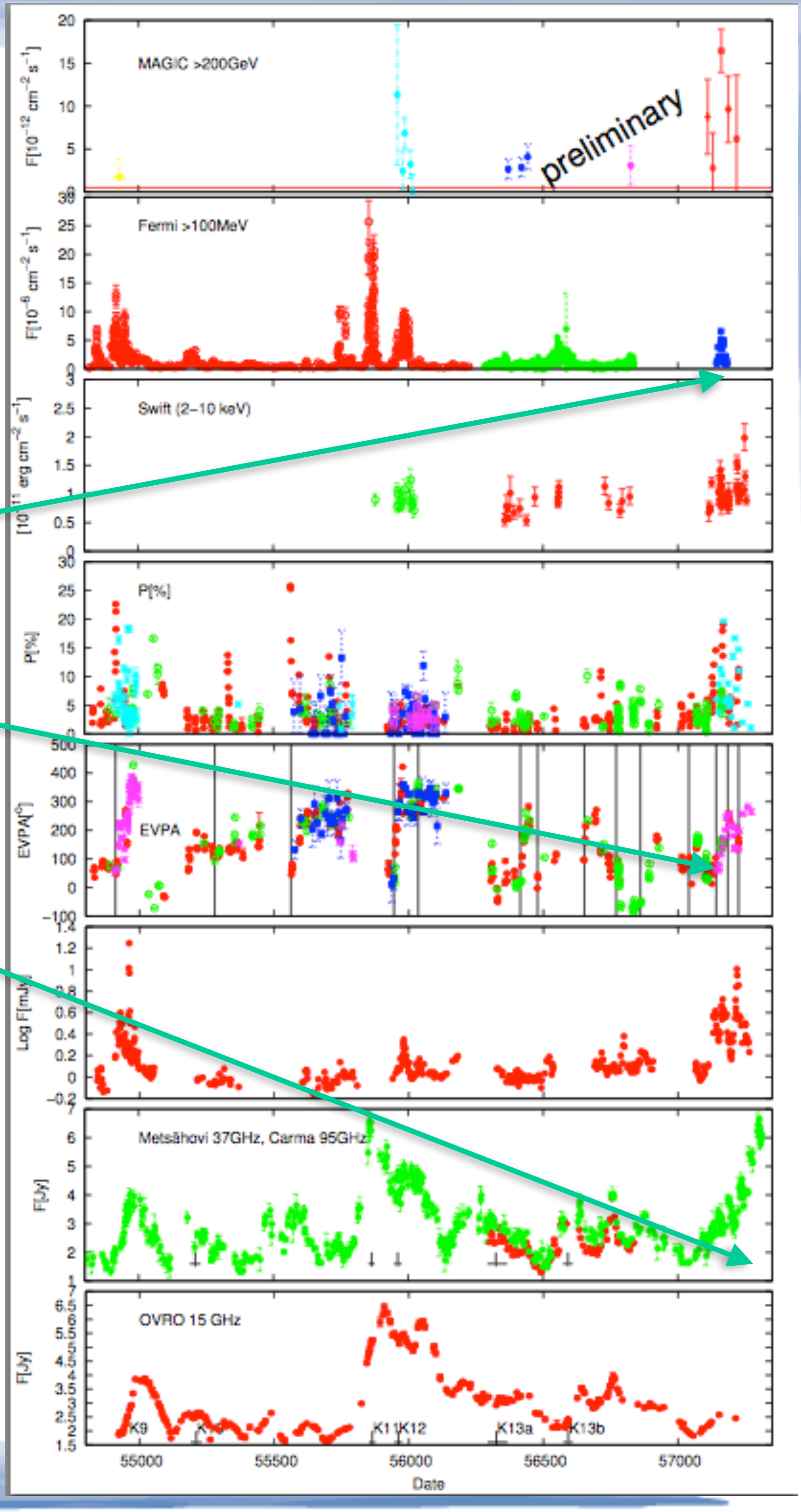
- Spectral energy distribution (average!) assuming seed photons for External Compton model from far out resources IR torus OR from slow sheath of the jet



- Far out scenario works here, does it work in general?

PKS 1510-089 story continues

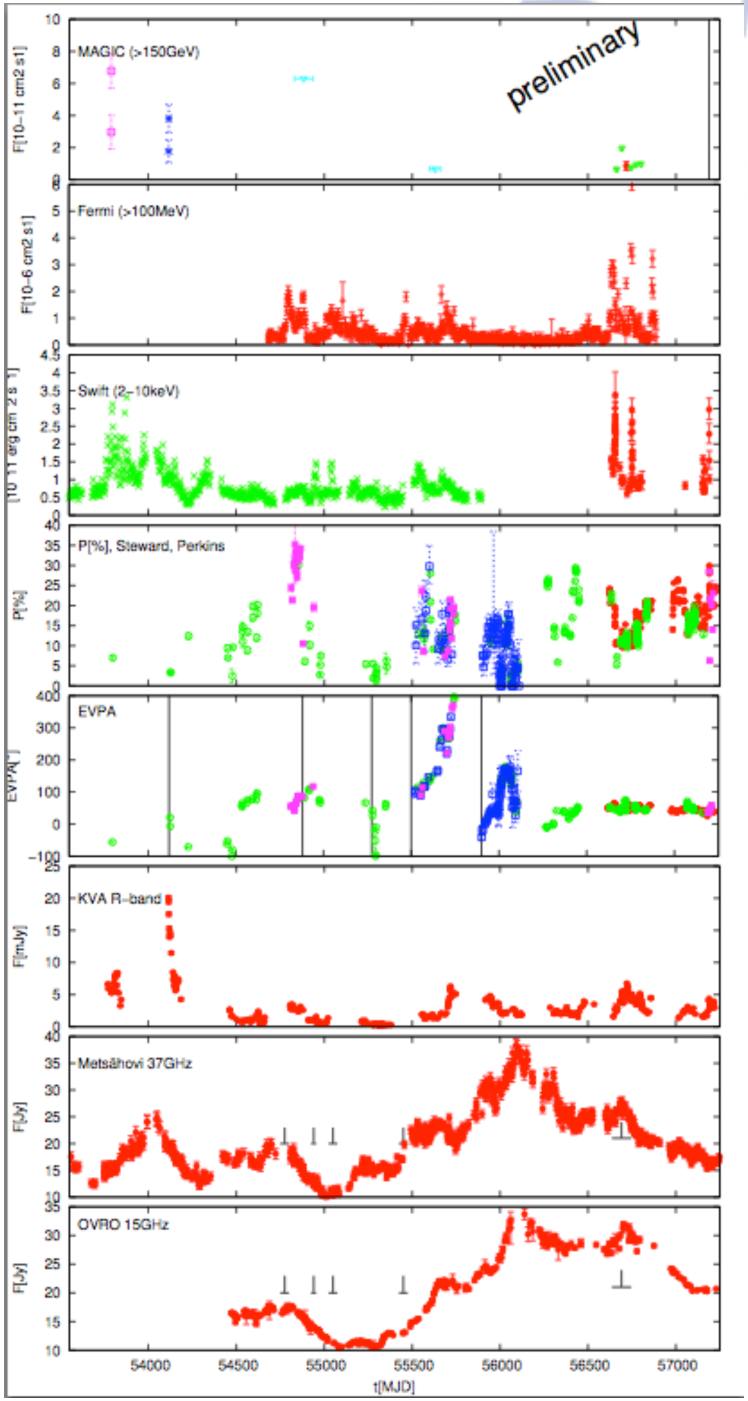
- Data from 2009-2015
- Radio-optical polarization-gamma connected?



- Work in progress: is the connection significant.

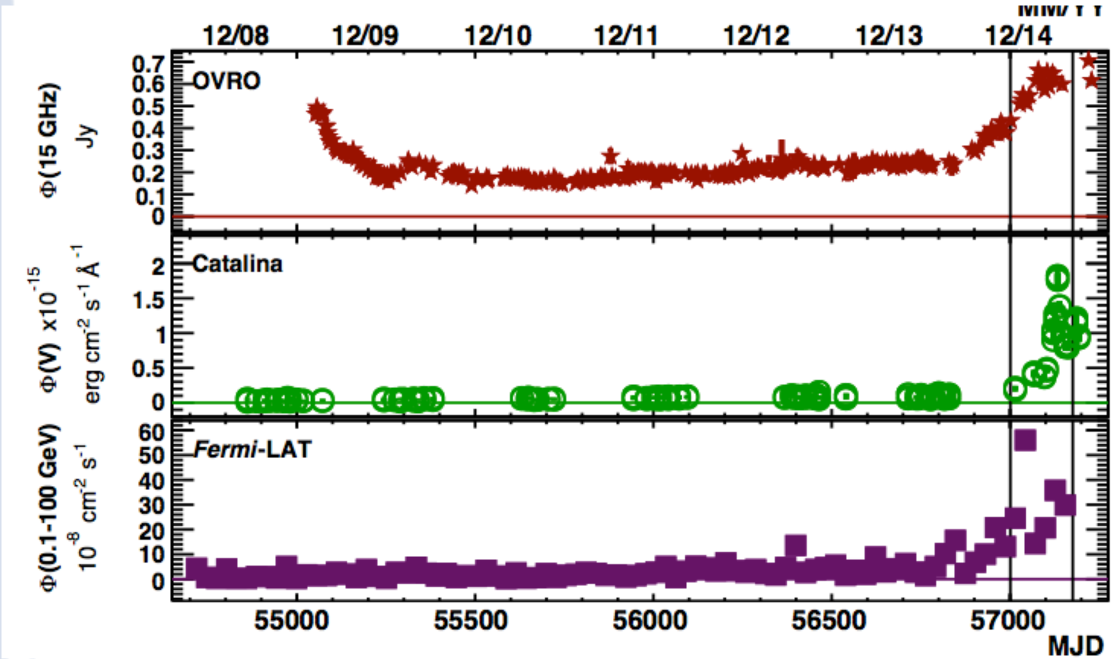
Other FSRQs: 3C279

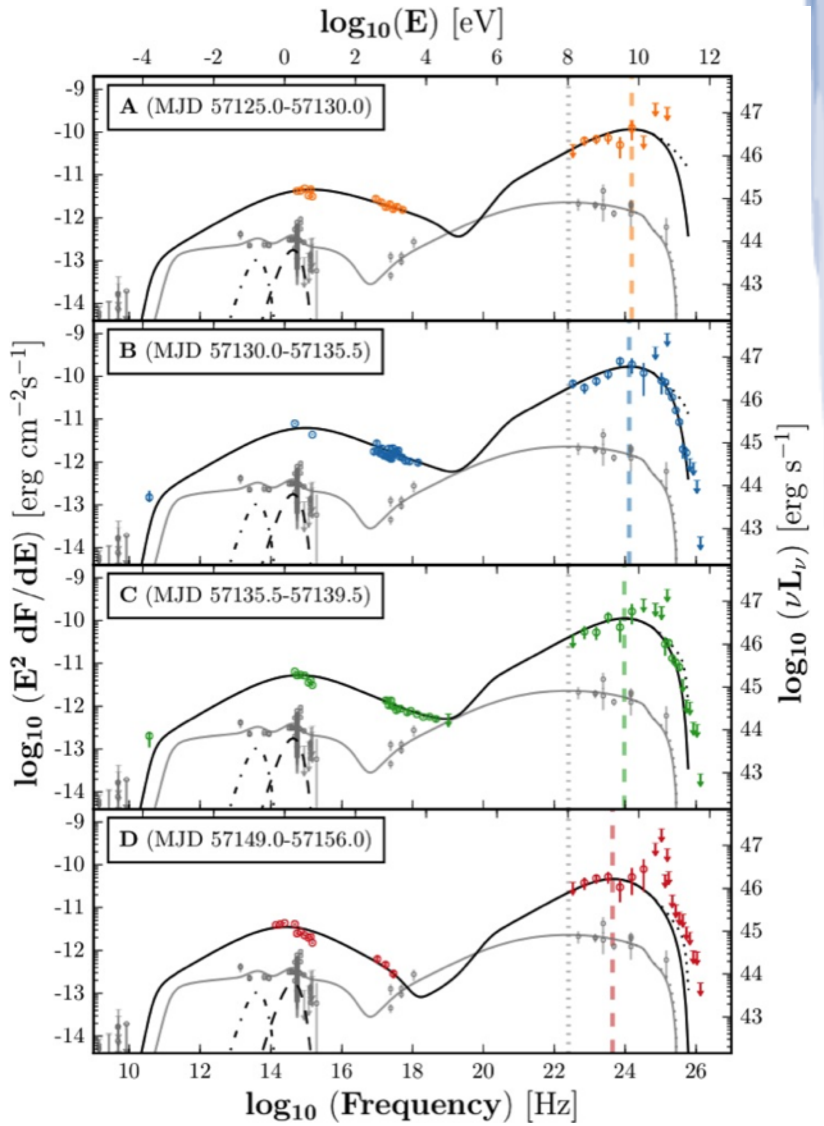
- In 2007: radio+rotation+VHE
- In 2014-2015
  - Major flaring in Fermi-band (Hayashida et al. 2015, Fermi Collaboration 2016)
  - Radio picture very complicated
  - No rotations in EVPA
  - No major flares in VHE?
- Work in progress



FSRQ PKS1441+25 at z=0.94

- Slow increase of flux
- Something "pushing" the energy dissipation region "out"?





Conclusions

- Currently many open questions on VHE gamma-ray emission of FSRQs:
  - emission site
  - seed photons for IC scattering
  - fast variability
  - low state VHE emission
- Long-term monitoring observations with good sensitivity below 100 GeV mandatory to solve the puzzle