On the radio and γ-ray connection: The extraordinary case of PKS 1510-089

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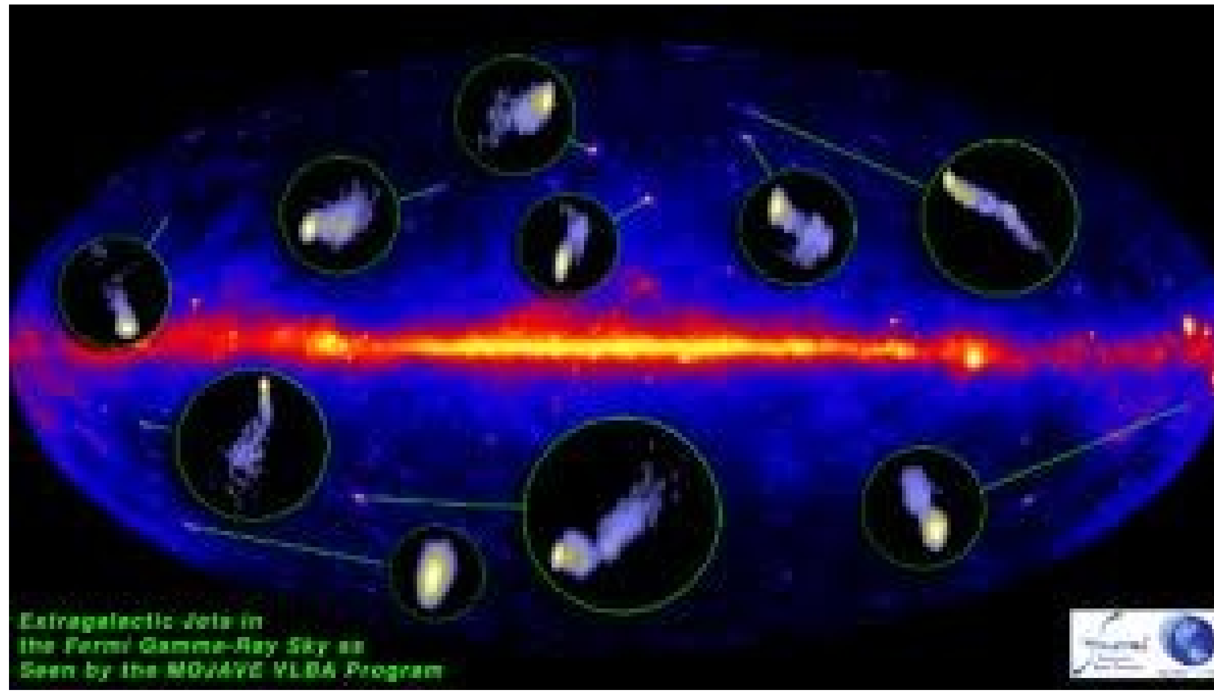
Outline

- The extragalactic γ-ray sky
- PKS 1510-089
- The extraordinary variability in 2011
- What causes the γ-ray flares?

The extragalactic γ-ray sky

In the 2LAC clean catalogue there are 886 extragalactic sources (Ackermann+2011):

- 862 (97%) blazars
  - 310 FSRQ
  - 395 BL Lac
- 26 (3%) other objects (4% in 1LAC)



Strong γ-ray emitters:

- High radio luminosity
- Fast apparent jet speed
- High variability Doppler

Savolainen+ 2010, Lister+ 09, Kovalev+ 2009

Extragalactic γ-ray sky dominated by radio-loud AGN

High energy emission

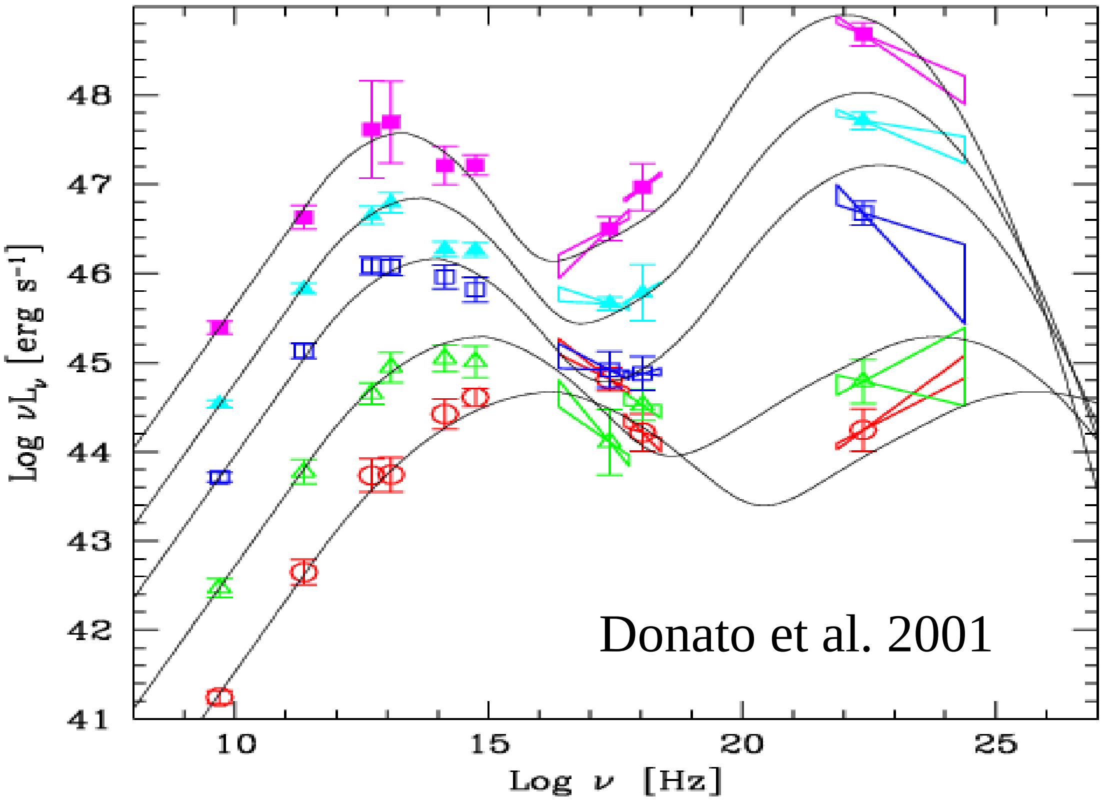
- Low energy: synchrotron

Relativistic electrons can scatter low energy photons

- High energy: inverse Compton

Photon seeds:

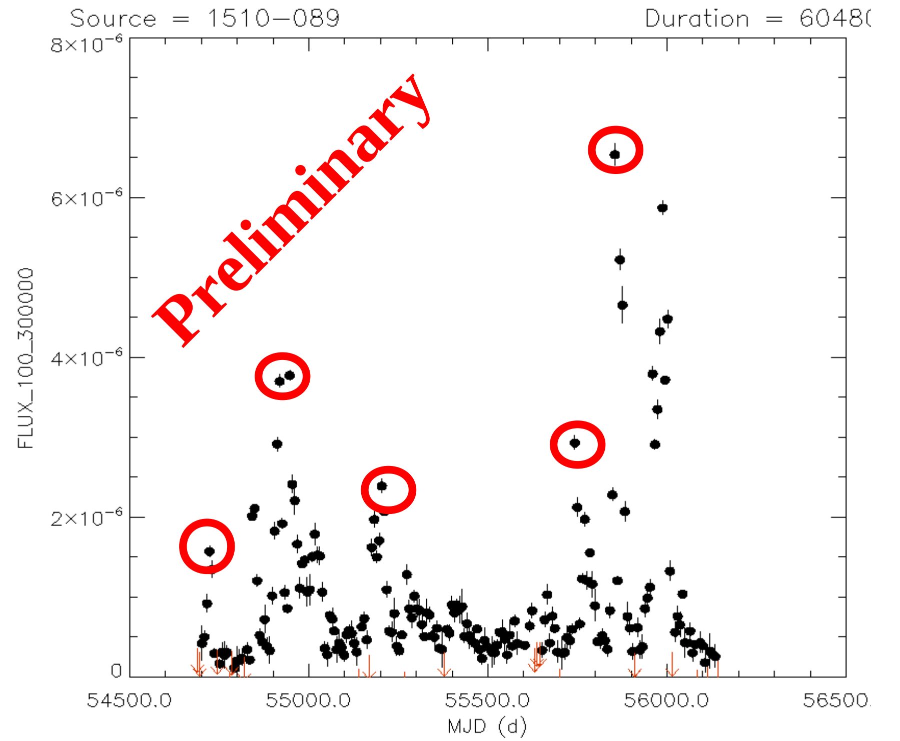
- their own synchrotron photons (Synchrotron-self Compton)
- external photons from torus, disk, BLR... (External Compton)



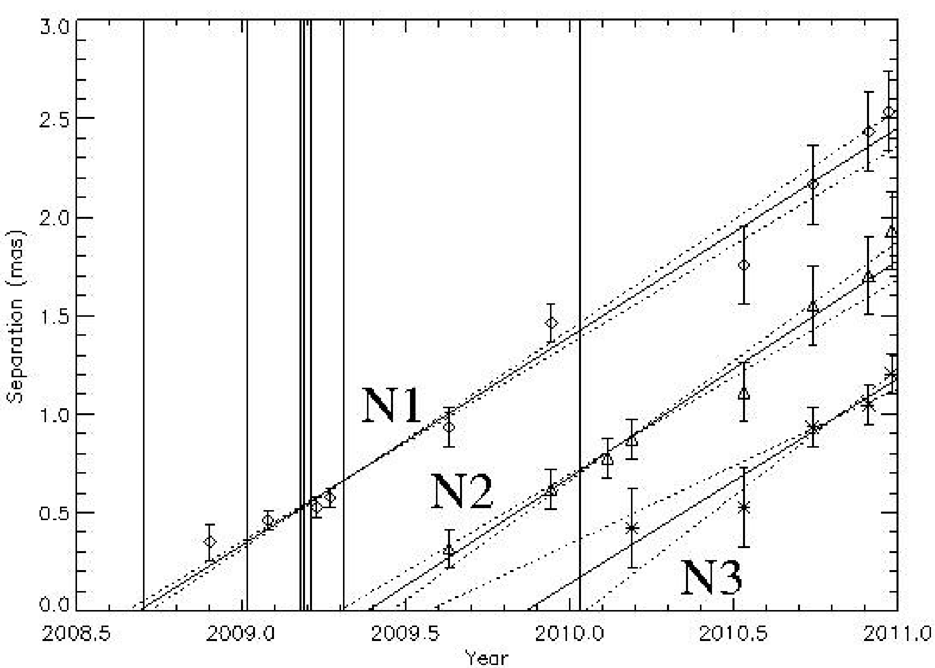
Derived from radio selected blazars by Fossati et al. (1998)

Why study PKS 1510-089?

- FSRQ at z=0.361
- **Strong variability across the entire e-m spectrum**
- Highly superluminal jet components ejected close in time with a γ-ray flare
- **Detected at VHE (E>100 GeV)**



Orienti+ 2011



- High level of polarized emission in radio and optical bands
- **Large rotation of the EVPA** close in time with γ-ray flares

Radio morphology

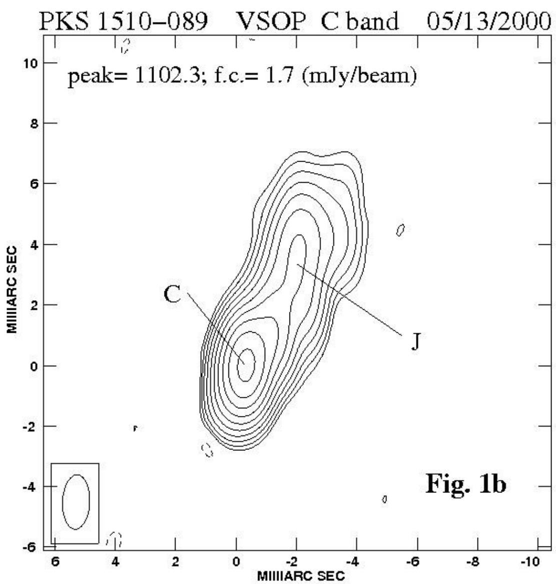


Fig. 1b

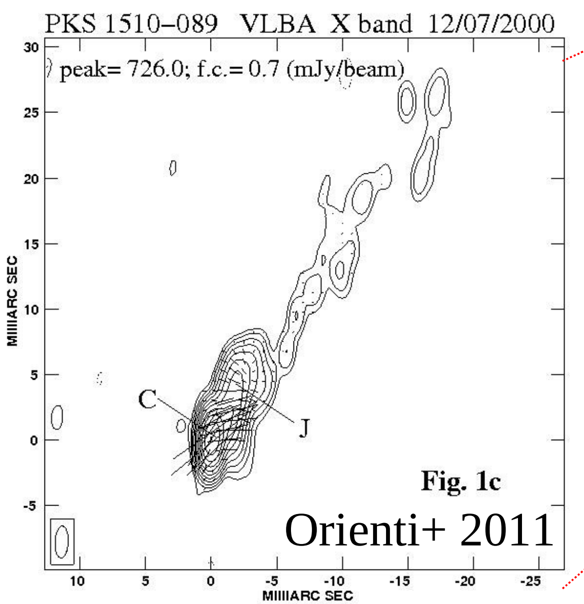
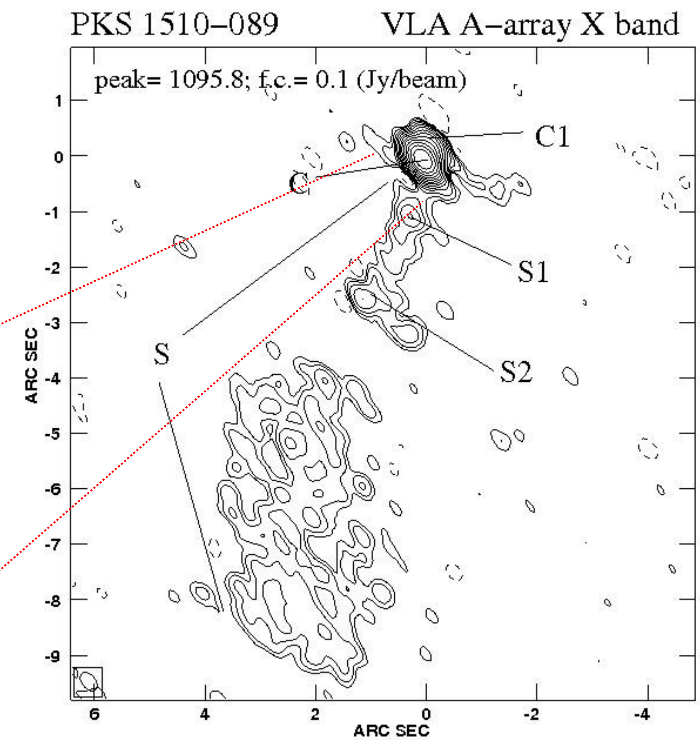


Fig. 1c

Orienti+ 2011

- Core-Jet structure
- Core dominates the radio total intensity and the polarized emission
- Jet emerges with PA -28° and it slightly bends at 10 pc from the core
- Deep observations detect the jet up to 125 pc from the core



- Misalignment of ~180° between pc and kpc scale.

- Jet is well collimated up to 10 kpc

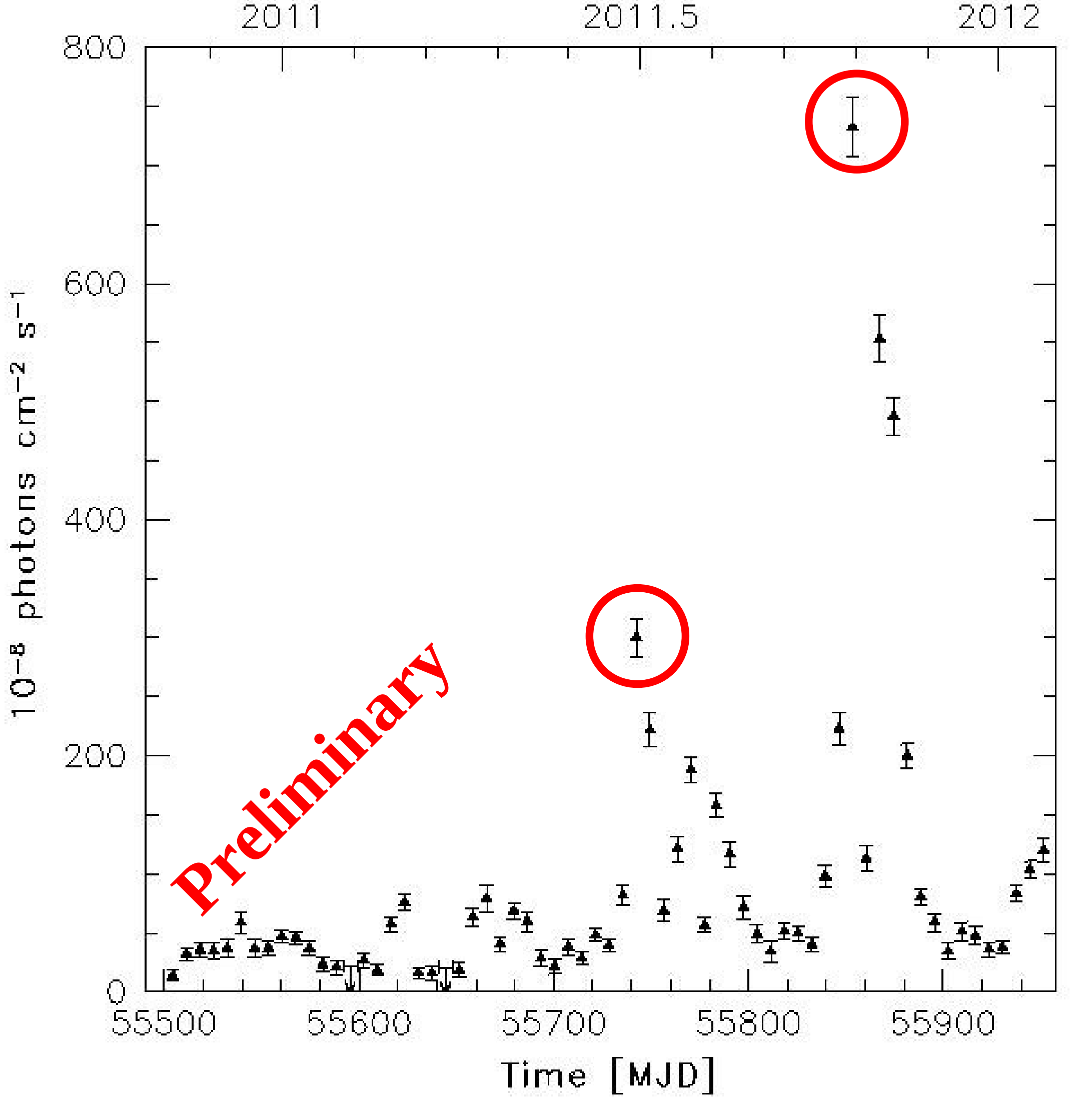
The 2011 flaring activity

Since the advent of AGILE and Fermi-LAT, PKS 1510-089 has shown many high-energy flares.

In 2011 it entered in a very active phase with the detection of two major flares on July 4 and on October 17, as reported in several ATels.

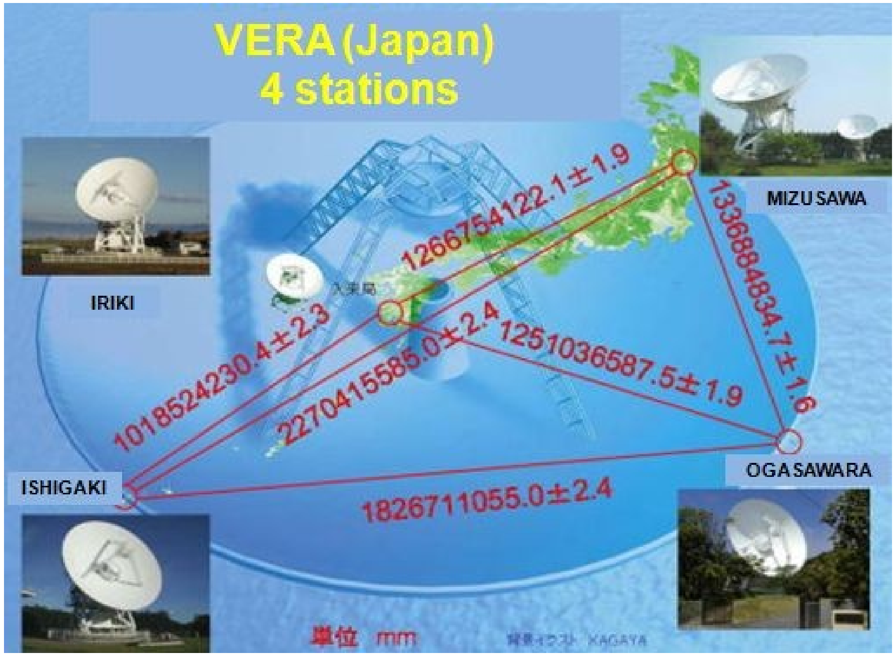
This is an excellent chance to investigate the possible radio and γ rays connection!

Orienti et al. 2012, MNRAS submitted



Radio counterparts?

- **Medicina observations at 5 and 8 GHz**
- **VERA observations at 22 GHz**
- **MOJAVE data at 15 GHz**
- **F-GAMMA programme (2.3 to 142 GHz)**
- **OVRO observations at 15 GHz**



- The July γ-ray flare triggered Medicina and VERA observations

- VERA consists of 4 VLBI Japanese antennas

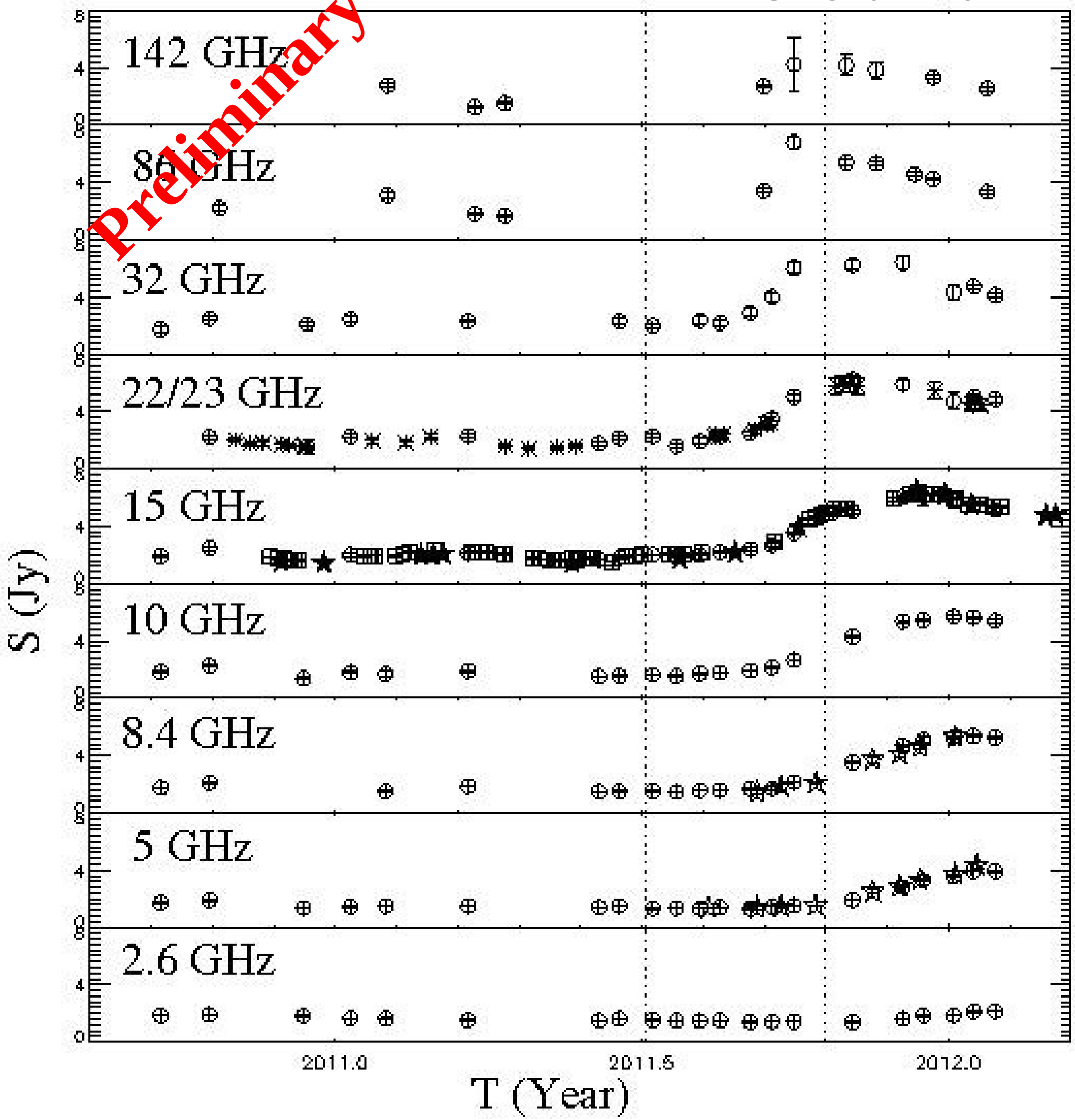
Multi-wavelength analysis

The peak flux density is not simultaneous at the various frequencies due to opacity effects.

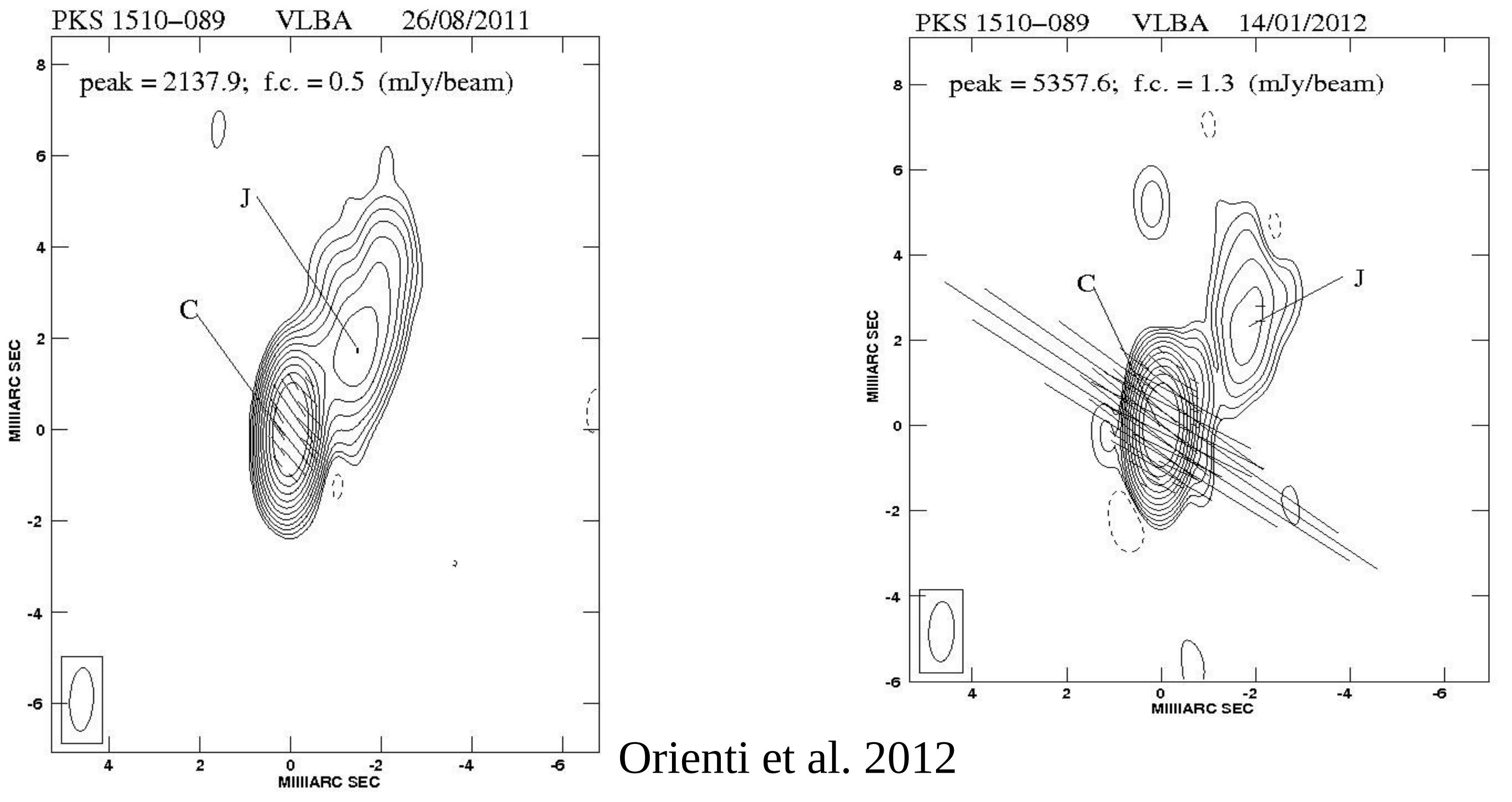
In the millimeter regime the maximum occurs at the end of September, although the sparse time coverage does not allow an accurate estimate.

At decimeter wavelength (2.6 GHz), the flux density was still increasing on 2012 January.

Orienti+ 2012



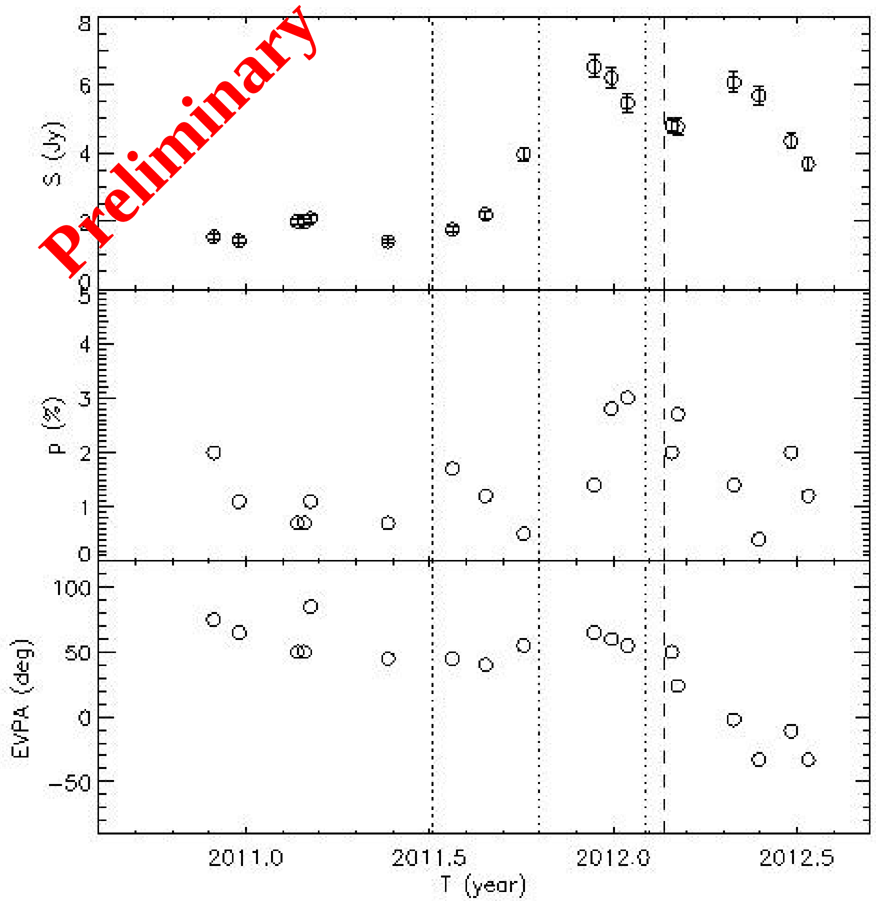
Parsec-scale morphology



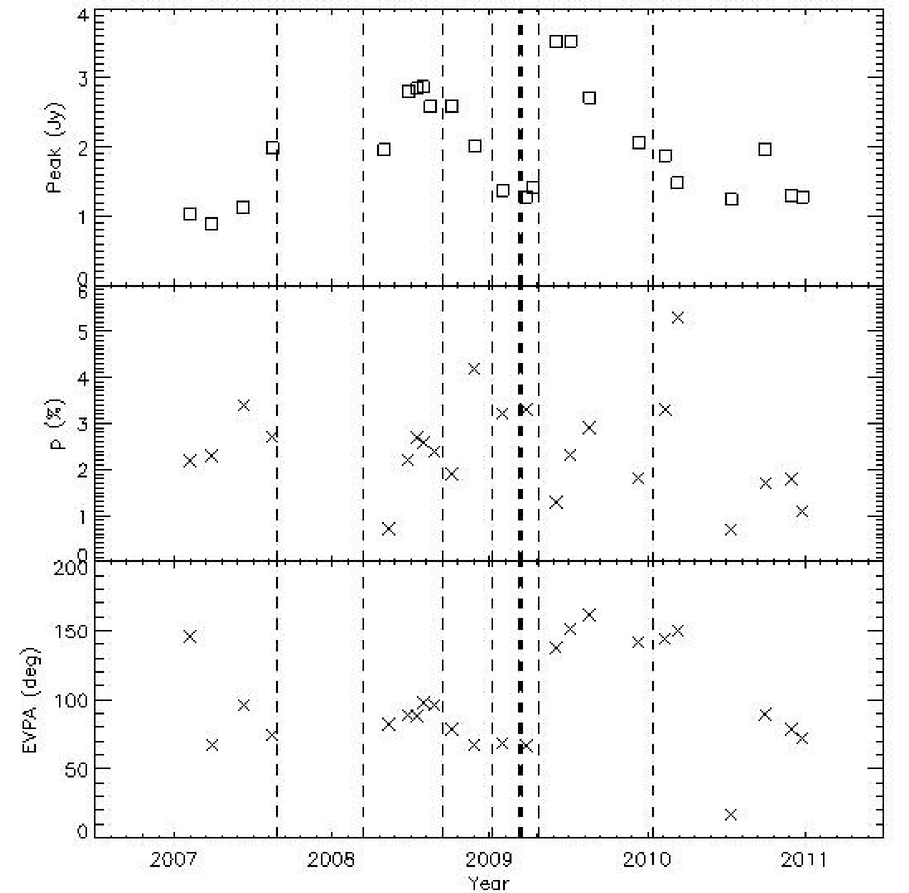
Orienti et al. 2012

EVPA constant with significant increase of the polarized emission in 2012 January. No strong polarized emission in the jet.
Component J is moving away from the core with β_{app}=33.4±2.2.

Parsec-scale properties



Orienti+ 2011



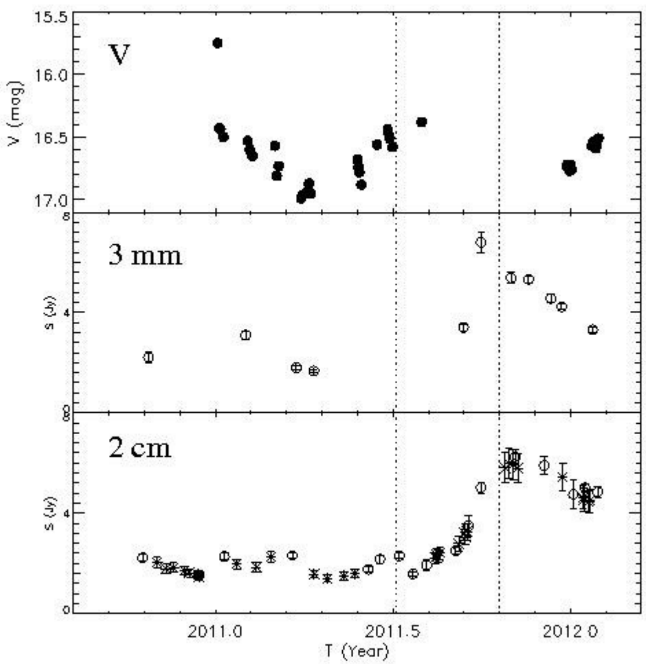
During different flares the polarized emission shows different behaviours:

- After 2011 flares radio **EVPA changed of ~10°**;
- After April 2009 flare radio **EVPA rotated of 75°** at 15 ang 43 GHz;
- After **MAGIC VHE detection** in February 2012, radio **EVPA rotated of 60°**

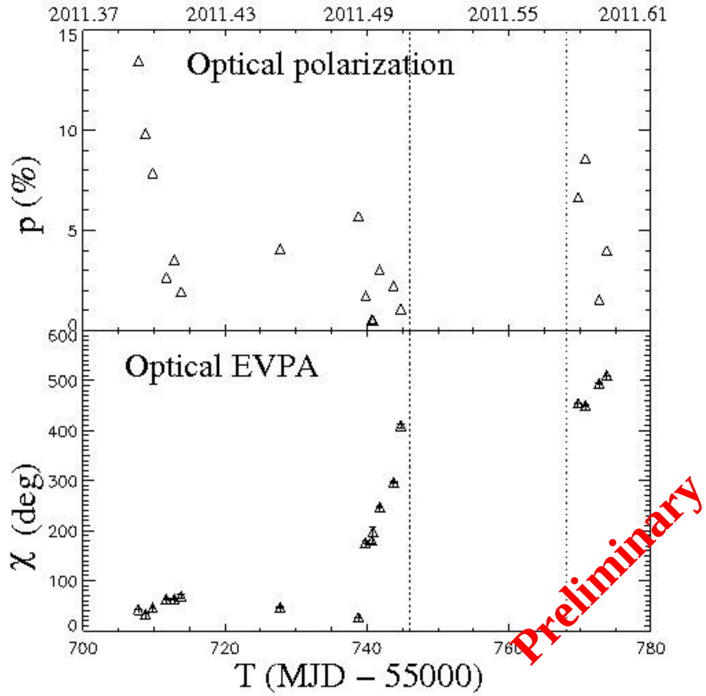
Optical properties

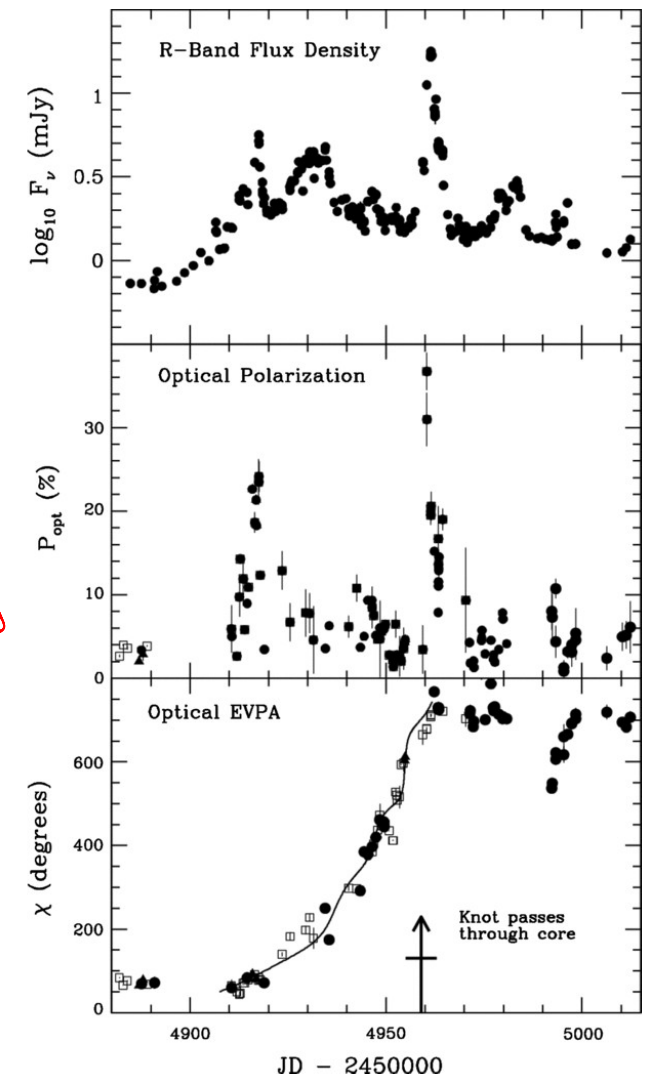
Marscher+ 2010

2011 January - 2012 January



May – July 2011





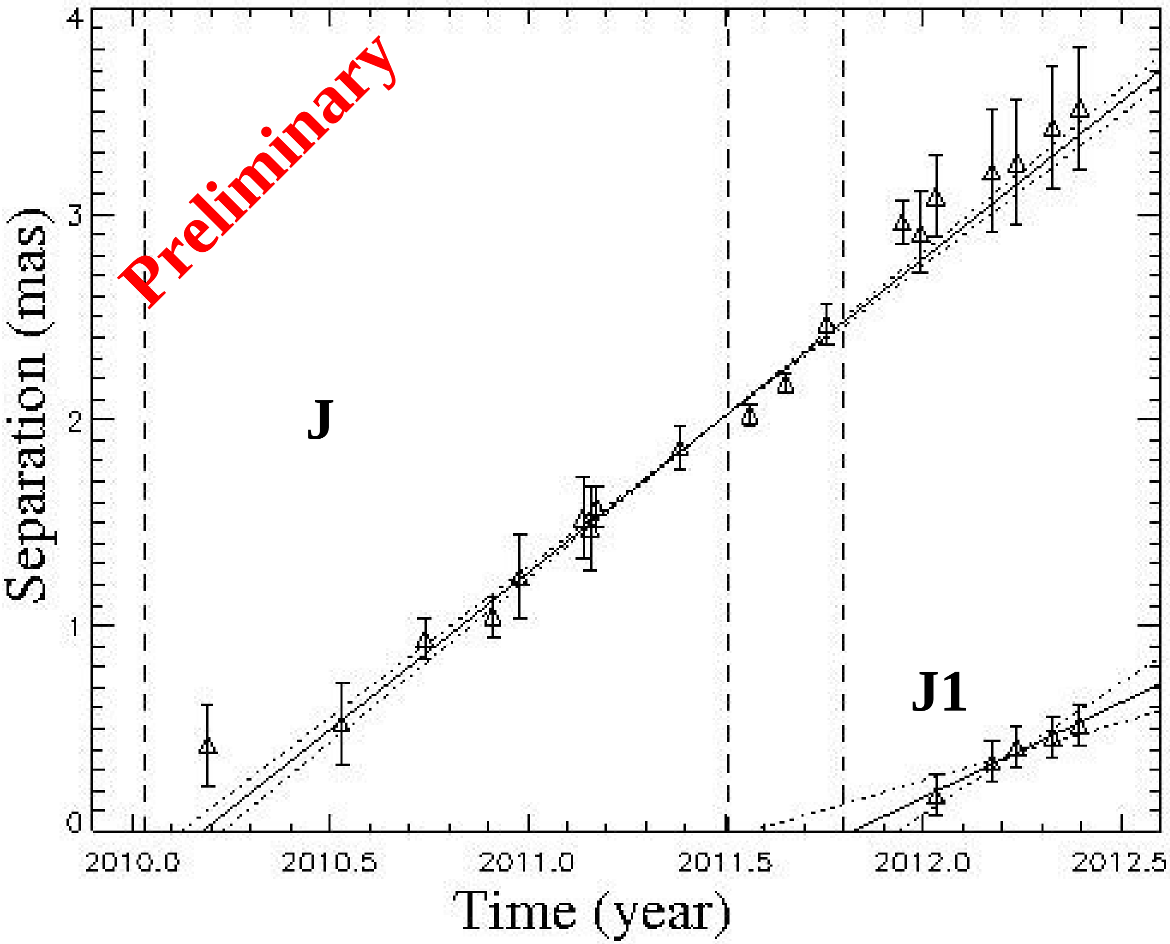
In April 2009 and July 2012 a large rotation of 720° and 380° of the optical EVPA culminates with the γ-ray flare, suggesting a co-spatiality of the γ-ray and optical emitting region.

An optical “orphan” flare was observed in January 2011

Proper motion

Component J is moving away from the core with an apparent superluminal velocity of 1.5±0.1 mas/yr, i.e. (33.4±2.2)c.
It was ejected at the beginning of 2010, close to a γ-ray flare (Striani+2010).

Since 2012 January a new component, J1, has been detected with an apparent speed of 0.9±0.4 mas/yr, i.e. (20.5±7.8)c.
The short time sampling and the uncertainties do not allow an accurate estimate of the ejection time.



T_0 ~ 10 Nov 2011 (ΔT=23 July – 4 Dec)

The origin of the γ-ray emission

The huge radio flare reached its maximum in the millimeter close in time with the γ-ray flare of 2011 October, suggesting a common emitting region. If the onset of the mm flare is a consequence of a shock propagating along the jet, it turns out that the γ-ray flare occurs off-nuclear:

$$\Delta r = \frac{\beta_{\rm app} c}{\sin\theta} \frac{\Delta t_{\rm obs}}{1+z}$$

ΔT_{obs} = 40 days
β_{app} = 20.5c
θ = 3°

→

Δr_{proj} ~ 0.5 pc
$\Delta\theta$ ~ 0.1 mas
Δr ~ 10 pc

The July γ-ray flare may be due to a **first perturbation occurring in the central region opaque to the radio emission.** As it propagates it becomes visible at longer wavelengths. **As it passes through a standing shock a second γ-ray flare is produced**, while the shock becomes visible as a superluminal knot.

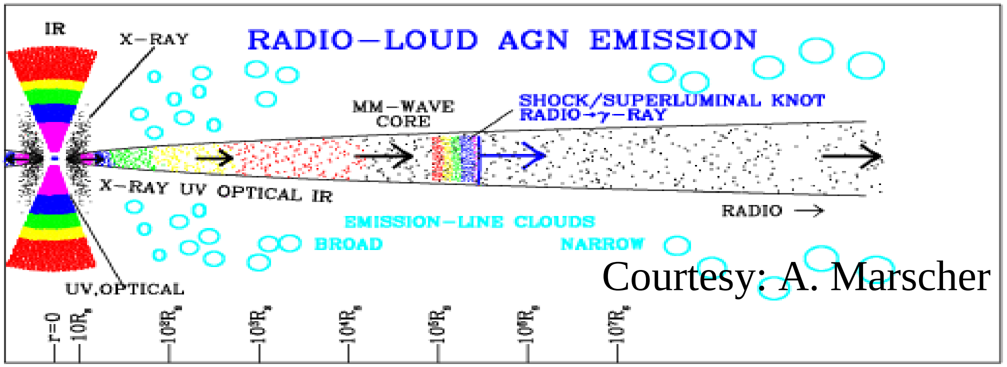
Conclusions

- PKS1510-089 underwent to a very active period in 2011, reaching its historical maximum flux in 2011 October

- The γ-ray flare in 2011 July occurs after a rotation of ~380° of the optical EVPA suggesting a common region for the optical and γ-ray emission

- Not all the flares have the same multiwavelength characteristics, suggesting shocks with different properties

- The new jet component is likely the manifestation of a shock propagating downstream along the jet



Courtesy: A. Marscher

If the γ-ray flare in 2011 October is related to the radio outburst it would strongly support the idea that some γ-ray flares are produced parsecs away from the nucleus.

Follow-up in the mm regime with the sensitivity of ALMA will be crucial in determining the high-energy emitting region