A parsec scale multi-frequency polarimetric analysis of the TeV blazar Mrk 421

Blazars through Sharp Multi-Wavelength Eyes conference.
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Presented by:
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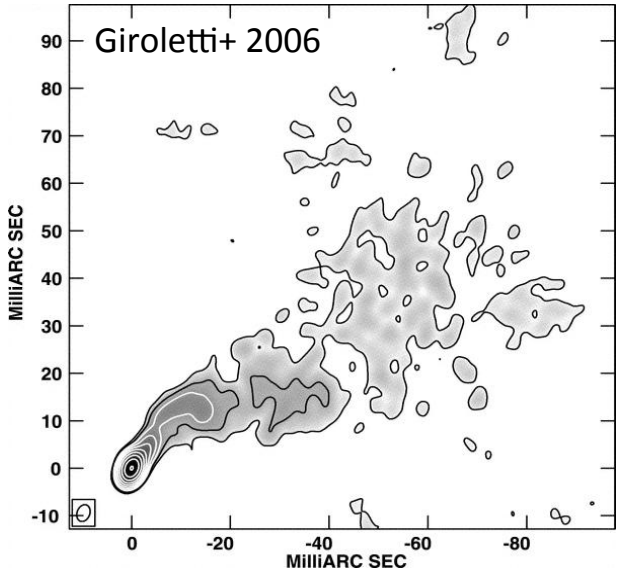
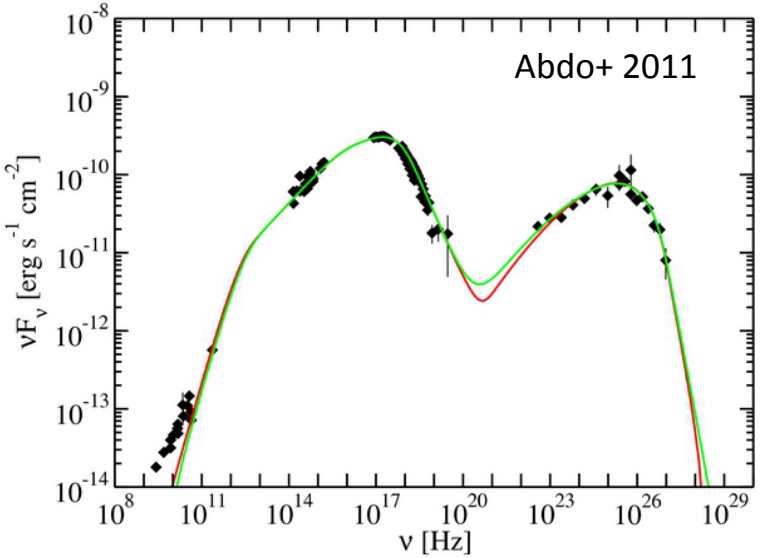
The HSP blazar Markarian 421

Mrk421 is a nearby BL Lac object (***z* = 0.031**)
$P_{1.4GHz}$~$10^{24.27}$ Watt/Hz
D_{core}~0.06-0.12 mas (~1-2x10^{17}cm)



It shows a jet structure oriented in North-West direction, starting from the core and extending for several tens of mas.



- HSP object.
- Detected by EGRET.
- It is a bright Fermi source.
- Multi-wavelength study by Abdo et al.

It is the first extragalactic object revealed in TeV band

Data set

VLBA obs. at 15, 24 and 43 GHz ⟺ 12 epochs during 2011

in total and polarized intensity

VLBA
(Very Long Baseline Array)

Main Goals

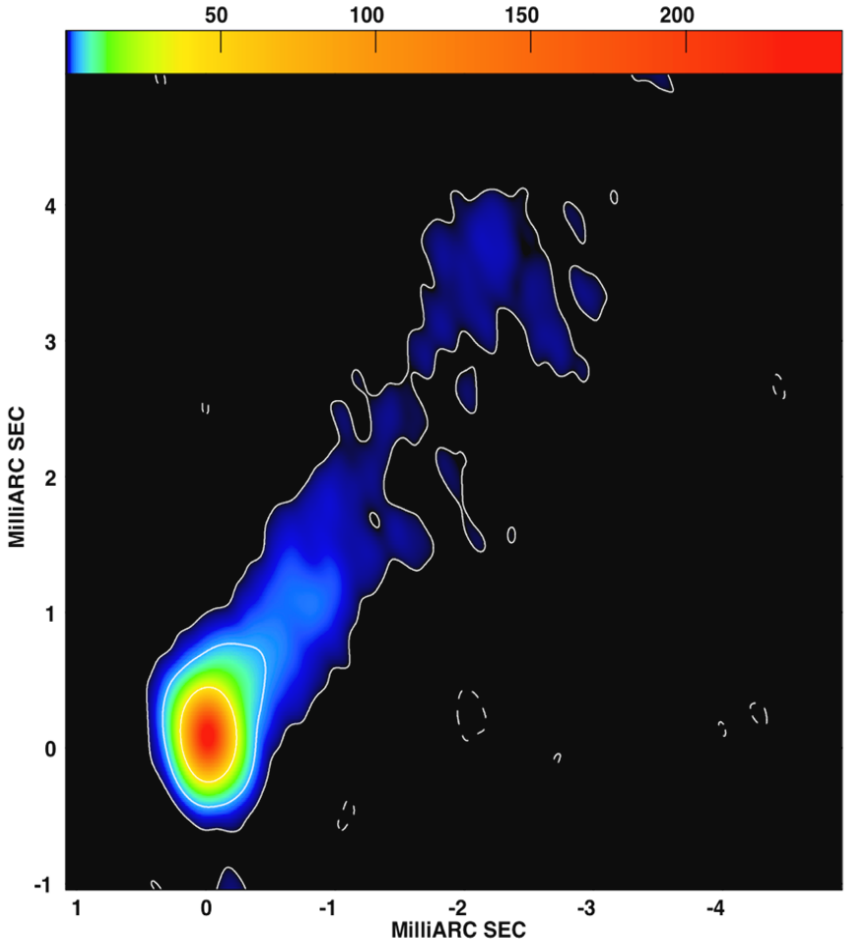
- Parsec scale analysis of the polarization structure and properties (core and jet region): fractional polarization, EVPAs, variability, Faraday rotation, limb brightening.

Multifrequency campaign

This study is part of a wider multifrequency campaign, with observations in:

sub-mm (**SMA**), opt./IR (**GASP**), UV/X-ray (**Swift, RXTE, MAXI**), and γ rays (**Fermi-LAT, MAGIC, VERITAS**).

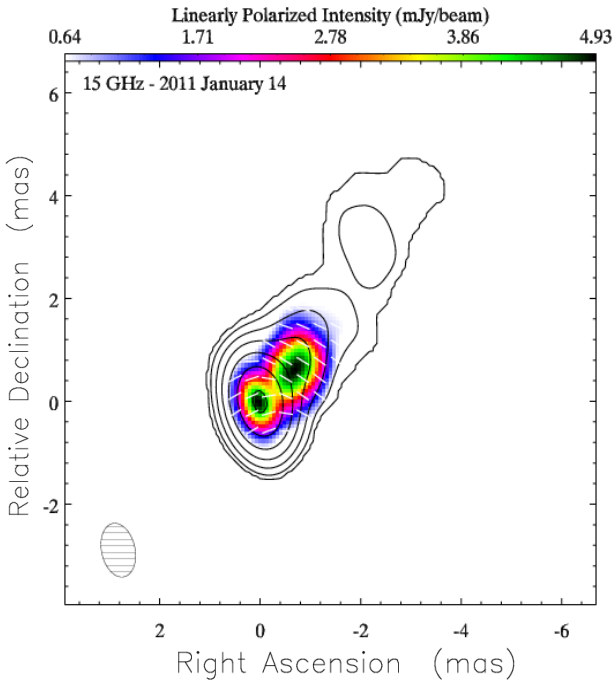
The HSP blazar Markarian 421



Blasi+2013.

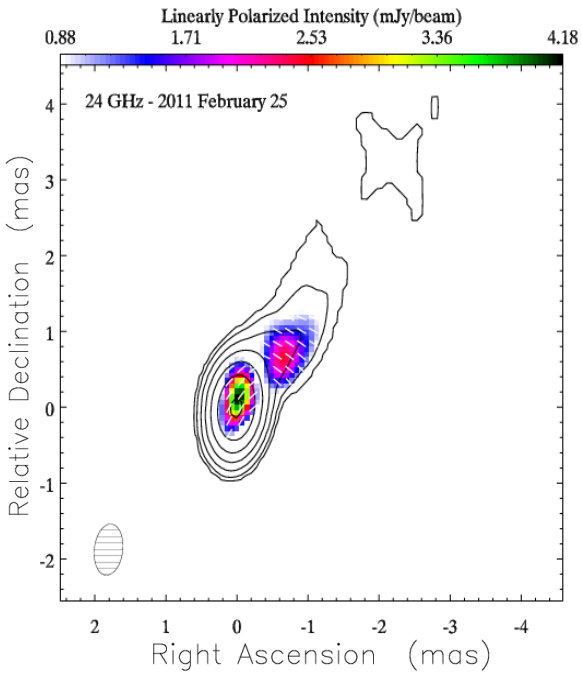
- Jet structure well defined and well-collimated emerging from a compact nuclear region.
- The **jet** is oriented in North-West direction (PA ~-35°), and it extends over an angular distance of ~4.5 mas (about 2.67 pc @ z=0.03).
- The mean **flux density** of nuclear region is ~350 mJy.
- Detected only stationary components within the jet, by using obs. over a 12-month period.

Polarized intensity images



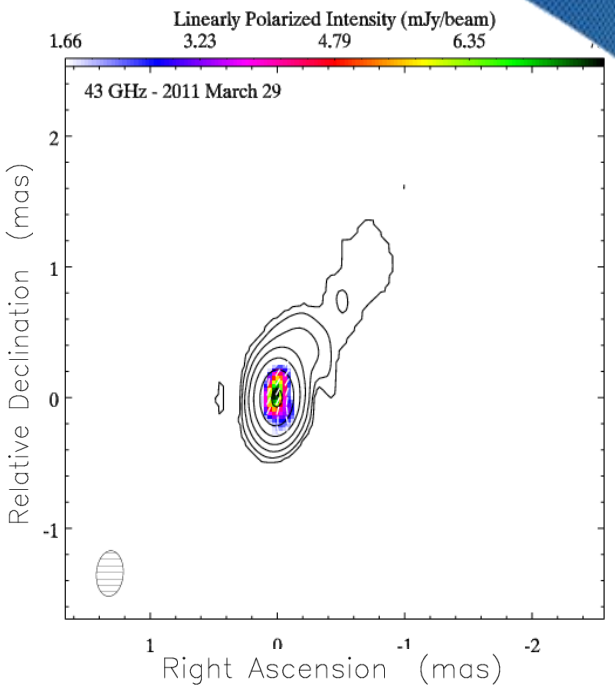
15GHz

Beam: 0.92mas x 0.54mas



24GHz

Beam: 0.58mas x 0.35mas



43GHz

Beam: 0.42mas x 0.27mas

- The polarized emission extends for about 1 mas from the core region at 15 and 24 GHz.
- At 43 GHz we only detect polarized emission within the core region.
- The mean degree of polarization for the core is ~1%, while for the Jet ~15%.
- EVPAs have different behavior with time, frequency and jet location.

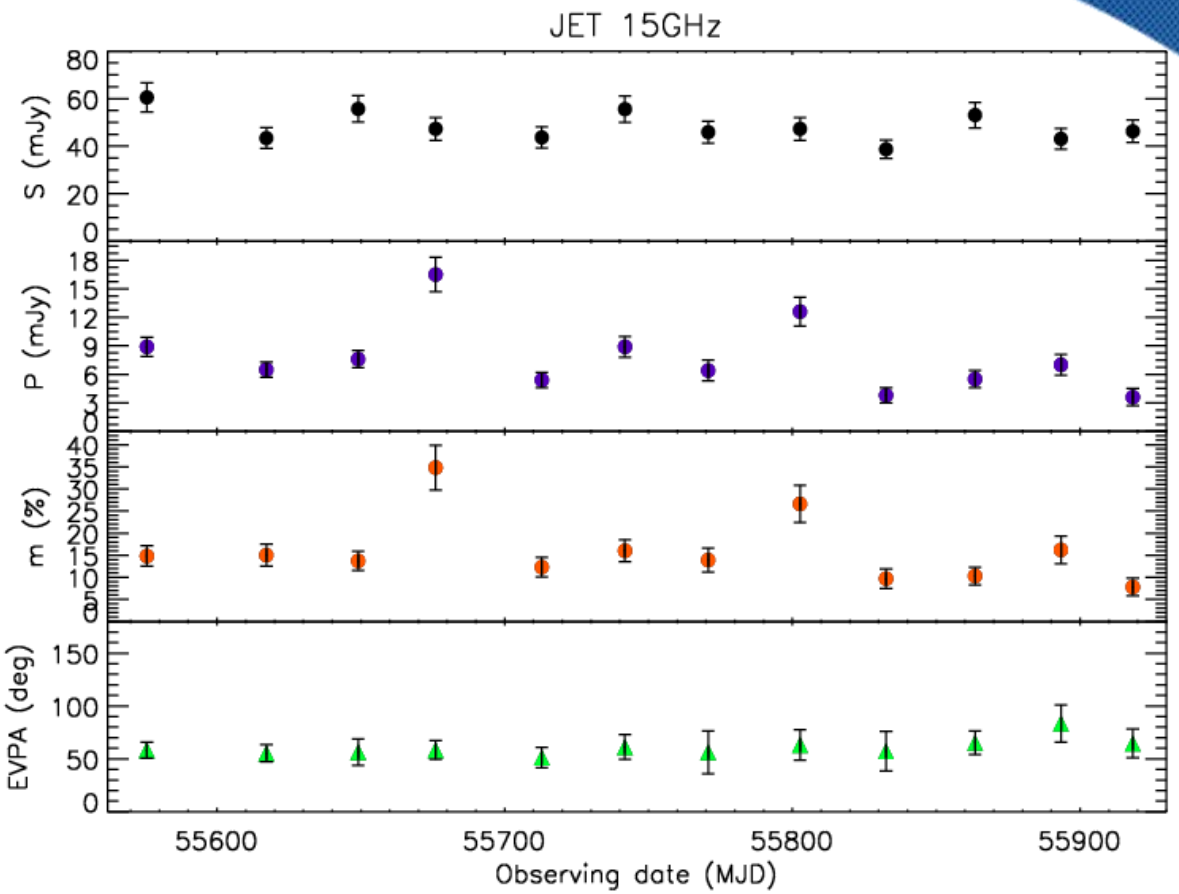
Polarization parameters: jet region at 15 GHz

Total intensity emission

Polarized emission

Fractional polarization

EVPAs



- Total intensity lightcurve not so variable (F_{var}=0.09±0.04).
- The polarized flux is variable (F_{var}=0.48±0.11). but no evidence of enhanced activity.
- The mean degree of polarization for the Jet is ~15%.
- EVPAs quite stable around a value of about 55° (i.e. magnetic field parallel to the jet PA).

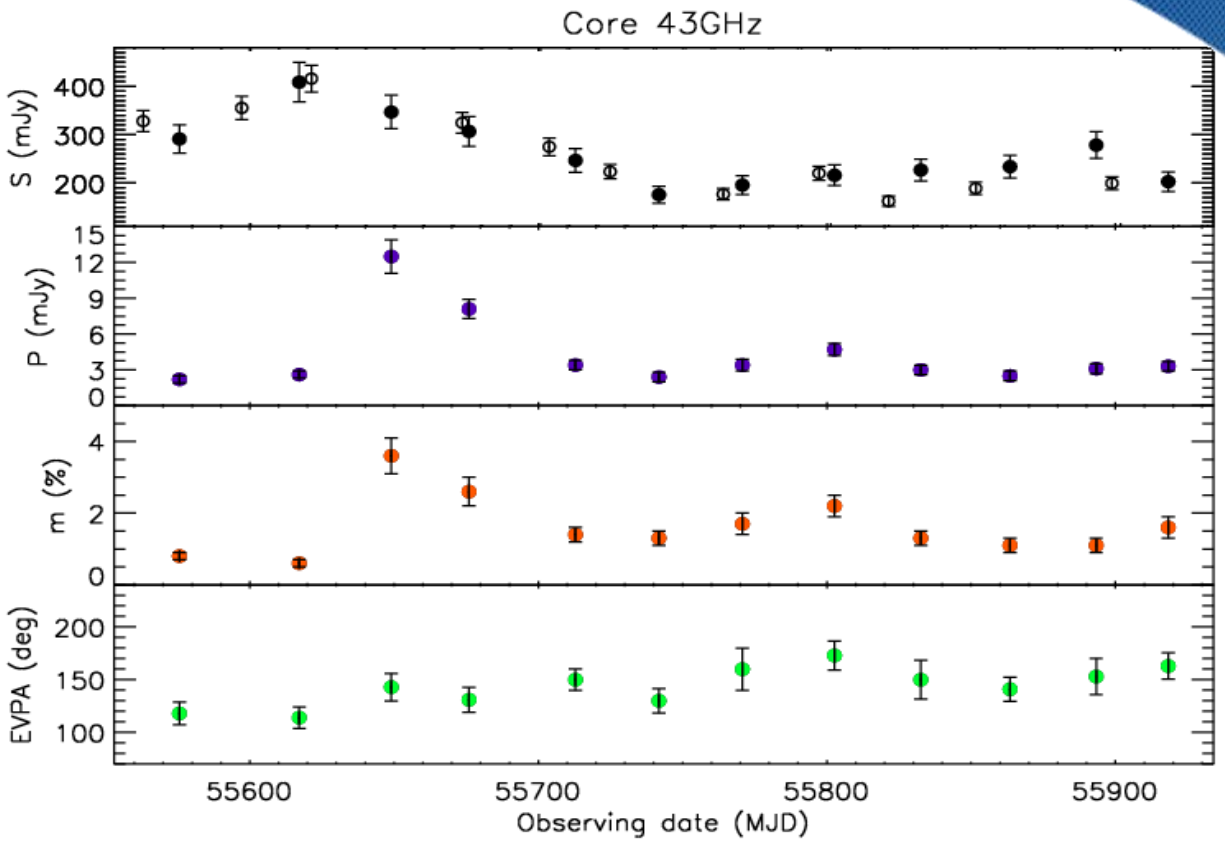
Polarization parameters: core region at 43 GHz

Total intensity emission

Polarized emission

Fractional polarization

EVPAs



- There is a main peak in the total intensity lightcurve
- The polarized flux reaches a 12 mJy peak during the 3th observing epoch.
- The mean degree of polarization for the core is ~2%.
- EVPAs have a stable behavior with the time around 150° (i.e. magnetic field transverse to the jet PA).

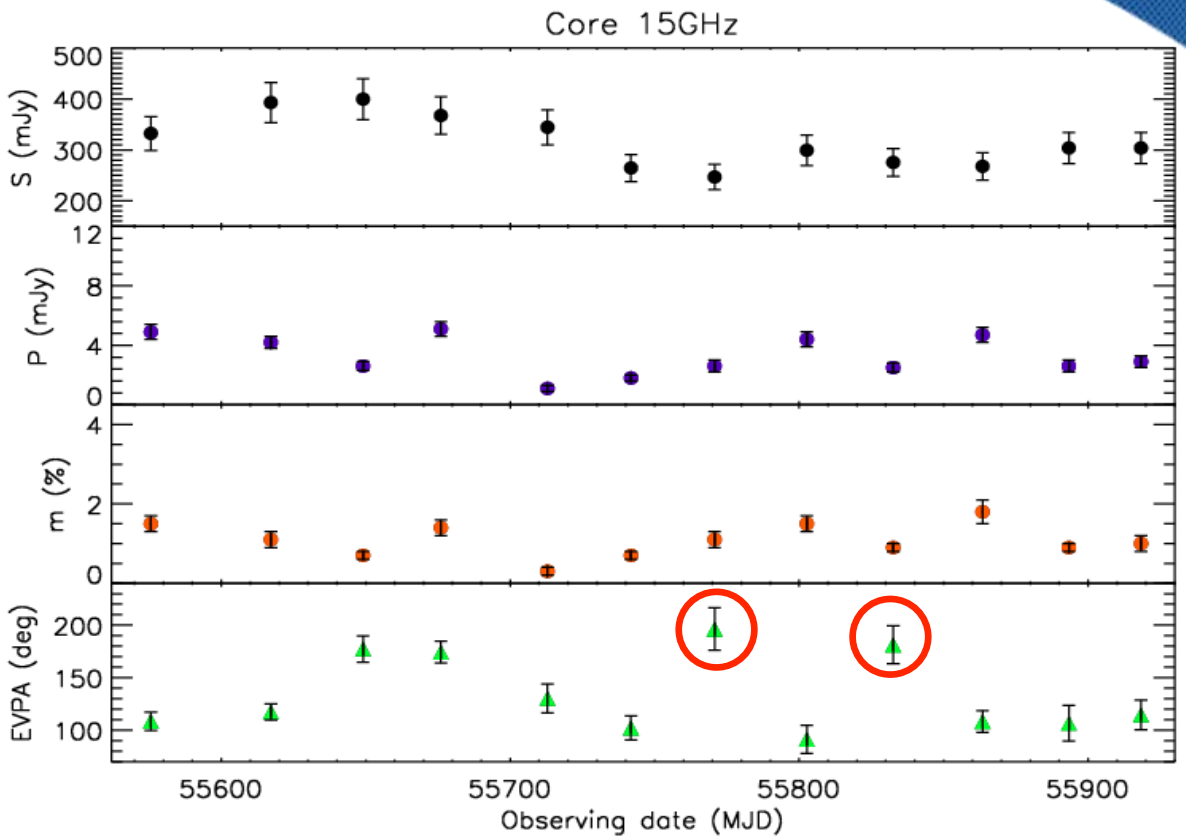
Polarization parameters: core region at 15 GHz

Total intensity emission

Polarized emission

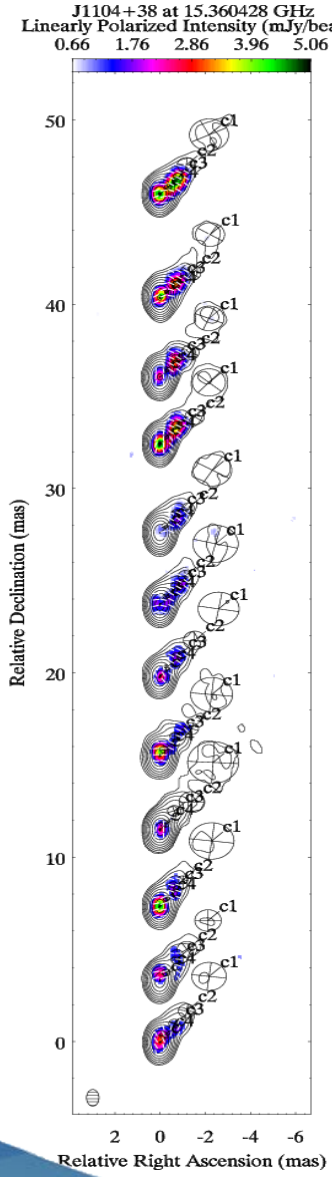
Fractional polarization

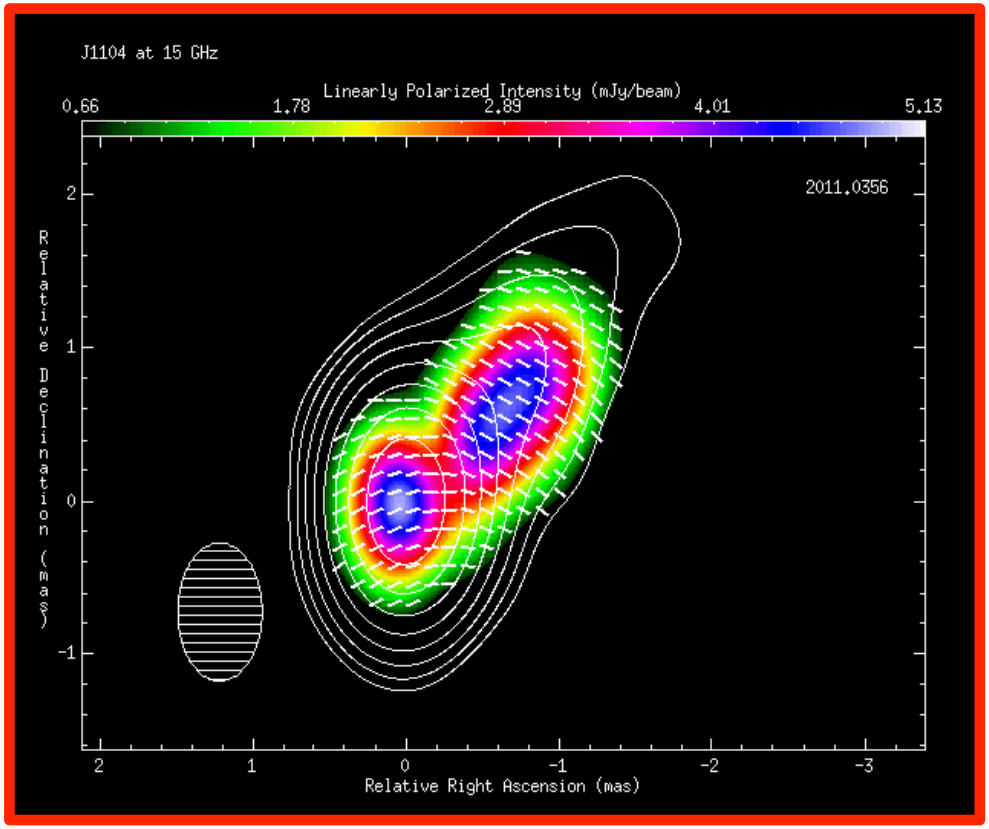
EVPAs



- There is a main peak in the total intensity lightcurve.
- The polarized flux is not extremely variable(F_{var}=0.40±0.09).
- The mean degree of polarization for the core is ~1%.
- EVPAs have different behavior with the time and they show two clear 90° flips → **Opacity!**

Linearly polarized intensity





Peak Total Intensity 0.3972 Jy/beam (noise at 0.85 mJy/beam - Noise Pol. 13.0% peak)
Total Intensity Contours 0.42,0.82,1.60,3.13,6.13,12.00,23.49,45.98,90% of peak
Beam FWHM 0.90x0.55 mas at 0.00 deg.

Interpretative framework

Jet region:

- Stable EVPAs → ~55° (i.e. perpendicular to the jet) → parallel magnetic field.

  - Velocity shear across the jet.
  - Helical magnetic field with a pitch angle less than 45° (Wardle 2013).

Core region:

- Stable EVPAs at 43 GHz → ~150° (i.e. parallel to the jet) → transverse magnetic field.

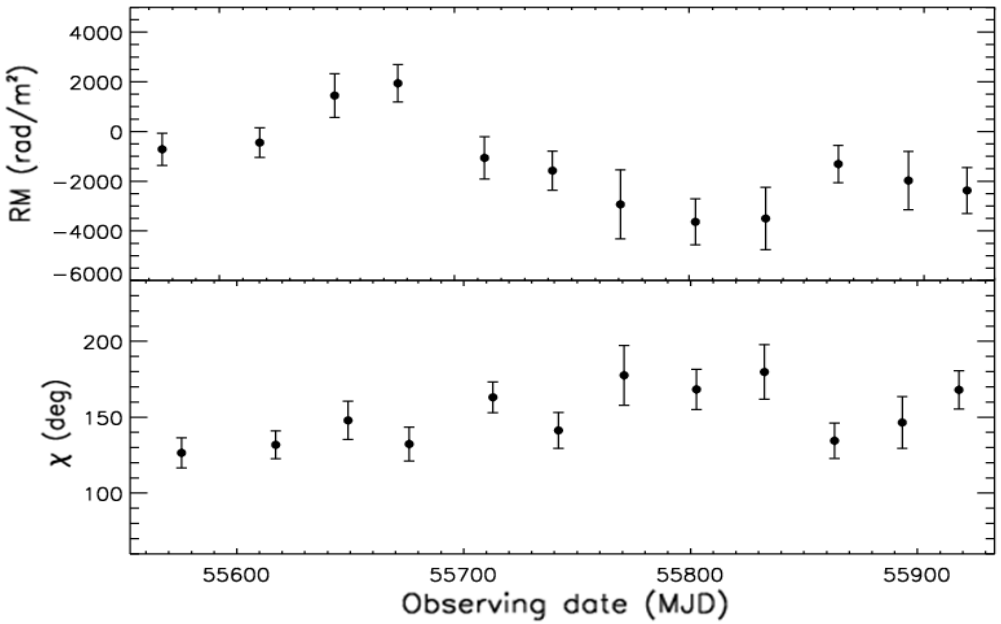
  - Transverse shock.

- EVPA variability at 15 GHz → opacity effect (...and variable Faraday rotation?)

A similar magnetic field configuration was revealed by Piner et & Edwards (2005).

Faraday rotation analysis

$$\chi_{\rm obs} = \chi_{\rm int} + RM \times \lambda^2$$



Time variable RM
(from -3000 to +2000 rad m^{-2})

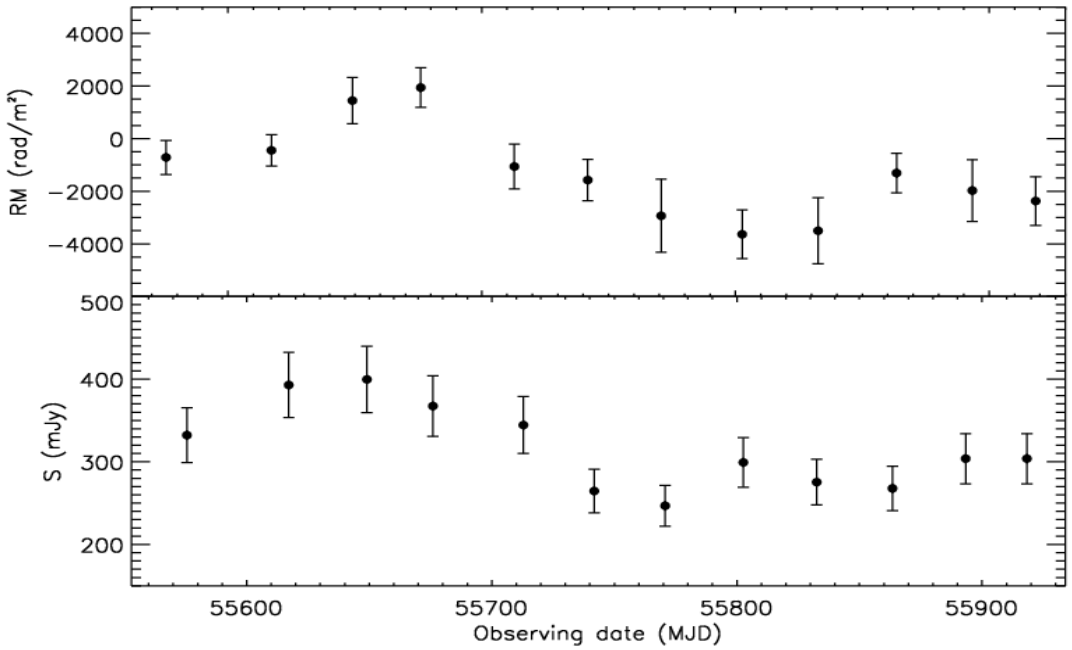
Higher variability at longer wavelenghts

- Intrinsic polarization angle less variable with respect the 15 GHz trend (F_{var}=0.10±0.04).

reflects the 43 GHz trend.

RM vs. accretion rate

$$RM = 812 \int n_e \mathbf{B}_{||} \cdot dl \quad [\mathrm{rad\ m^{-2}}]$$

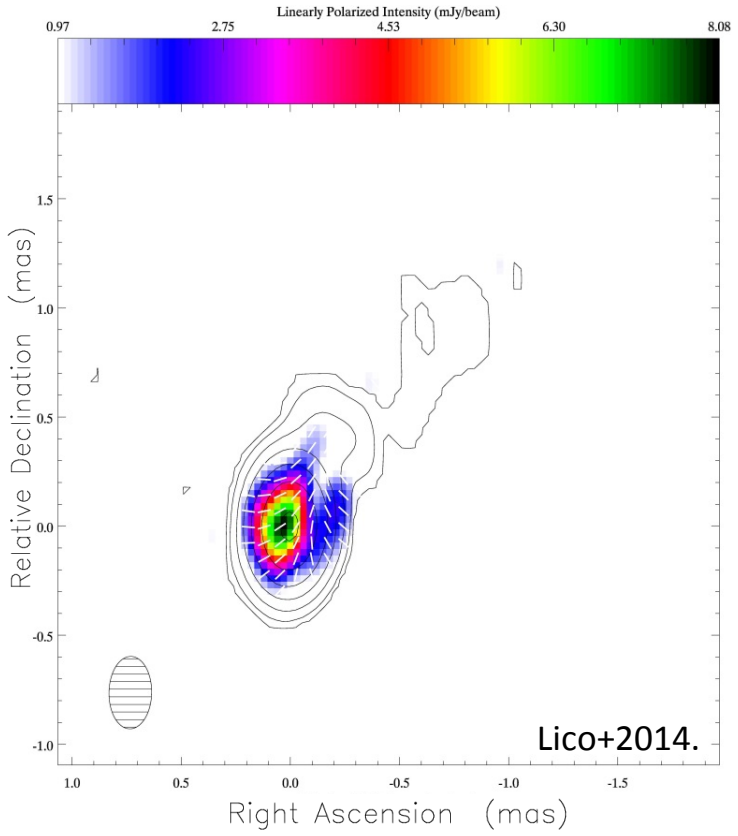


RM time evolution

15 GHz Tot int light curve

- RM and core flux density → similar trend
- RM variability related to changes in the accretion rate?

Limb brightening at 43 GHz



At 43 GHz in the inner part of the jet we clearly observe a **traverse EVPA distribution** and a **limb brightening structure** in the polarized emission.

⇩

Spine/layer polarization structure that seems to be a common feature in TeV blazars (e.g. Mrk 501)

Velocity shear → parallel magnetic field in the jet.

- Limb brightening structure.
- Low pol. degree in the core region.

⇨ Blend of sub-components within the beam.

Summary

- The source shows polarized emission (core and jet region).
- EVPAs have different behavior with the time, the frequency and the jet location.
- Higher variability at longer wavelenghts -> opacity effect + variable RM.

Jet region:

✓ Fractional polarization ~15%.
✓ Stable EVPAs → ~55° (i.e. perpendicular to the jet) → parallel magnetic field.

Core region:

✓ Fractional polarization ~1% at 15 GHz, ~2% at 43 GHz.
✓ Stable EVPAs at 43 GHz → ~150° (i.e. parallel to the jet) → transverse magnetic field.
✓ EVPA variability at 15 GHz → opacity and variable Faraday rotation.

➢ Similar trend for RMs and tot int light curve → accretion rate?

Thank You!

Lico+ 2014, A&A 571, A54 -- Blasi+ 2013, A&A 559, 75 -- Lico+ 2012, A&A 545, 117.