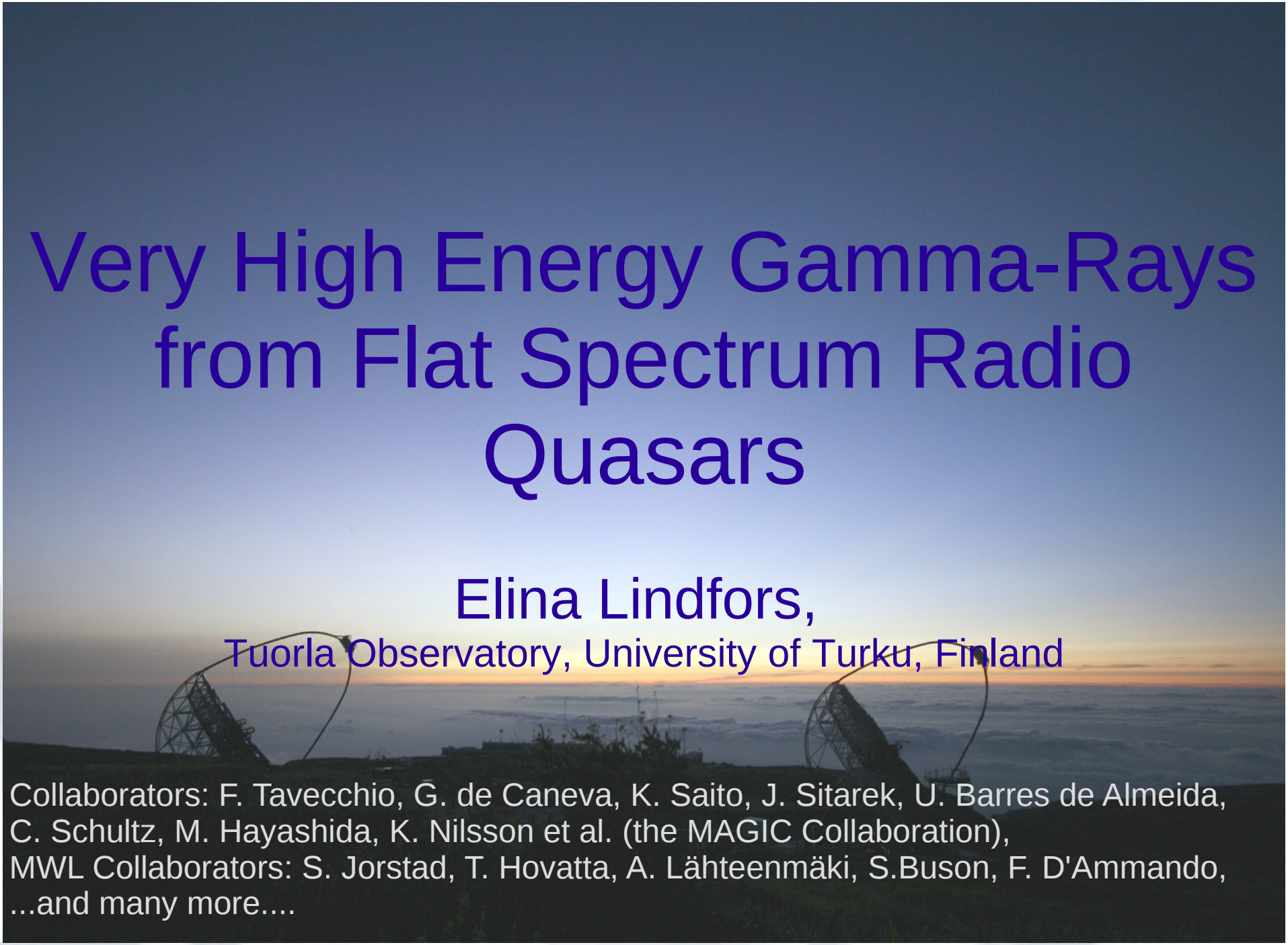
# Very High Energy Gamma-Rays from Flat Spectrum Radio Quasars

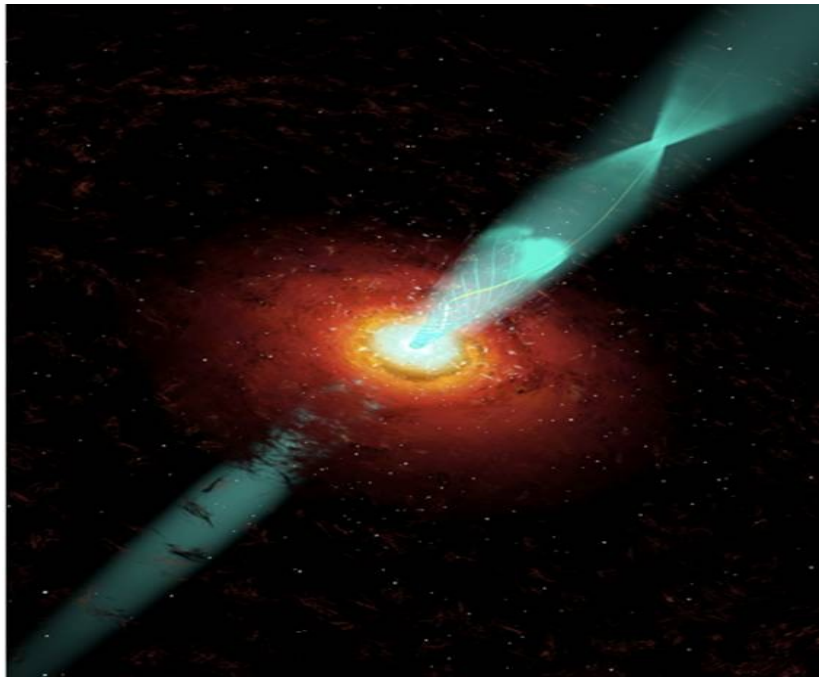
Elina Lindfors,
Tuorla Observatory, University of Turku, Finland



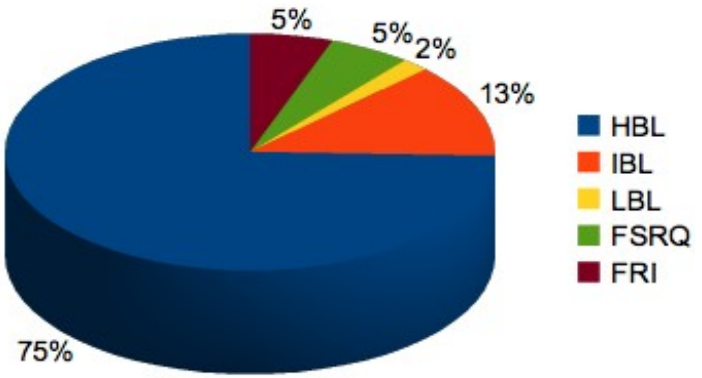
Collaborators: F. Tavecchio, G. de Caneva, K. Saito, J. Sitarek, U. Barres de Almeida, C. Schultz, M. Hayashida, K. Nilsson et al. (the MAGIC Collaboration),
MWL Collaborators: S. Jorstad, T. Hovatta, A. Lähteenmäki, S.Buson, F. D'Ammando, ...and many more....

# Extragalactic VHE gamma-ray sky

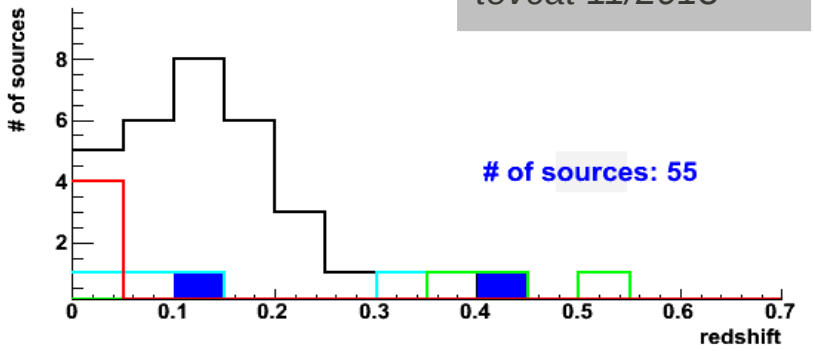
- 2003: 5 sources
  2013: 55 sources
- Active galactic nuclei of blazar type (~50), radio galaxies (4) starburst galaxies (2)



currently known TeV AGN

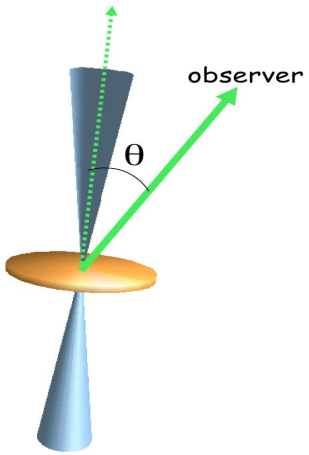


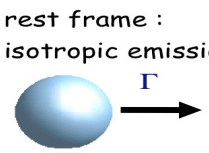

*tevcat 11/2013*



# Blazars

-Relativistic jet, small angle to line of sight of the observer
-BL Lac objects and Flat spectrum radio quasars





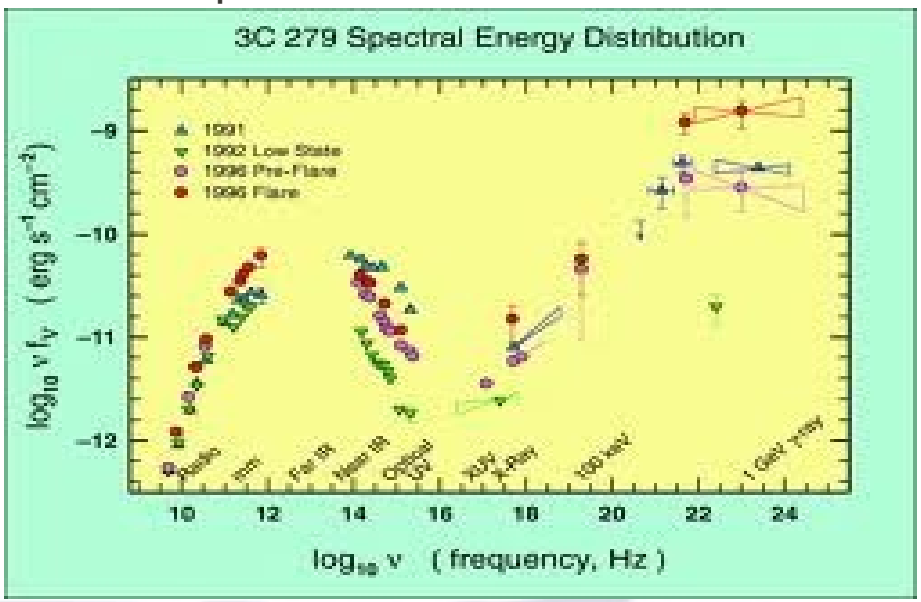
Beaming factor:

- $\delta = \frac{1}{\Gamma(1-\beta cos(\theta))}$
- $\theta = 1/\Gamma$

Radio to optical-X-rays: Synchrotron emission from relativistic electrons spiraling in the magnetic field of the jet

X-rays to gamma-rays: Inverse Compton Scattering off *seed photons* from relativistic Electrons

Seed photons: the synchrotron photons or external photon field



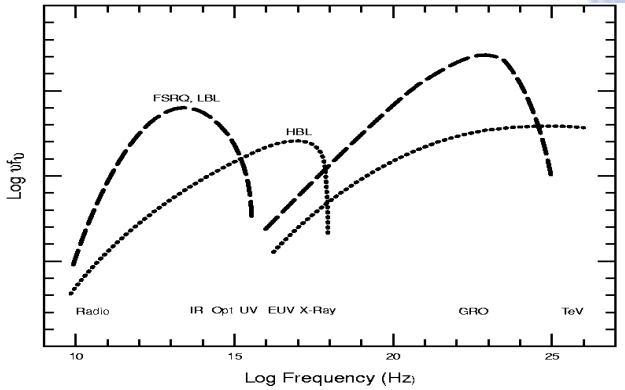
# Flat Spectrum Radio Quasars

- Within the gamma-ray emitting AGN class: the most luminous sources
- 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)

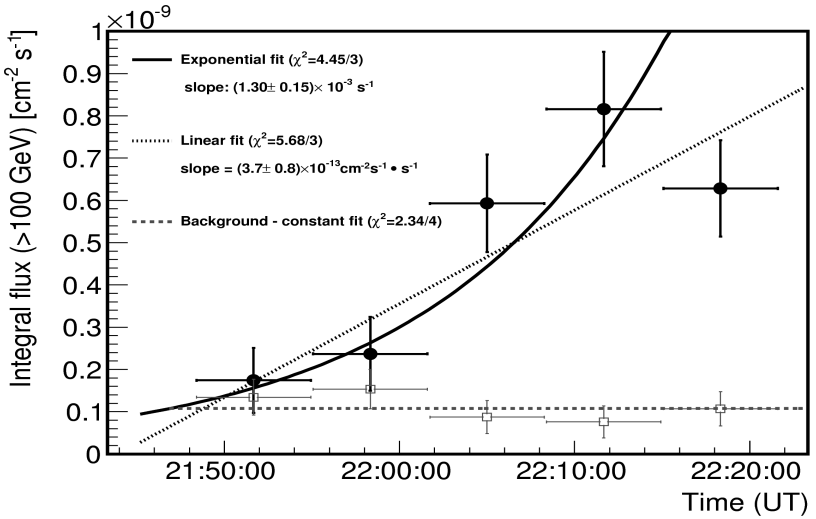


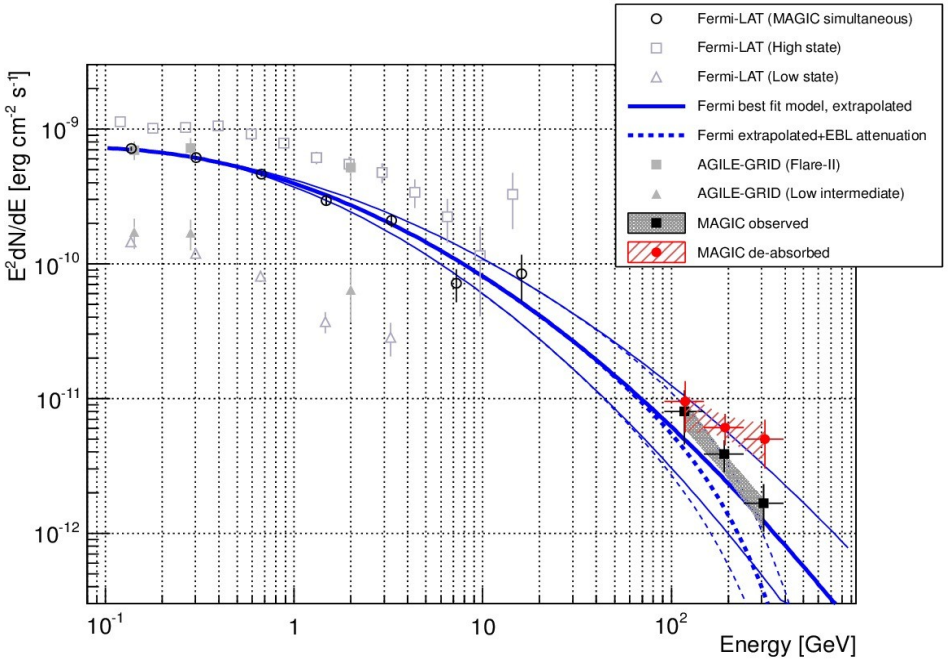

- In VHE gamma-rays only 3 known (70 in FHL):
  -3C279 (MAGIC in Feb 2006 and Jan 2007, single night detections)
  -PKS1510-089 (H.E.S.S. in 2009, MAGIC in 2012, no VHE variability)
  -PKS1222+216 (MAGIC Single night in June 2010, VERITAS several nights in Feb 2014)

# VHE gamma-rays from FSRQs

FSRQs detected only during “high states” in lower energy regimes

Fast variability in gamma-rays: e.g. PKS1222+216 <10 minutes in VHE (Aleksic et al. 2011), PKS 1510-089 20 minutes in HE (Foschini et al. 2013)

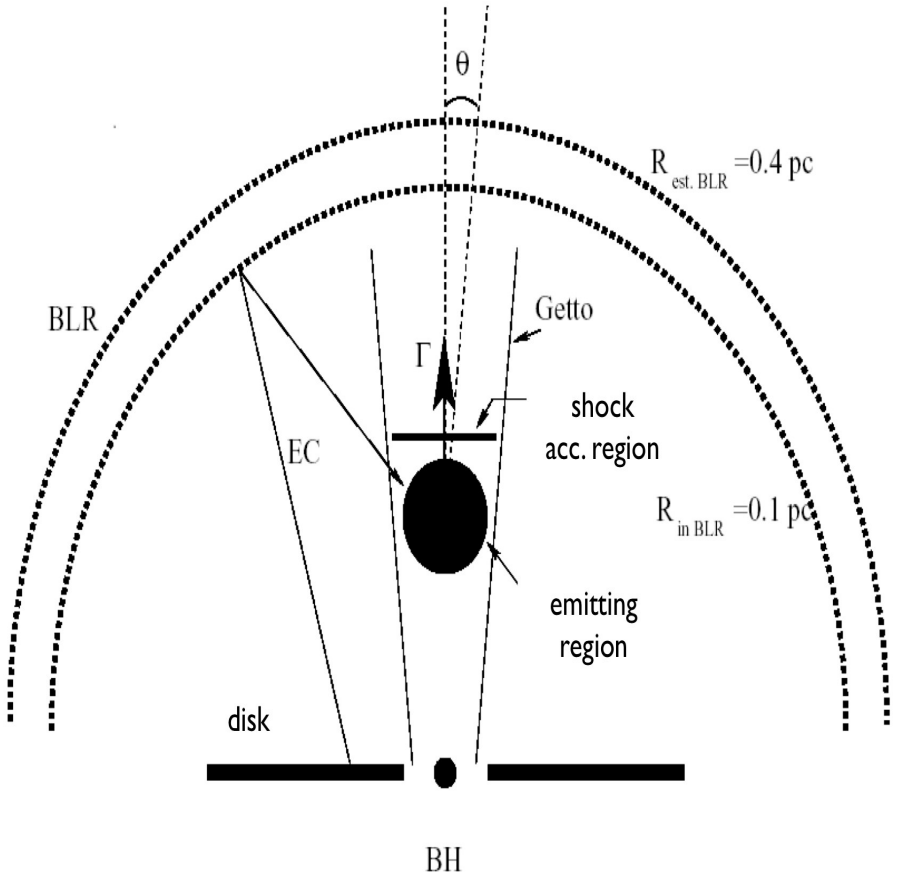



Gamma-ray SEDs:
-HE and VHE connect smoothly
-soft spectrum, signal <400 GeV

# Emission models and open questions

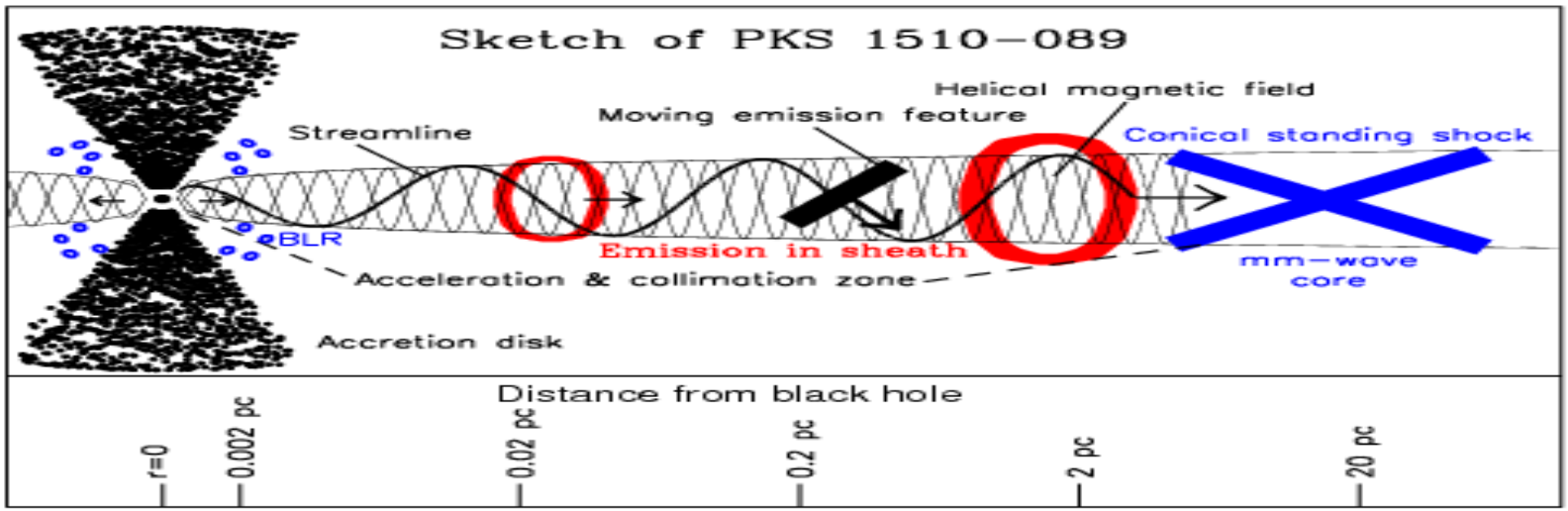
# Emission scenarios: “Close to the central engine”




- Emission region close to central engine is the most economic way to produce the high luminosity (G. Ghisellini)
- And the most natural way to accommodate the short time scale variability (e.g. Tavecchio et al. 2010)
- A strong depression above ~20 GeV due to absorption (Donea & Protheroe 2003; Sitarek & Bednarek 2008; Tavecchio & Mazin 2009; Poutanen & Stern 2010)

# Emission scenarios: “Far out emission region”

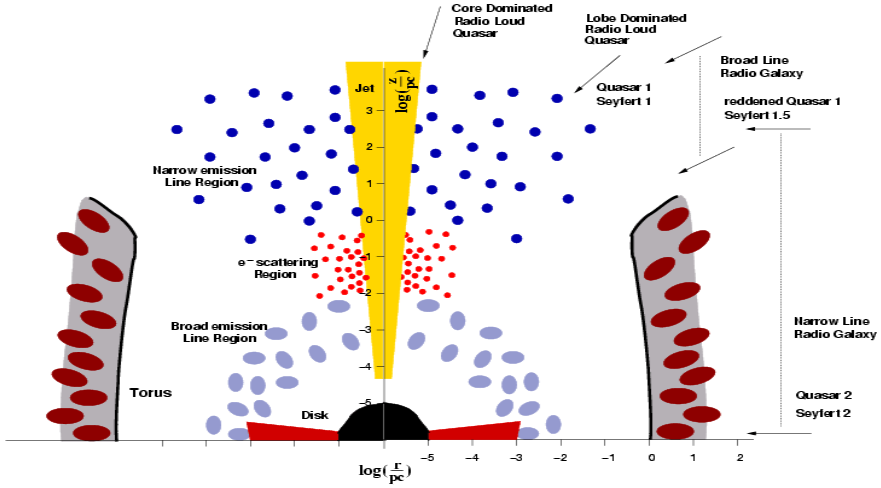
- Coincident timing of the radio and gamma events: Main part of the emission originates close to the 43GHz VLBA core (suggested already in EGRET era by Valtaoja et al. 1996, Jorstad et al. 2001)
- Marscher et al. (2010): Moving emission feature on helical path (rotation of the optical polarization angle), hits the conical standing shock (the 43GHz VLBA core) => gamma-ray flare, ejection of new component from the VLBA core

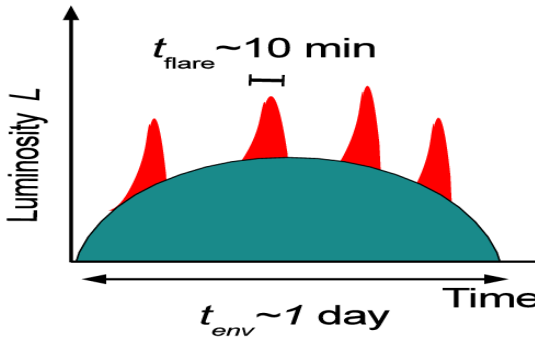


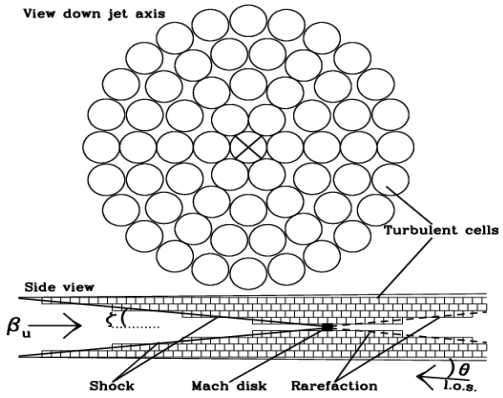
# Emission scenarios: “Far out emission region”

-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?)



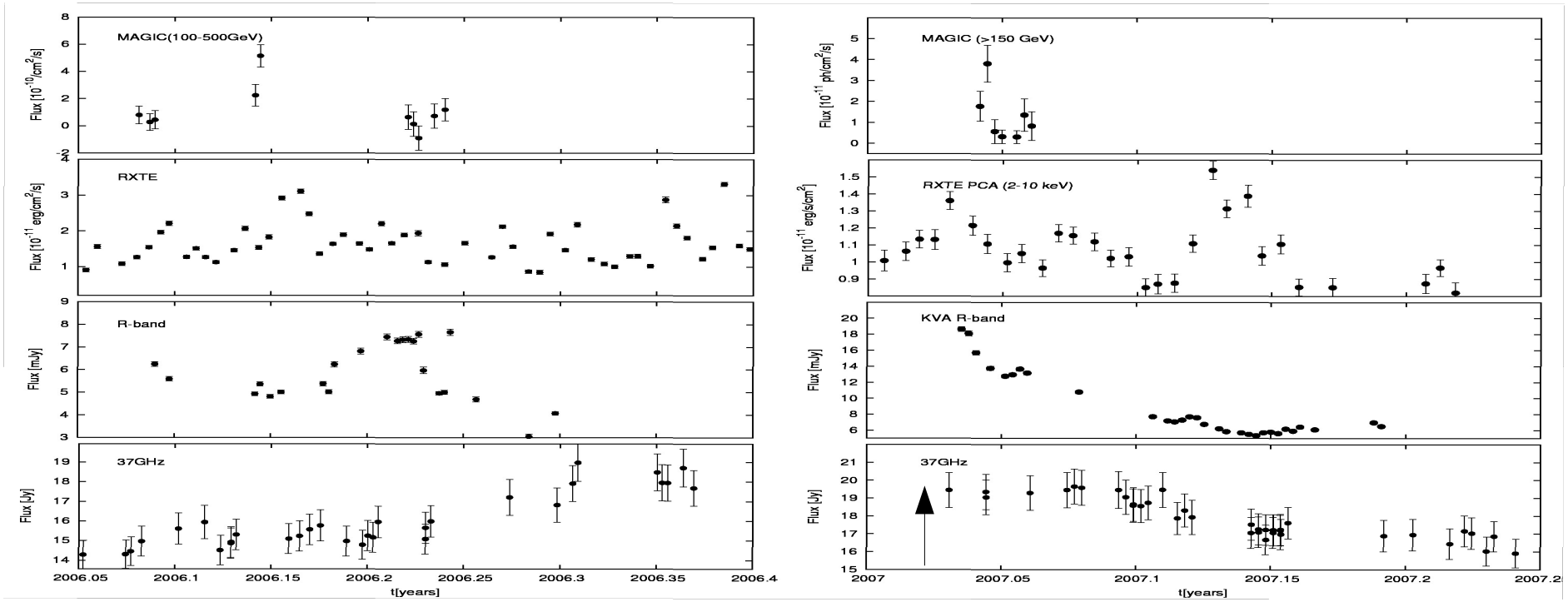



# VHE observations and MWL behaviour

# MWL behaviour: 3C279 in 2006 and 2007

- 2006: optical flare, bright in X-rays, nothing in VLBA
- 2007: major optical flare, ejection of new VLBA knot, low in X-rays

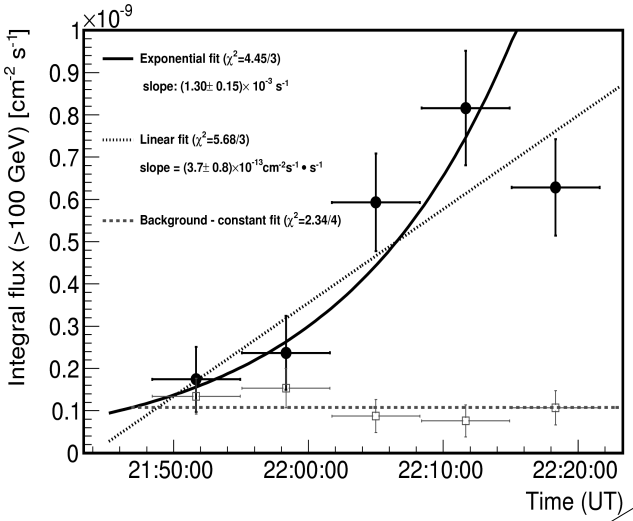



Emission region inside BLR?

Ejection of VLBA component
Multiple regions, VHE emission outside BLR?
Seed photons for IC from IR torus

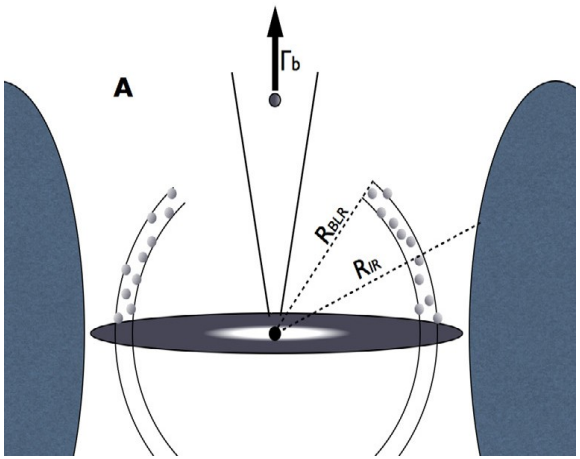
Aleksic et al. A&A, 2011

# MWL behaviour: PKS1222+216 in 2010

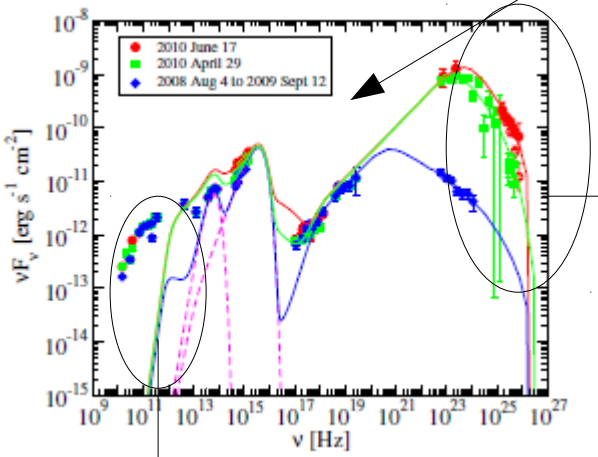



Fast VHE variability:

Single emission region, smaller than the cross section of the jet at that distance



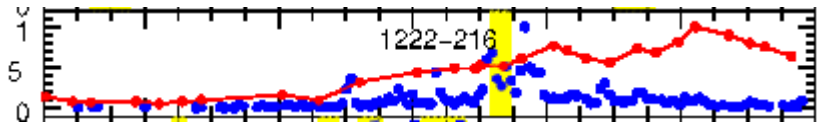

Tavecchio, Becerra-Gonzalez et al. 2011




The region must be outside the BLR

Ackermann et al. 2014, ApJ

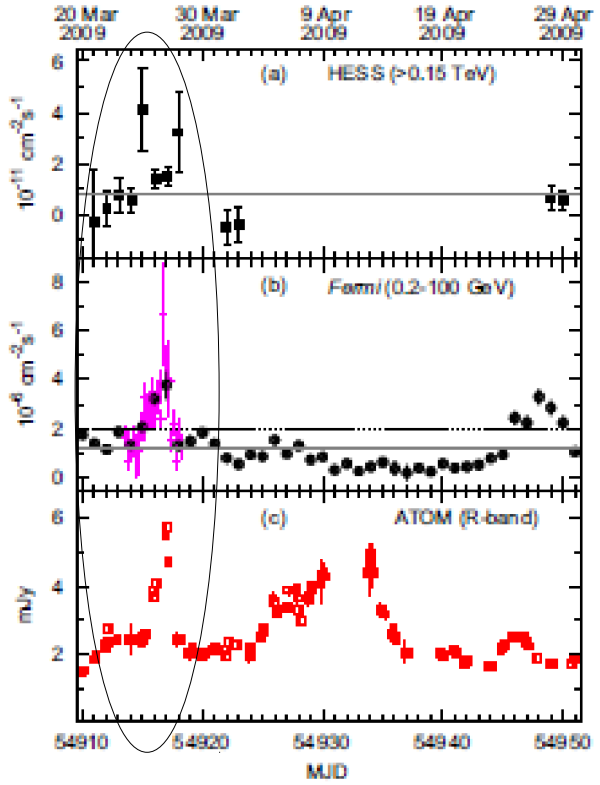
The compact region cannot emit at radio wavelengths




During the gamma-ray flaring activity, ejection of new component from the 43GHz VLBA core (Marscher et al. 2012)

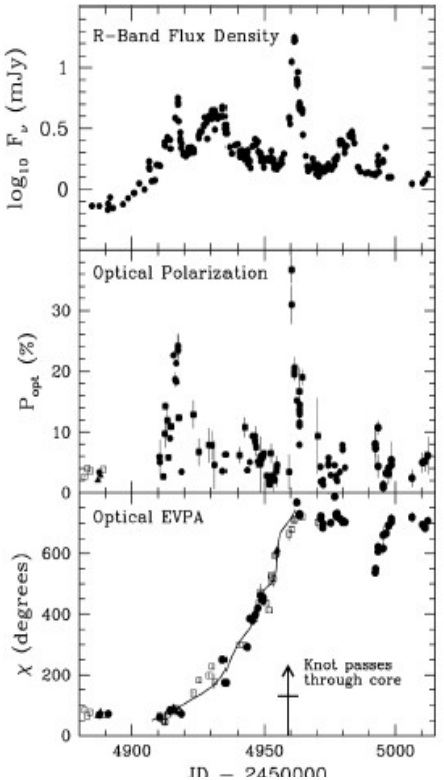
# MWL behaviour: PKS1510-089 in 2009

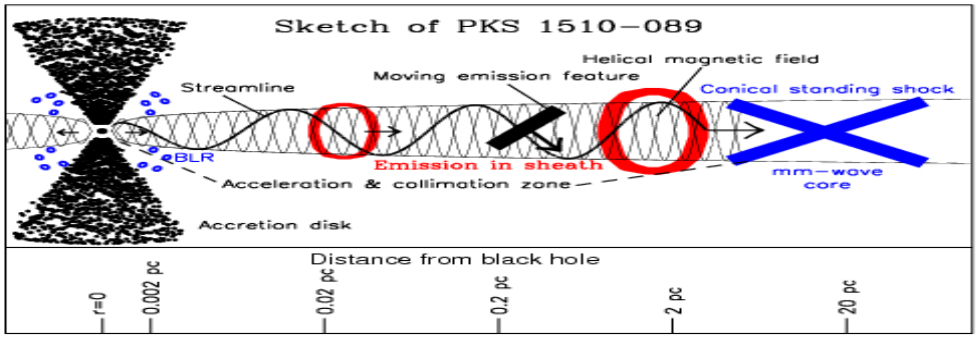
No significant VHE variability,
VHE emission during optical-HE gamma-ray state




Abramowski et al. 2013

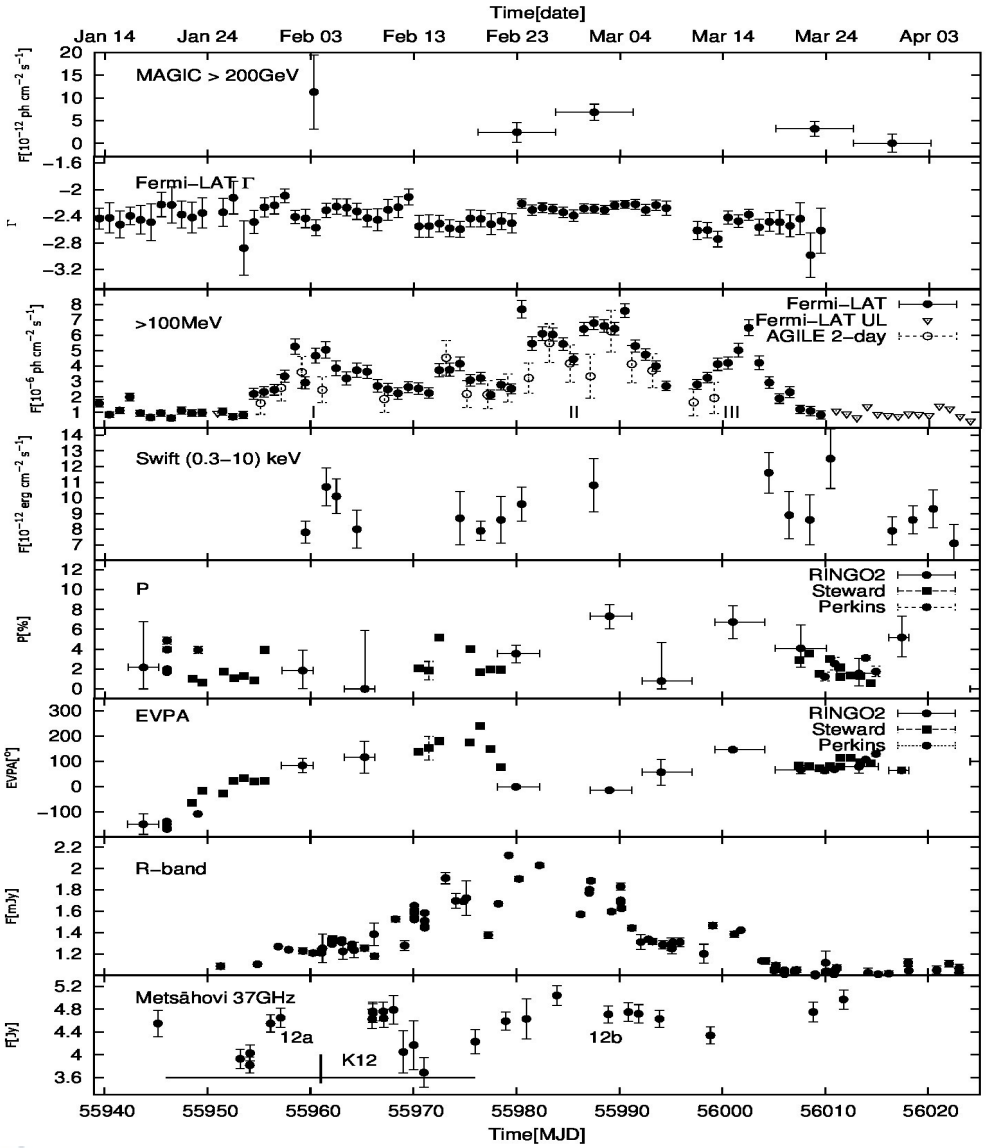
Radio to optical behavior:
Rotation of the EVPA,
VLBA knot passes through core



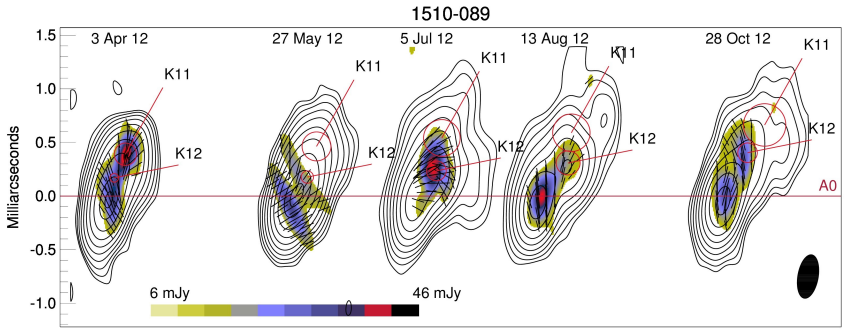




Marscher et al. 2010

# New results: 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. 2014, accepted to A&A, arXiV:1401.5646

# New results: PKS 1510-089 in 2012

- The gamma-ray SED: Fermi-LAT (average) and MAGIC connect smoothly
- The non-variability of the VHE gamma-rays can be (at least partially) be explained with “bad luck”
- “Big picture” looks similar to 2009 behaviour: emission originated outside BLR, close to 43 GHz VLBA core

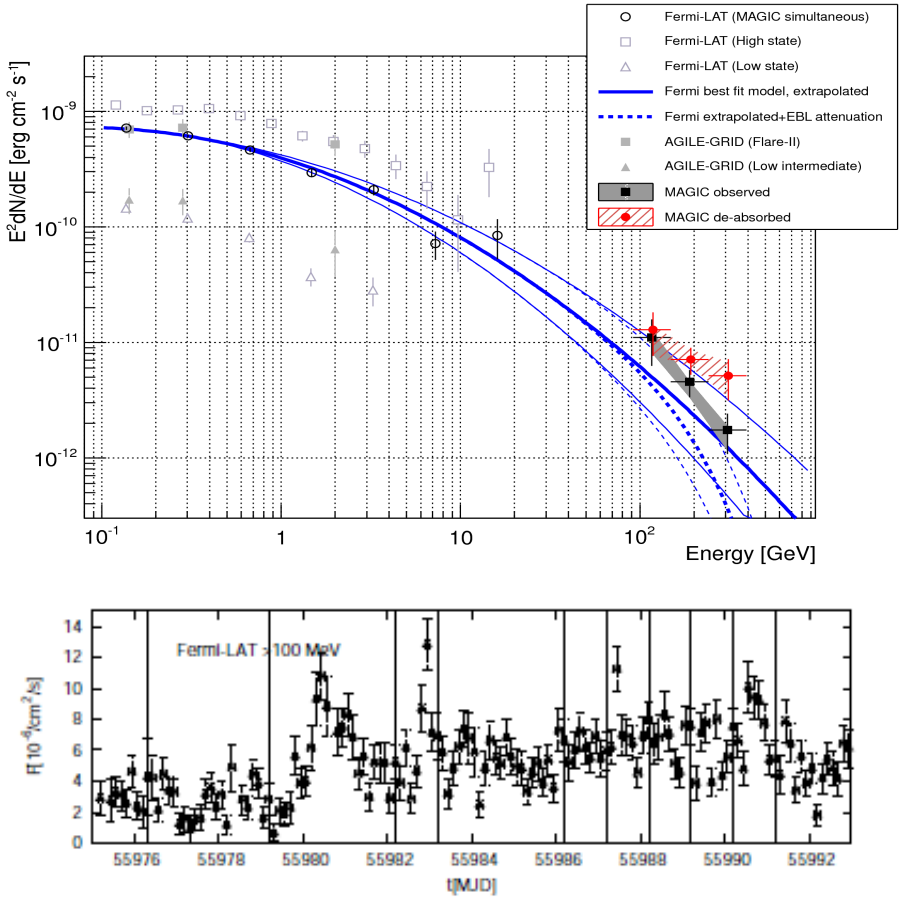
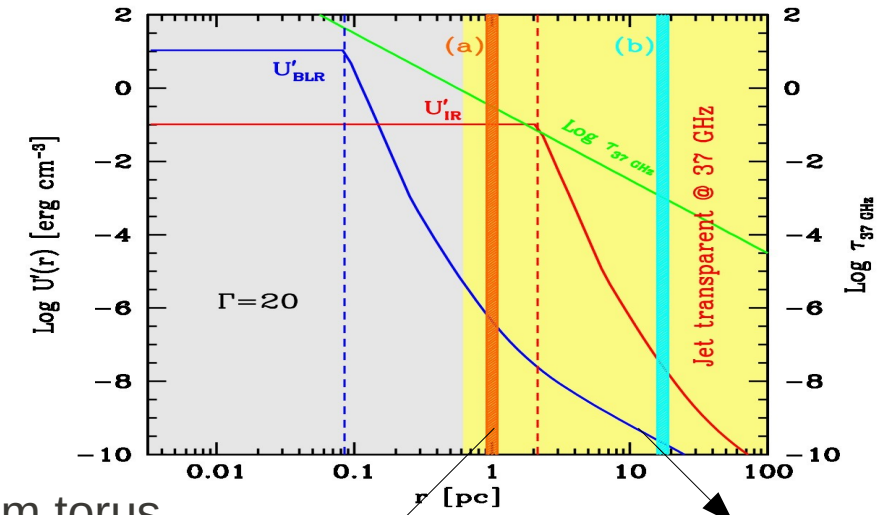



**Fig. 3.** *Fermi*-LAT >100 MeV light curve in the three hour bins for the first MAGIC observing period. The vertical lines represent the MAGIC observing times (all shorter than 3 hours in duration) showing that the MAGIC observation windows missed the times of the fastest HE $\gamma$-ray variability.

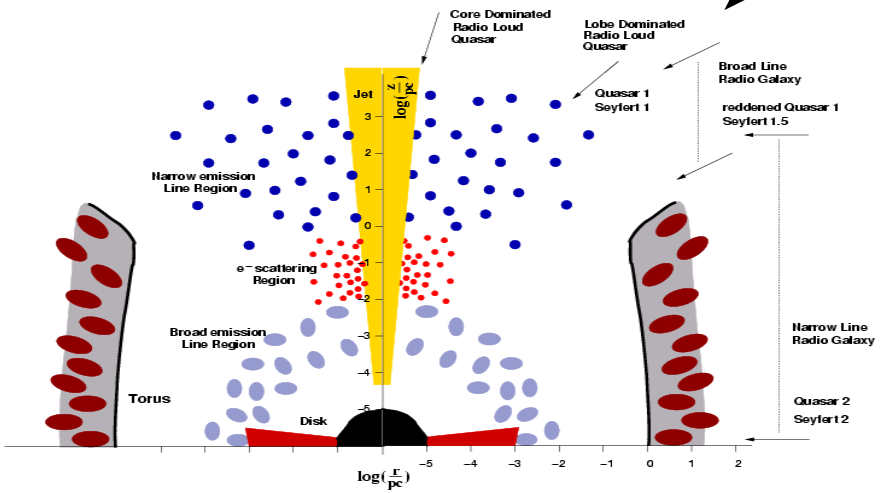
# New Results: PKS 1510-089 in 2012

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

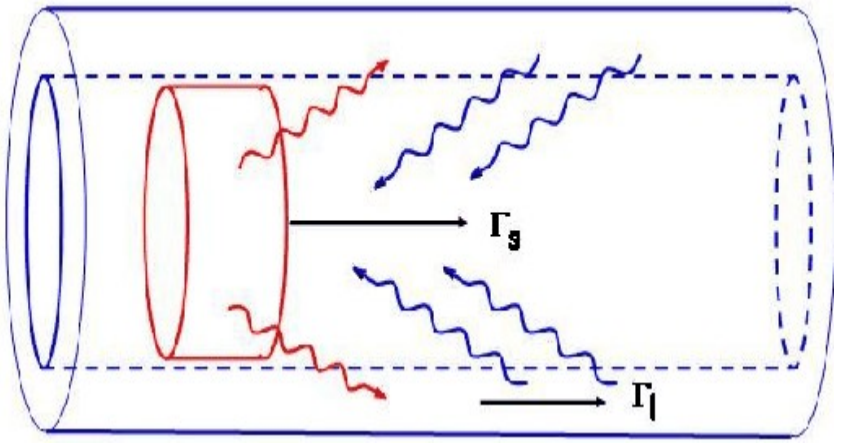



Blue: BLR
Red: IR torus

Seed photons from torus




Seed photons from slow sheath




Ghisellini et al. 2005

# New Results: 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

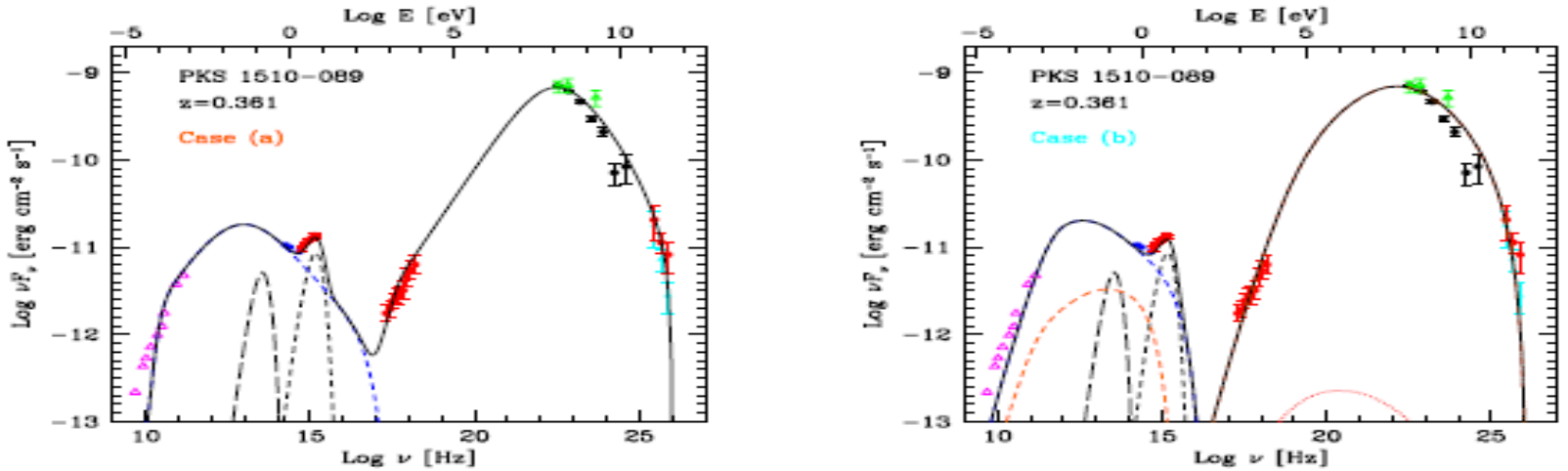
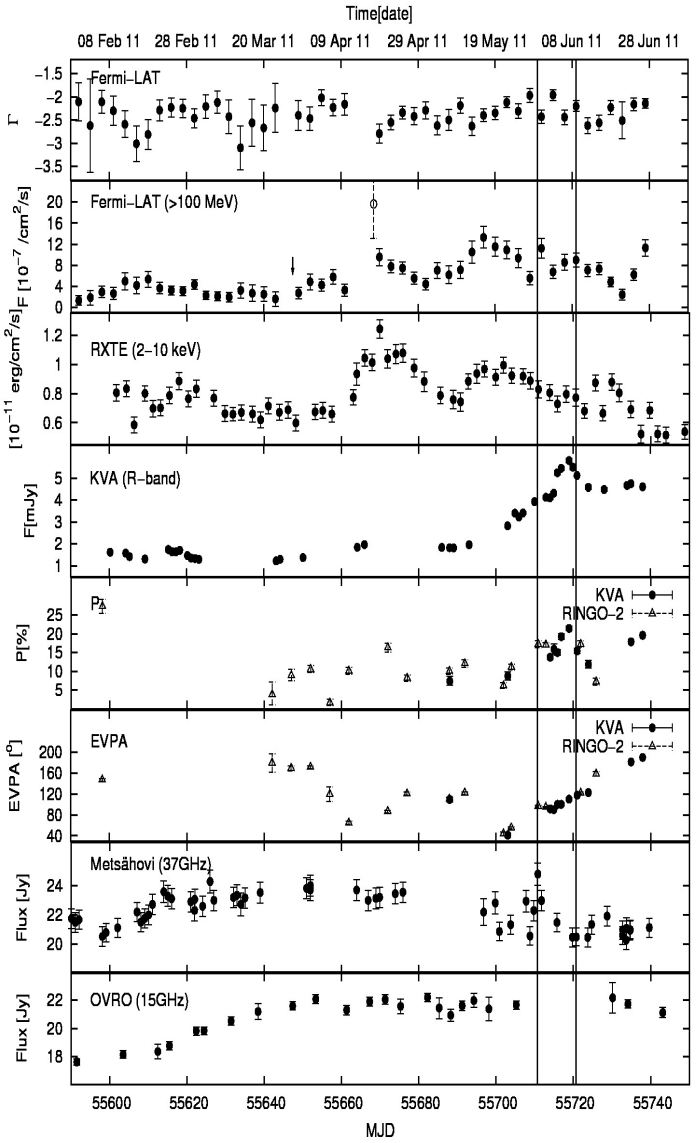



**Fig. 15.** The SED of PKS 1510-089 in February-April 2012 as observed by F-GAMMA and Metsähovi (magenta triangles), GASP-WEBT (blue filled circles), *Swift*-UVOT and XRT (red filled circles), *Fermi*-LAT (black filled circles), AGILE-GRID (green triangles) and MAGIC (cyan, observed; red, EBL corrected). **Left:** The solid black curve shows the overall emission modelled, where the high energy bump is dominated by the external Compton mechanism, using the infrared torus (long dashed line) photons as seed photons (case *a*). The short dashed line is the thermal component from the accretion disk. **Right:** The black curve shows the model assuming that the emission region is located at the radio core (case *b*). The orange dashed line shows the additional external photon field representing the slow sheath of the jet.

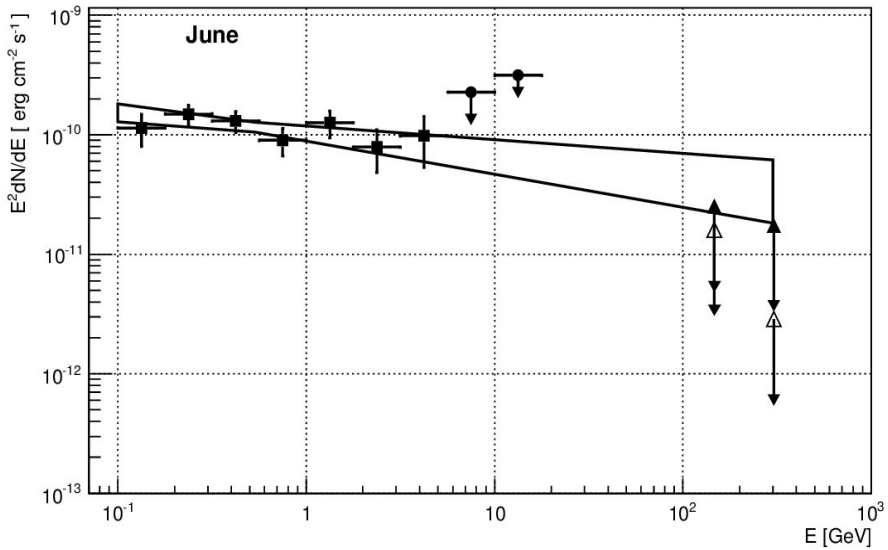
| model | $\gamma_{min}$ | $\gamma_b$ | $\gamma_{max}$ | $n_1$ | $n_2$ | $B$ [G] | $K$ [cm$^{-3}$] | $R$ [$10^{16}$ cm] | $\Gamma$ |
|---|---|---|---|---|---|---|---|---|---|
| IR torus | 3 | 9e2 | 6.5e4 | 1.9 | 3.85 | 0.12 | 20 | 30 | 20 |
| Sheath | 800 | 7e3 | 5e4 | 2 | 3.4 | 1.3e-2 | 18 | 600 | 2.2 |
| Spine | 800 | 2.6e3 | 8e4 | 2 | 3.7 | 6.5e-3 | 2.5 | 510 | 20 |

# New results: 3C279 in 2011

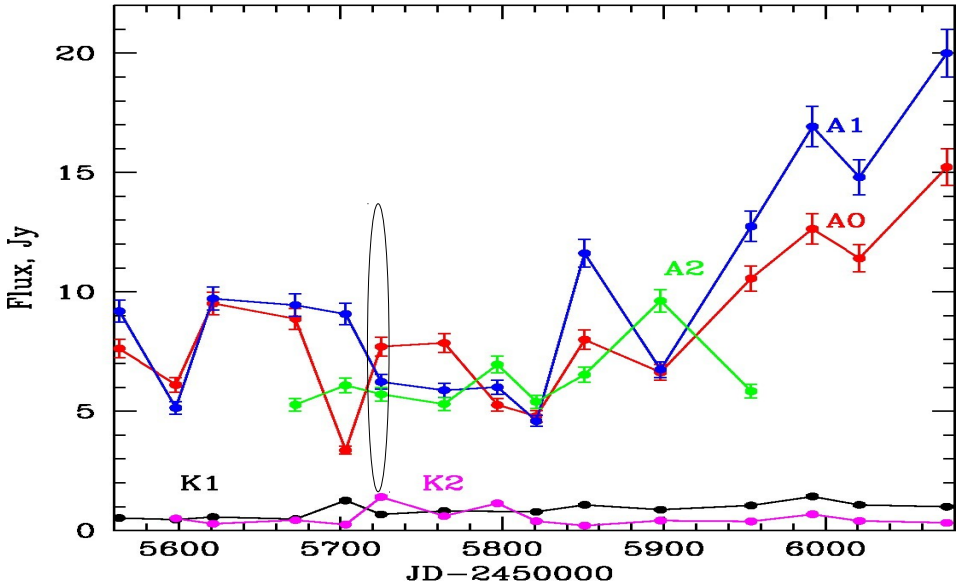
- 3C279 (z=0.536) has been detected twice by MAGIC: in February 2006 and in January 2007, in both cases in single nights (Albert et al. 2008, Science and Aleksic et al. 2011)
- Was also observed in 2009 (Albert et al. 2011) and 2011 (Aleksic et al. 2014, A&A, in press, arxiv:1311.2833 )
- The case of 2011 observations is particularly interesting: source in high HE gamma-rays state and rotation of the optical polarization angle



# New results: 3C279 in 2011




- Fermi-LAT Spectrum+ MAGIC upperlimits: break?
- Emission region inside BLR?

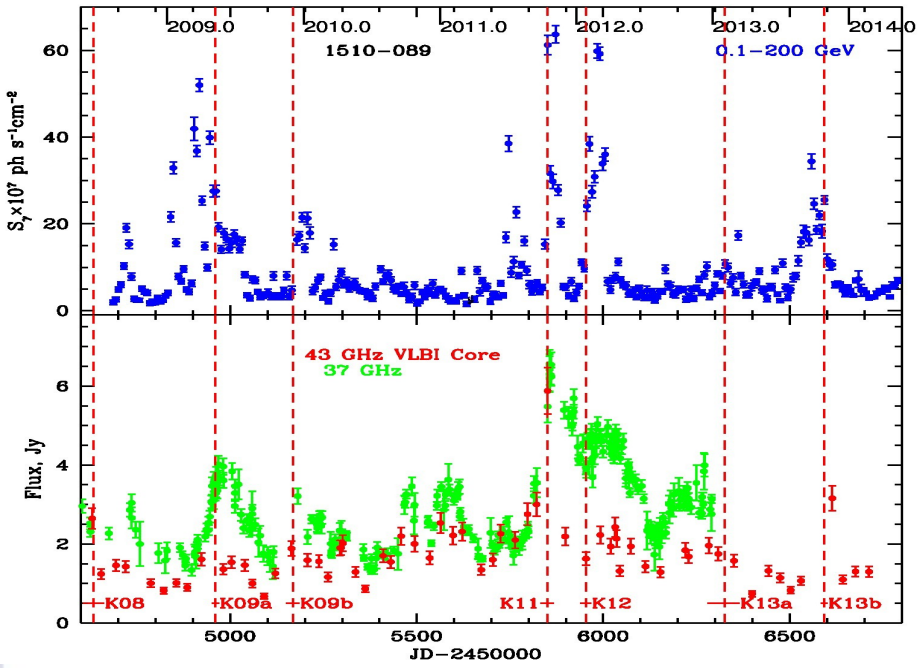



- 43GHZ VLBA monitoring (by the Boston University group): no new components emerging

(Aleksic et al. 2014, A&A, in press, arxiv:1311.2833 )

# More to come...

- PKS 1510-089 in 2013




Top: Fermi-LAT
Bottom: VLBI core,
Metsähovi single dish

- PKS 1222+216 in Feb 2014

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

ATel #5981; J. Holder for the VERITAS Collaboration

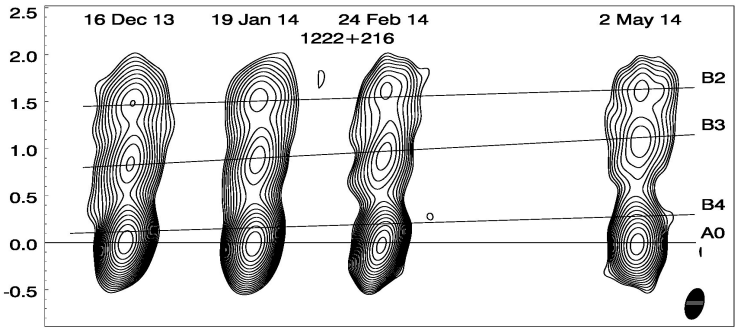
on 14 Mar 2014; 18:34 UT

Credential Certification: Jamie Holder (jholder@physics.udel.edu)

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

Referred to by ATel #: 6194, 6207

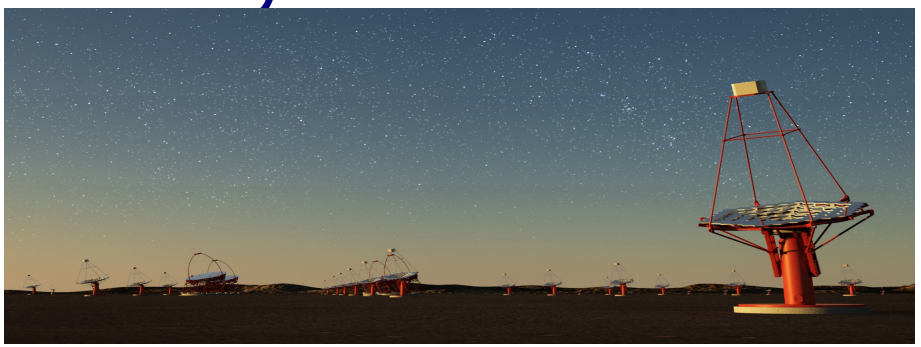
The VERITAS collaboration reports the detection of very-high-energy (VHE, E>100GeV) gamma-ray emission from the flat spectrum radio quasar PKS 1222+216 (z=0.432). This source has previously shown intense and rapid flaring episodes in the gamma-ray band (ATel #2584, ATel #2684, ATel #2687).




S. Jorstad (the VLBA-BU-blazar program, priv. comm.)

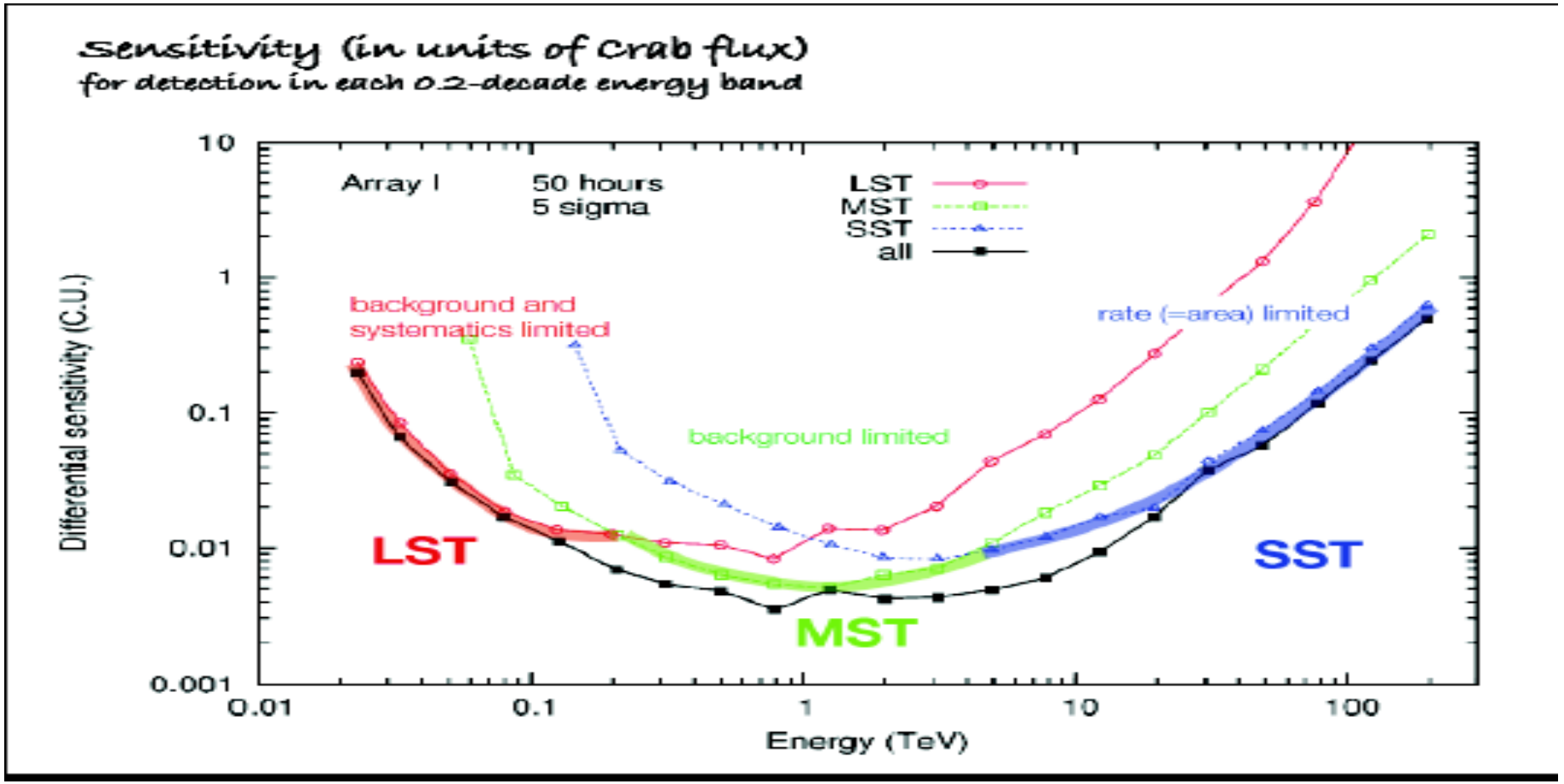
# Outlook: CTA

- In order to distangle and further constrain the models, we need **more** VHE gamma-ray observations with good MWL coverage
- Even the very few VHE detections we have, do not show the same MWL behavior
- VHE gamma-ray monitoring of these sources would require better sensitivity than current instruments have



# CTA sensitivity (for FSRQ observations)

- Up to few 100 GeV the sensitivity is dominated by LSTs: for FSRQs Array of LSTs would be enough



# Conclusions

- Currently many open questions on VHE gamma-ray emission of FSRQs:

  -emission site

  -seed photons for IC scattering

  -fast variability

- Current experiments are limited to observations during high state: CTA should *monitor* FSRQs to truly learn something new.