Radio and γ-ray connection. Variability and polarization properties in relativistic jets

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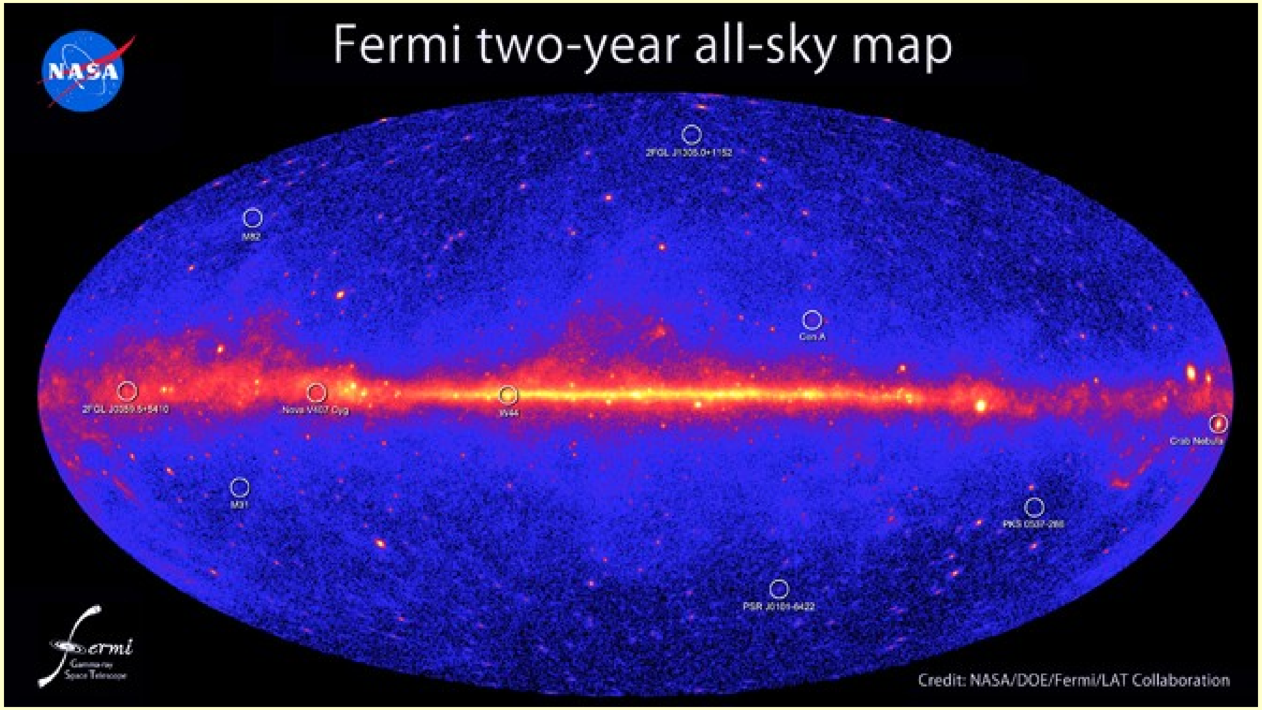
In collaboration with people involved in GENJI, OVRO, FGAMMA, FERMI-LAT Collaboration

This research has made use of data from the MOJAVE database that is maintained by the MOJAVE team (Lister et al., 2009, AJ, 137, 3718)

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

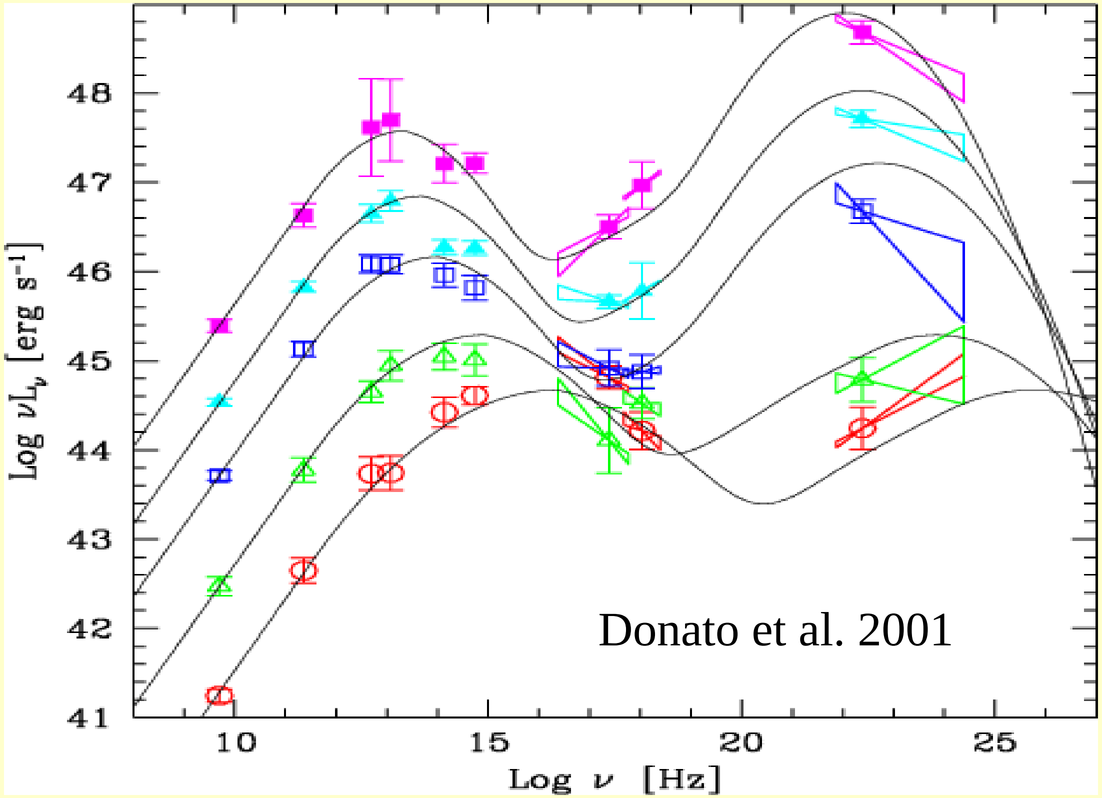
- Low energy: synchrotron

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)



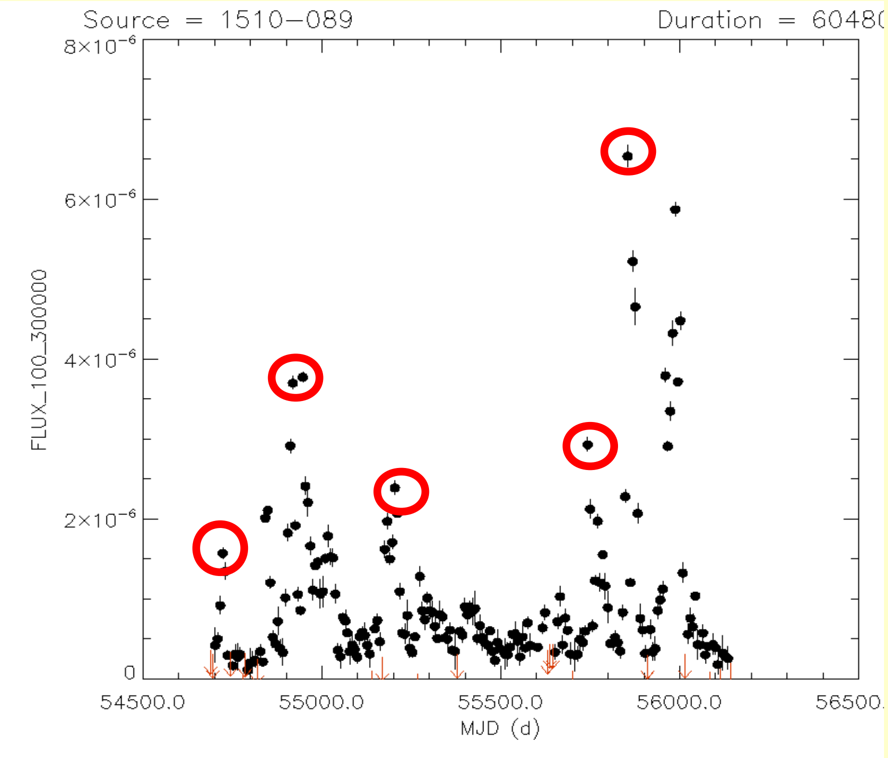
Derived from radio selected blazars by Fossati et al. (1998)

Open questions

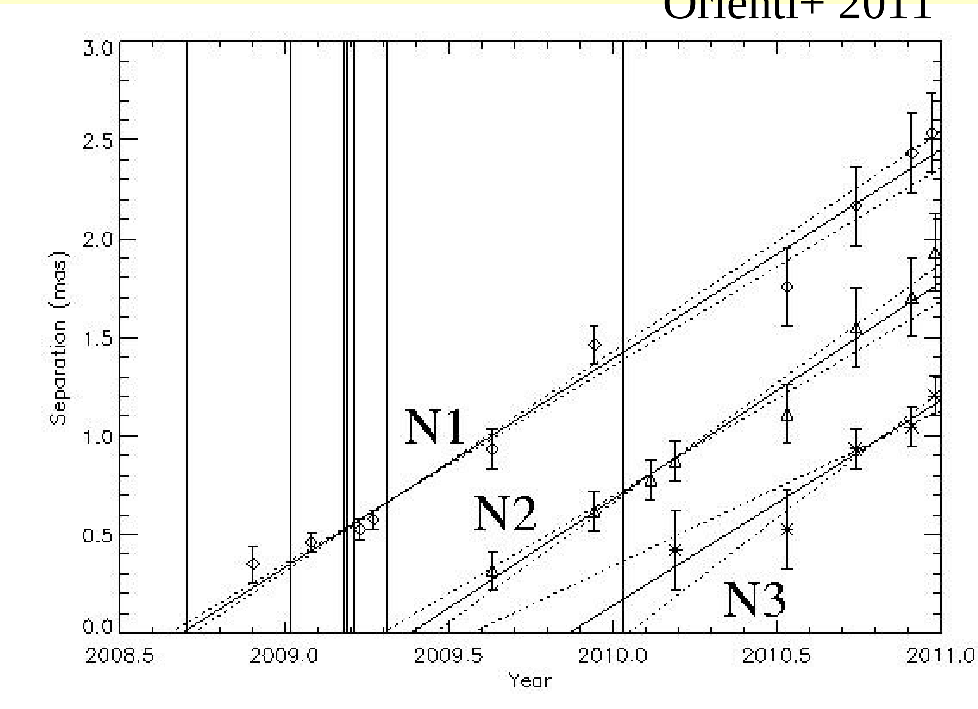
- How do jets form?
- What is the γ-ray emitting mechanism?
- Where is the region responsible for γ-ray emission?
- What is the “jet-base”?
- .....

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

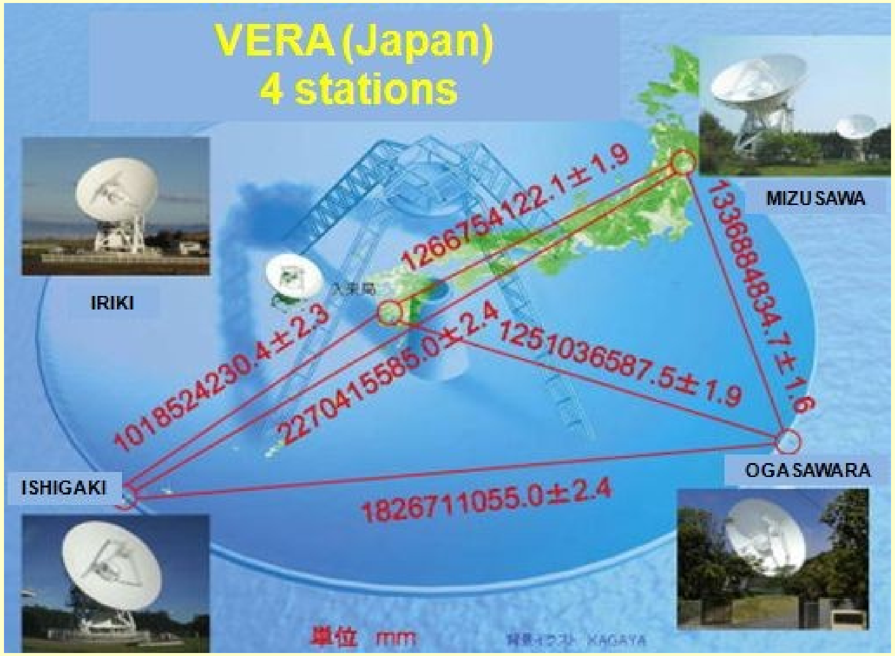


- High level of polarized emission in radio and optical bands
- **Large rotation of the EVPA** close in time with γ-ray flares

Radio follow up

Single-dish obseravtions:

- Medicina observations at 5 and 8 GHz
- 40-m OVRO observations at 15 GHz
- F-GAMMA data from 2.6 to 142 GHz



High resolution:

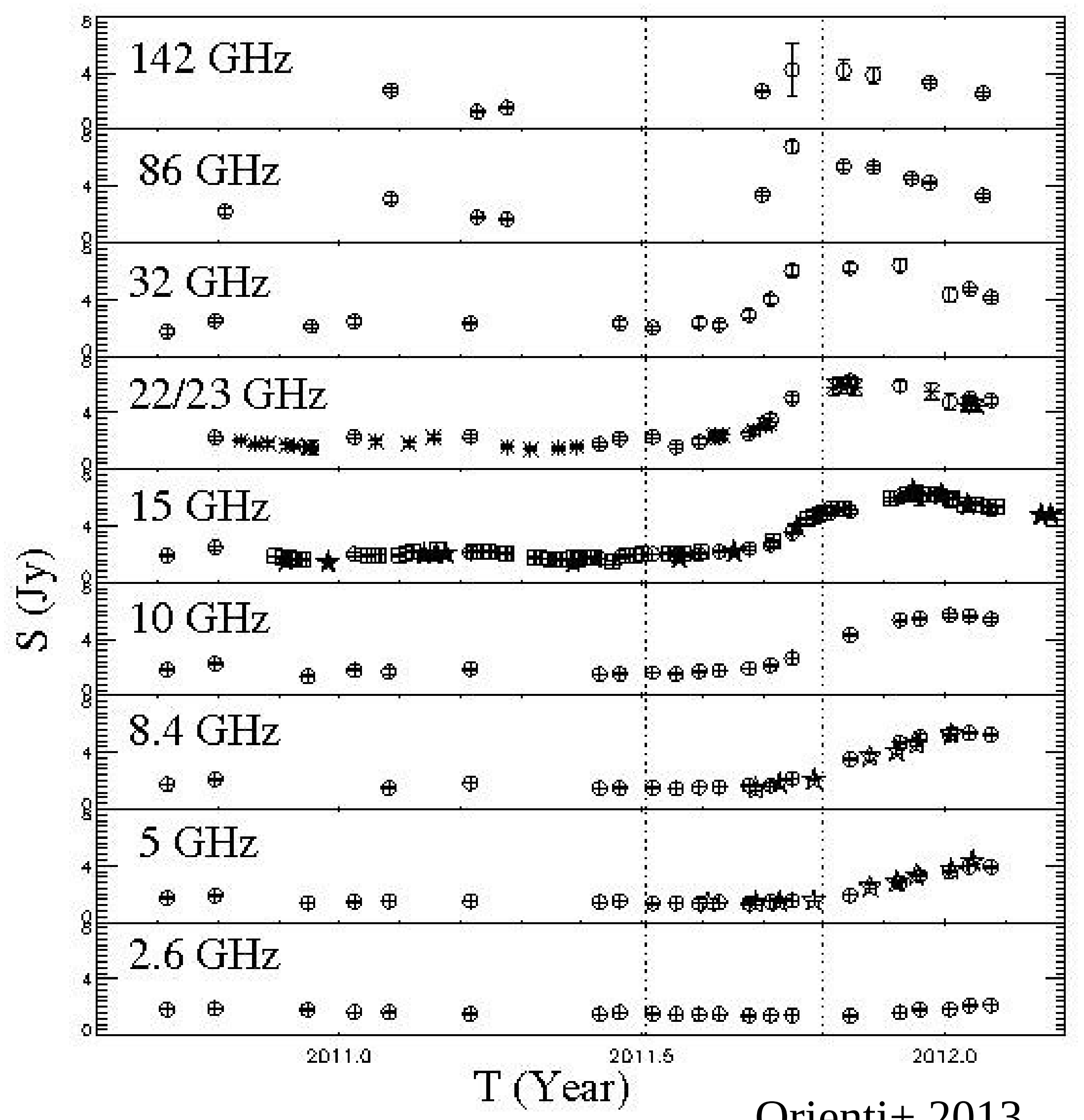
- MOJAVE data at 15 GHz
- VERA observations at 22 GHz

Multiwavelength 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+ 2013

Proper motion

Component A:

v= (34.7±0.7)c

T_0~ 2010.20

γ-ray flare: Jan 2010

Component B:

v= (27.5±2.4)c

T_0~ 2011.9

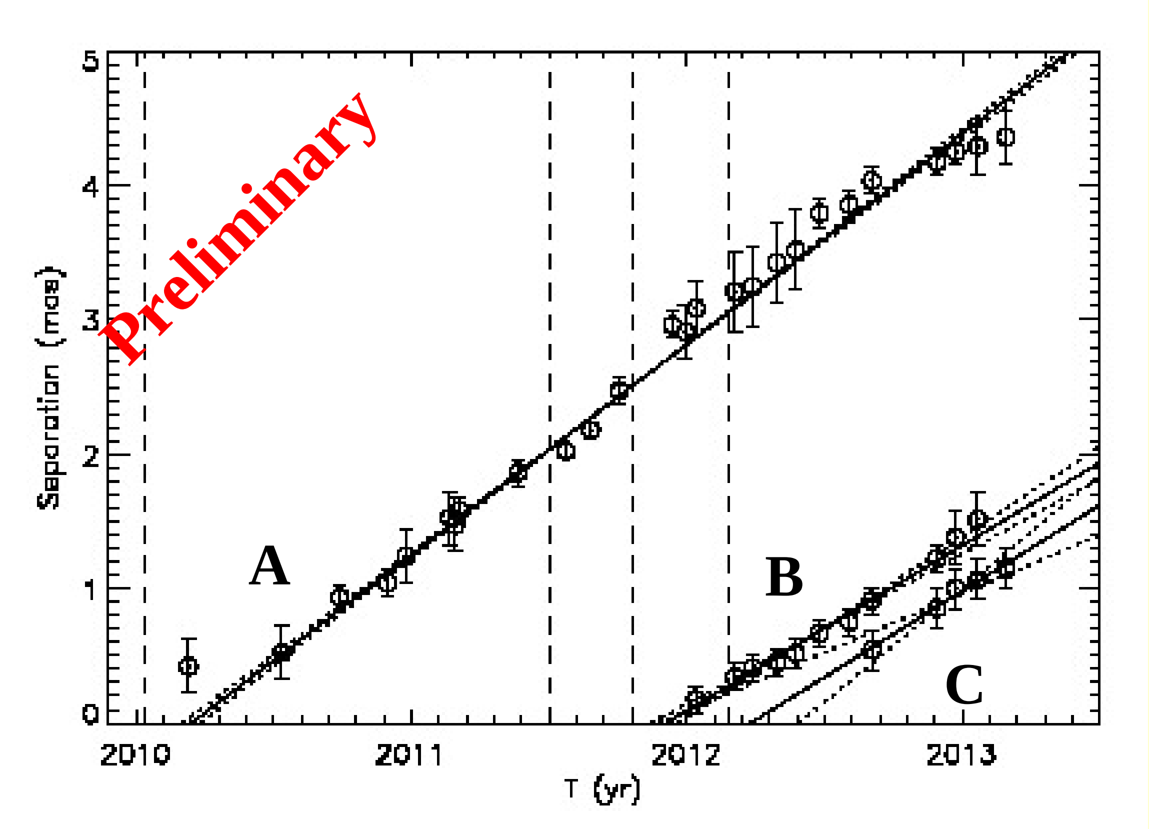
γ-ray flare: Oct 2011

Component C:

v= (28.5±8.9)c

T_0~ 2012.20

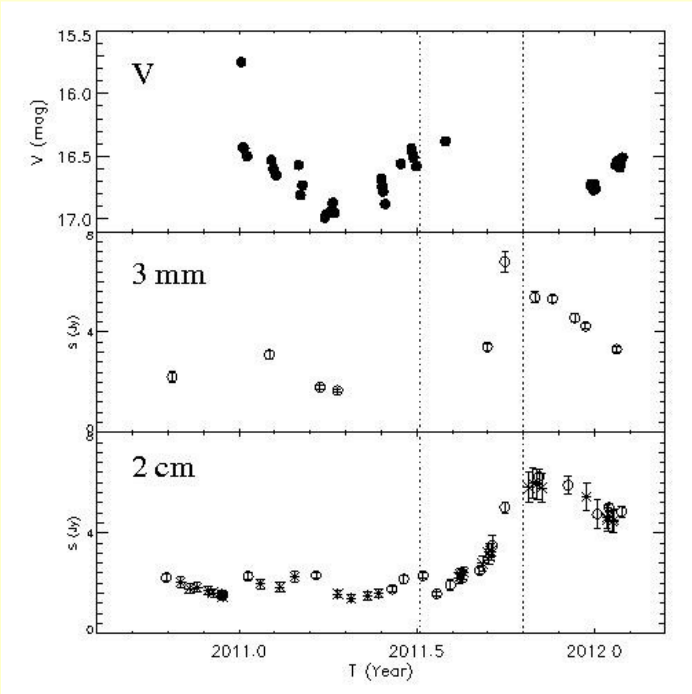
γ-ray & VHE flare: Feb 2012



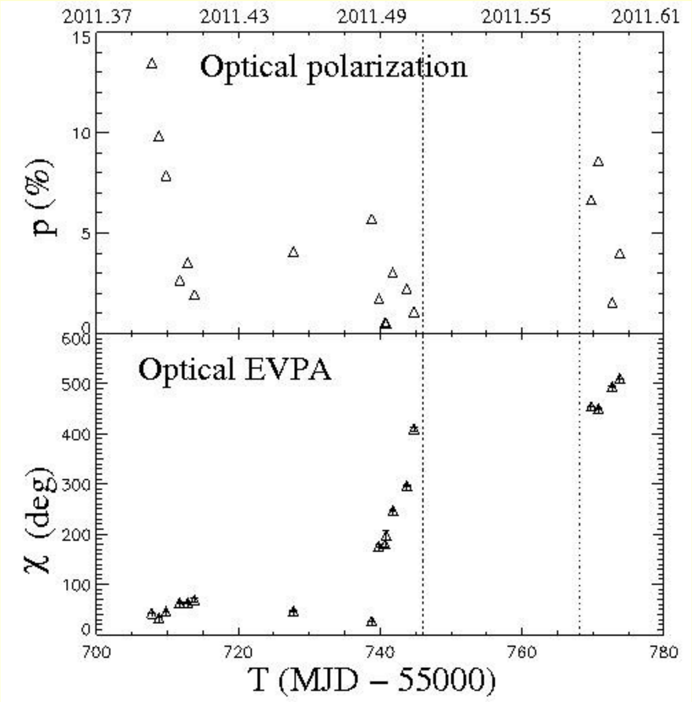
No obvious component ejection close to the July 2011 flare

Optical properties

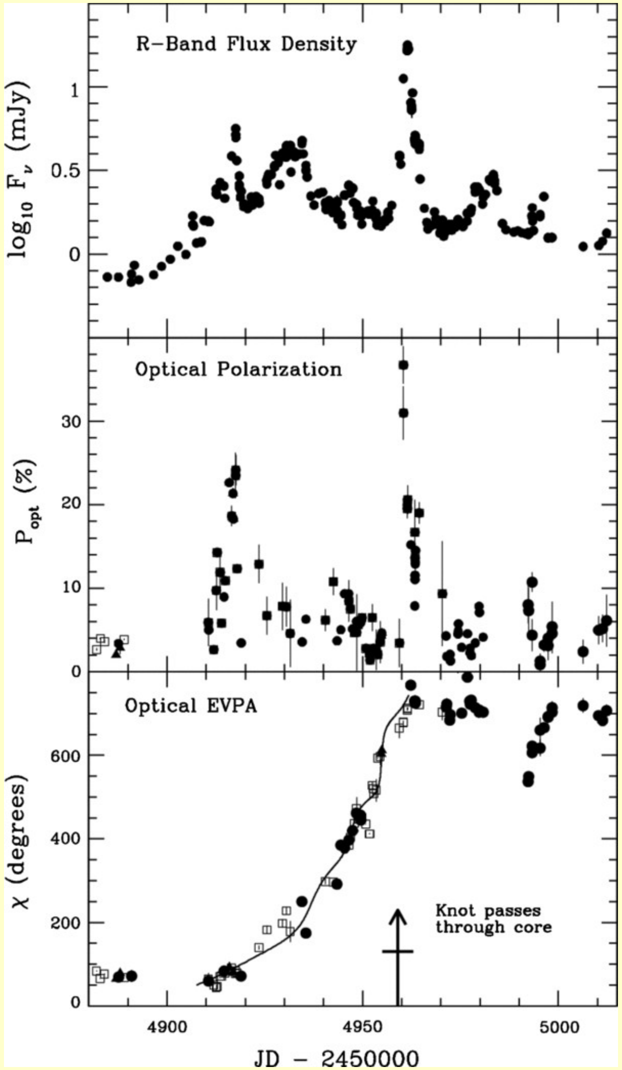
2011 January - 2012 January



May – July 2011



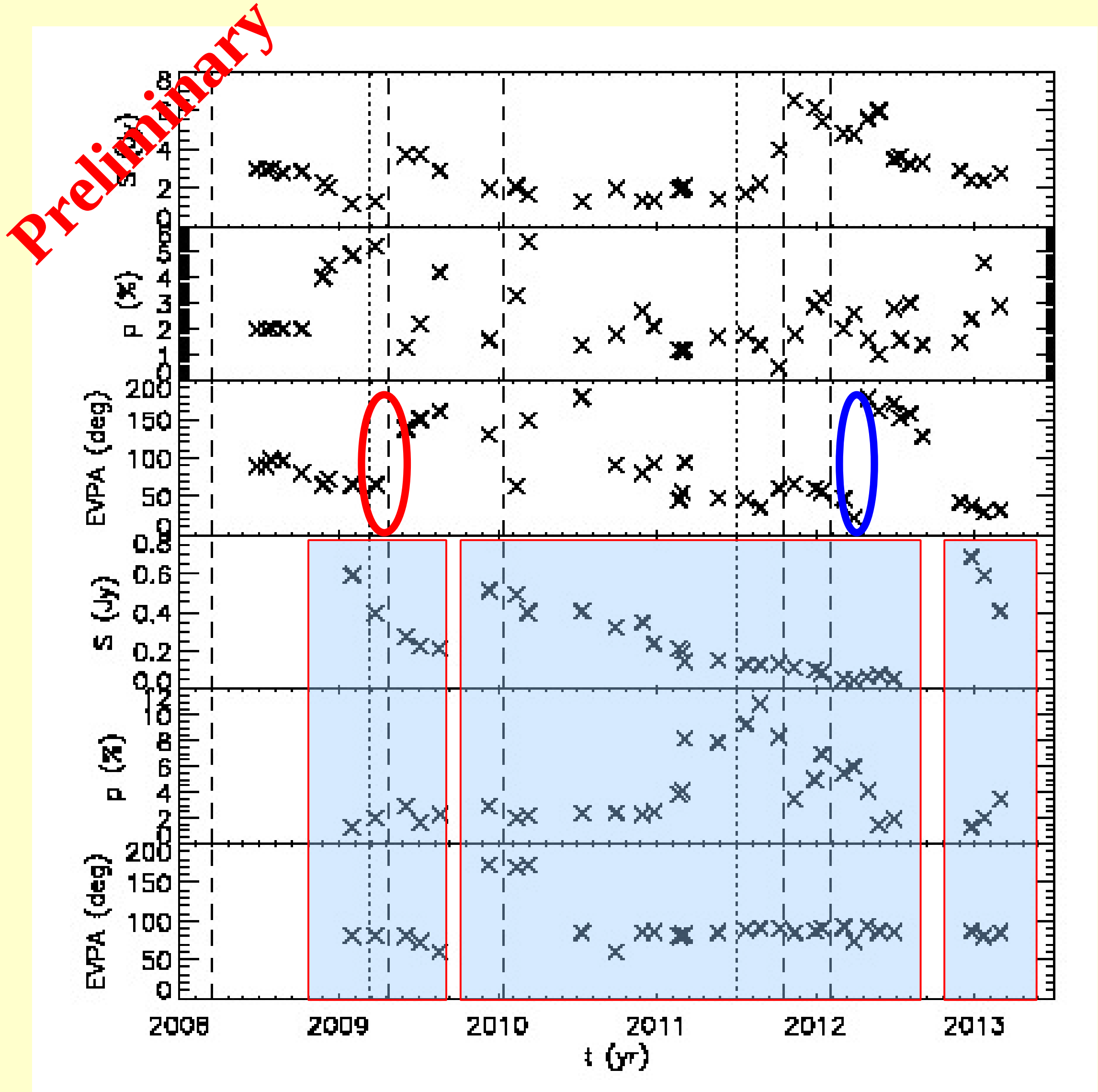
Marscher+ 2010



In April 2009 and July 2011 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

Polarization properties



Core component

- No clear trend is observed in the polarization properties
- Fractional polarization <6%
- 70° EVPA rotation after 2009 flare, detected also by HESS at VHE
- EVPA rotation starting after 2012 flare detected by MAGIC at VHE

Jet components

- Properties change as the blob evolves (adiabatic losses)
- Fractional polarization up to 10%
- EVPA almost constant
- Main jet H dominates on the individual blob?

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:

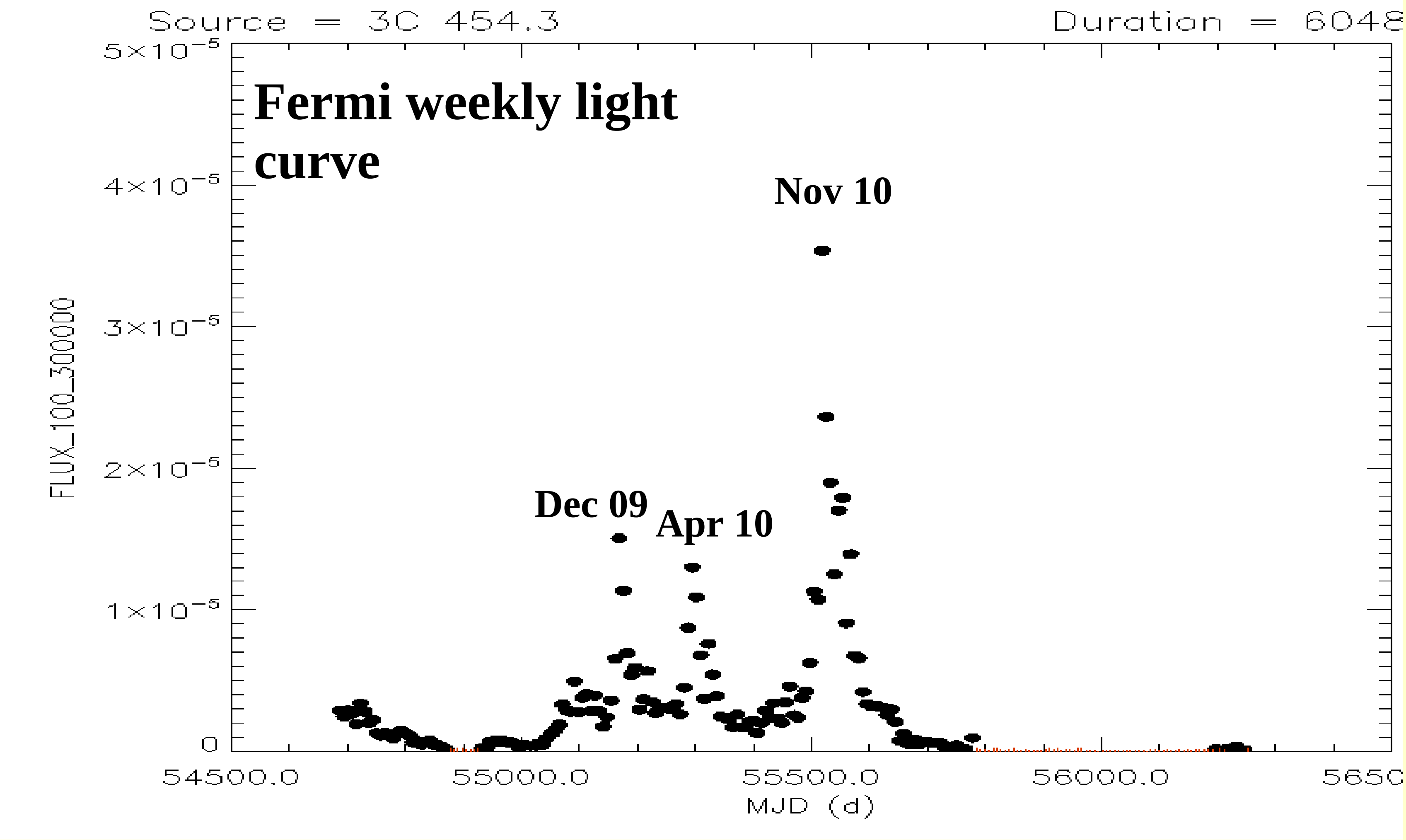
$$\Delta r = \frac{\beta_{\rm app} c}{\sin\theta} \frac{\Delta t_{\rm obs}}{1+z}$$

ΔT_{obs} = 40 days
β_{app} = 27.5c
θ = 3°

$\Delta r_{proj} \sim 0.5$ pc
$\Delta\theta \sim 0.1$ mas
$\Delta r \sim 10$ pc

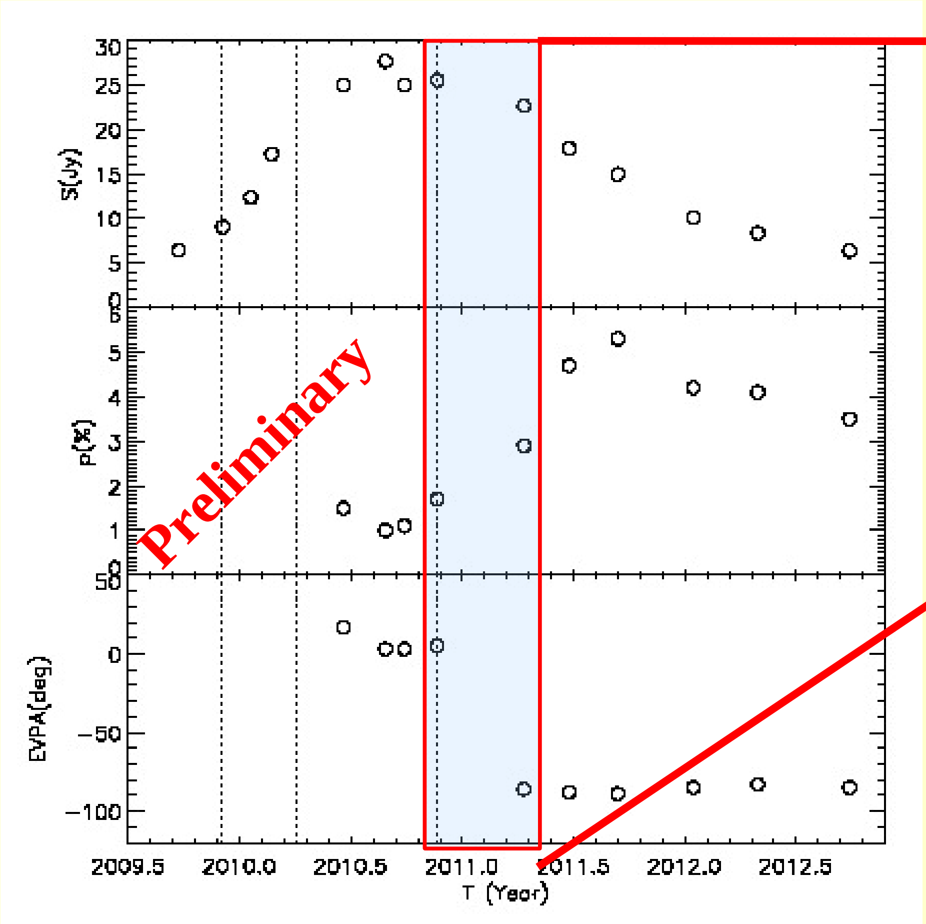
The July γ-ray flare may be due to a **first perturbation occurring in the central region opaque to the radio emission.** As it propagates it becomes visible at longer wavelengths. **As it passes through a standing shock a second γ-ray flare is produced**, while the shock becomes visible as a superluminal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

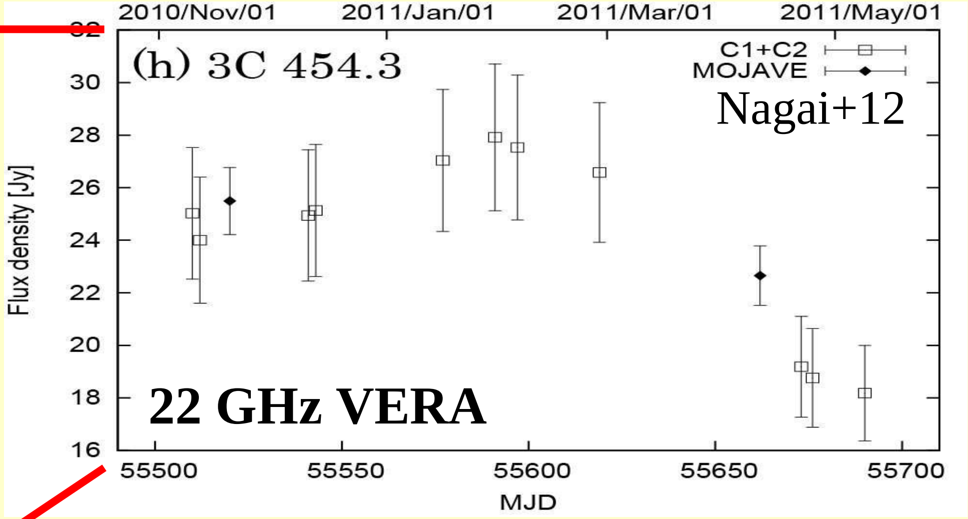
3C 454.3: γ-ray light curve



3C 454.3 was the most active blazar in gamma rays during the first 3 years of Fermi operation, now is sleeping…an ideal candidate to investigate the radio and gamma rays connection!

Pc-scale radio light curve





22 GHz VERA peak in February 2011

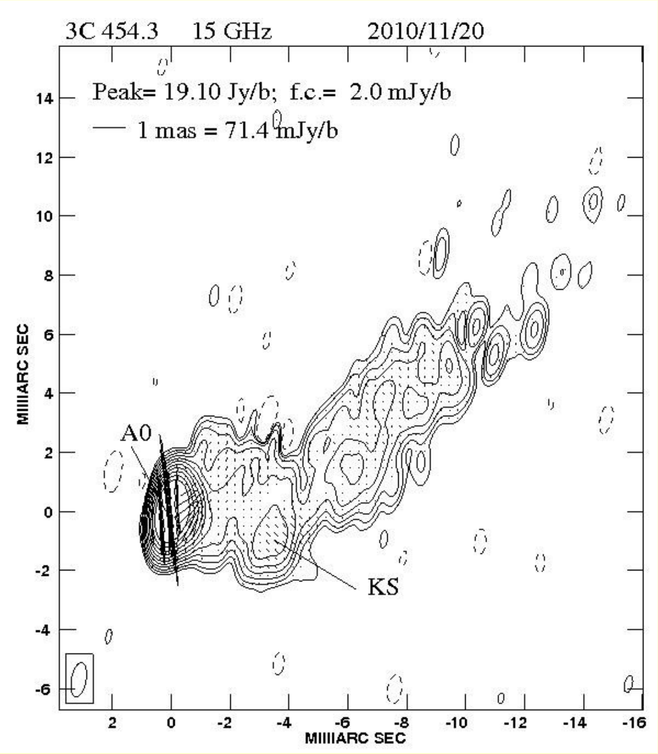
43 GHz VLBA peak in January 2011

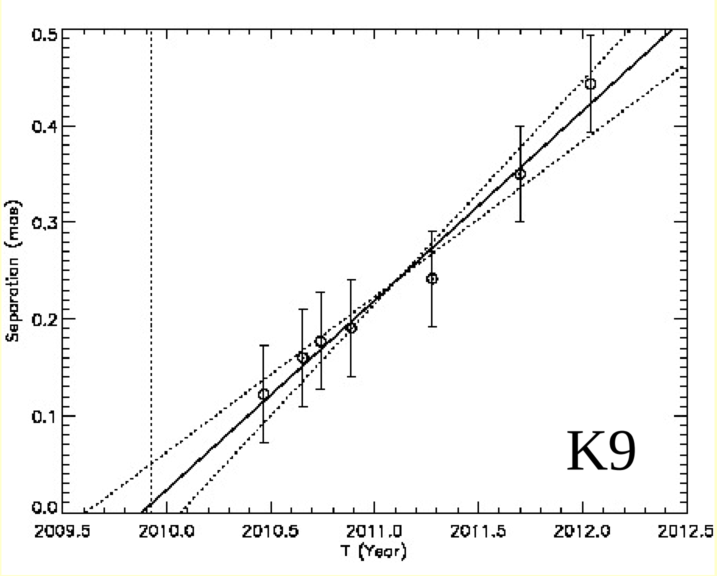
No good time-sampling at 15 GHz

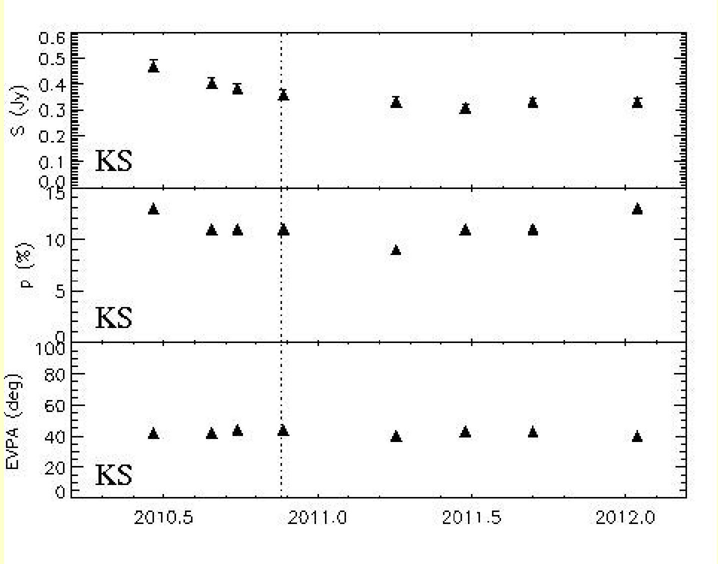
Change in core polarization properties

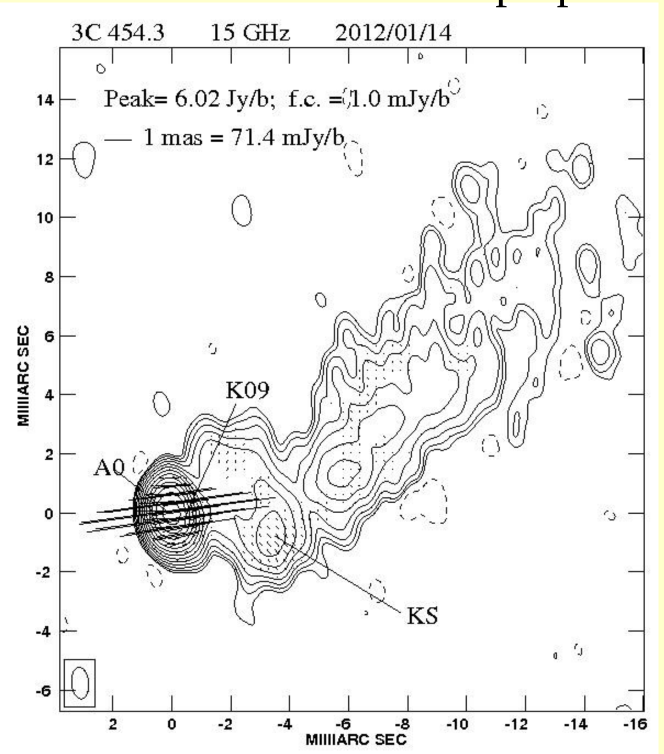
Parsec-scale morphology

Orienti+ in prep.





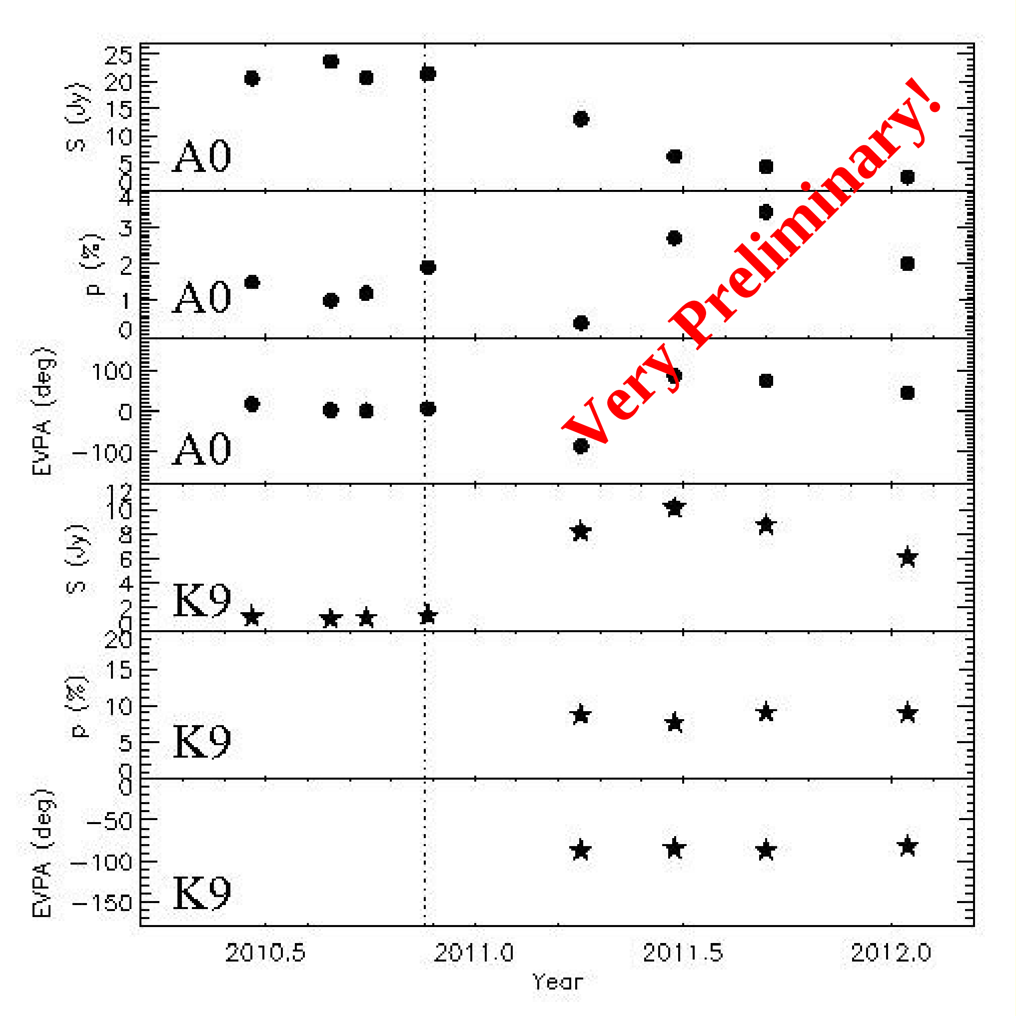


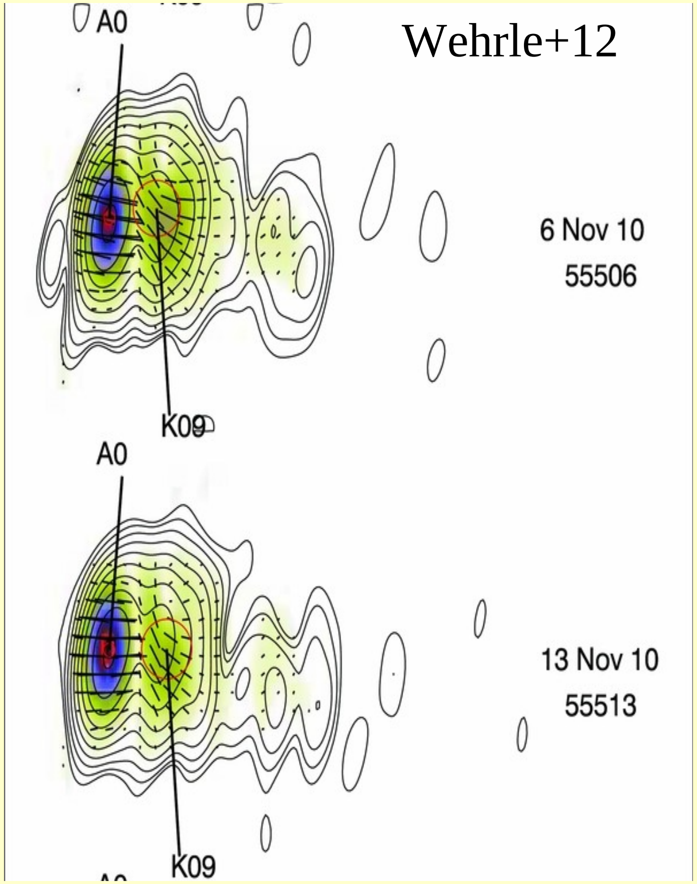


KS roughly stationary

K9: $\beta_{app} = 9.2 \pm 0.6$

Resolving the core components





Abrupt change of ~90° of the EVPA first visible at 43 GHz and then at 15 GHz.

After the November 2010 γ-ray flare, K9 seems the dominant component

High energy emitting region

The location of the high-energy emission is still under debate:

Different flares may be produced in **different regions**

AGN region → July 2011 flare in PKS 1510-089; November 2010 flare in 3C454.3

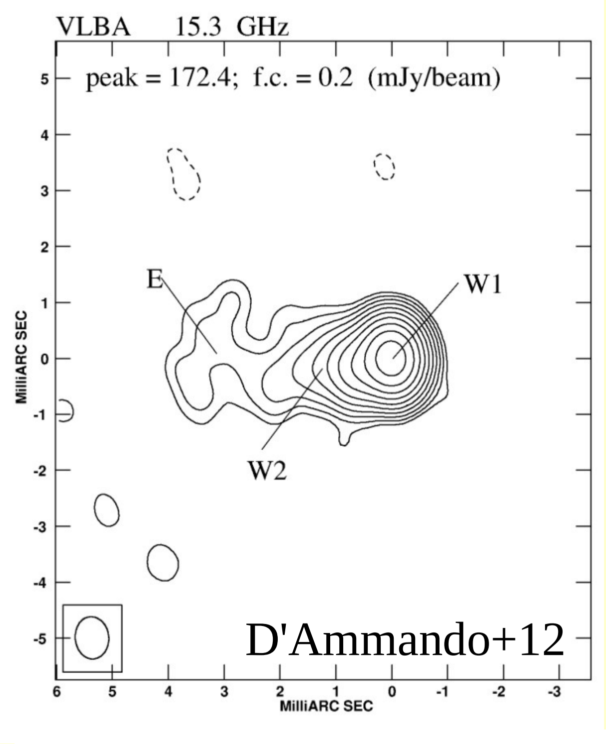
JET region → November 2010 flare in 3C454.3; October 2011 flare in PKS 1510-089

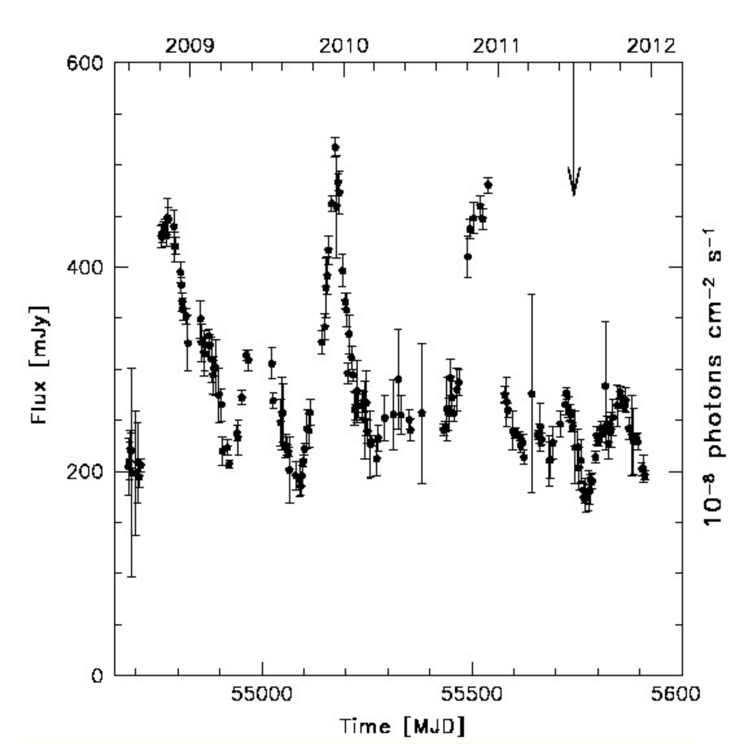
The **main mechanism** and the **seed photons** at the basis of high-energy emission may vary **depending on the location** of the flare region

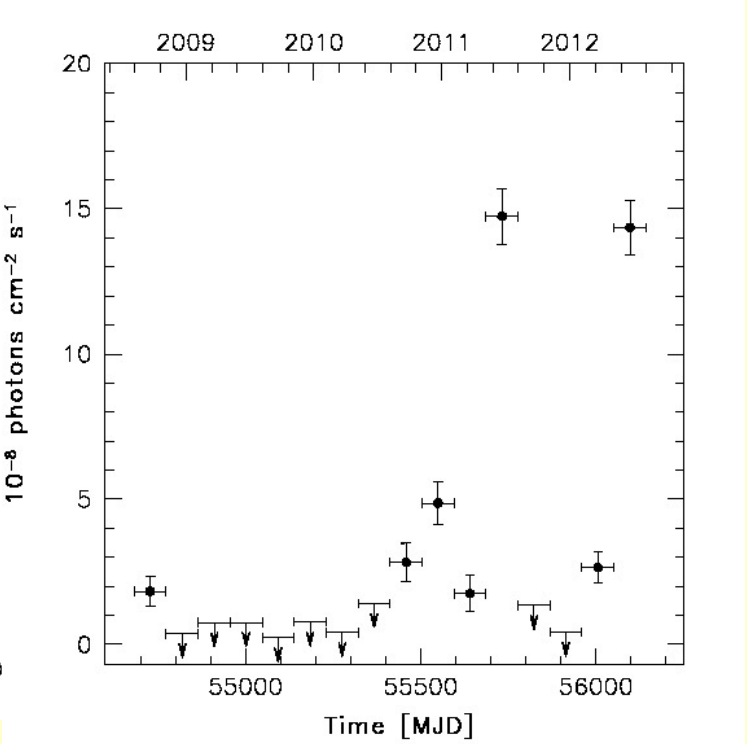
AGN region → **UV/optical photons from disk/BLR**; **SSC/external synchrotron photons**

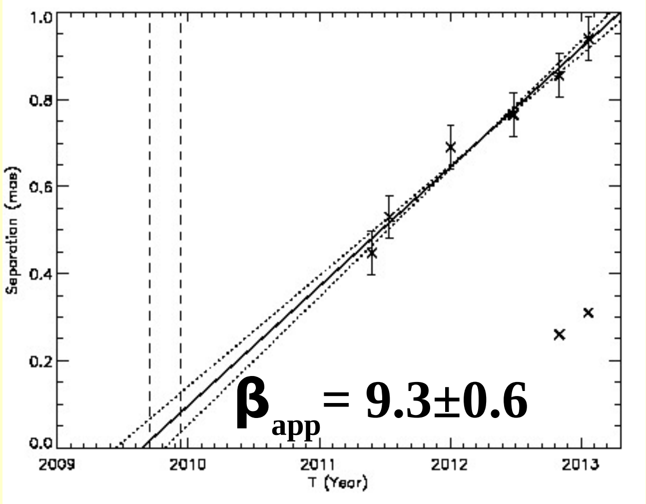
JET region → **SSC/external synchrotron photons**; **IR photons from dusty torus**

SBS0846+513: relativistic jet in NLSy1









No clear γ-ray flare detected close in time with the ejection of a new jet component.

See D'Ammando's talk

Conclusions

The γ-ray flares may not show the same observational characteristics at different wavelength:

- Not all the γ-ray flares occurs close in time with the ejection of a blob

- The ejection of new jet components may not be associated with any γ-ray flare

- Large EVPA rotations in radio are not observed after each γ-ray flare

- 90° EVPA is observed first at high frequency and then at low frequencies: Opacity effects?

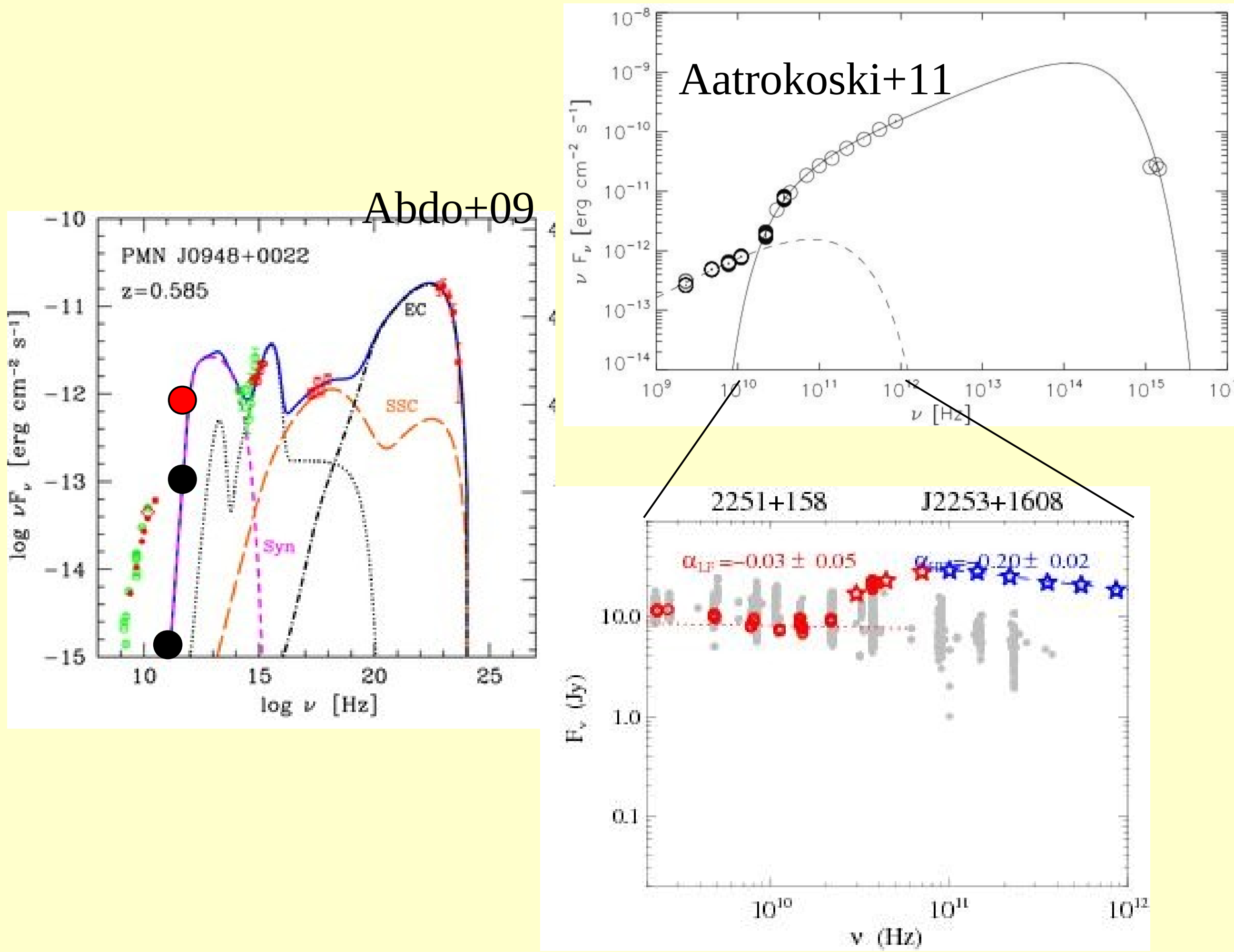
- In PKS 1510-089 the EVPA along the jet is almost constant suggesting that the magnetic field of the main jet structure dominates over the blob.

What about the future?...ALMA

Planck 10σ is 0.25–1.0 Jy depending on the band. Only the brightest objects can be observed.

The majority of the radio sources is much fainter!!!

ALMA rms in 1 min: **~0.1, 0.3, 0.6, 5.3 mJy beam^{-1}** at 100, 230, 345, and 675 GHz



Almost 2 orders of magnitude more sensitive and it provides full polarization information