Very Long Baseline Polarimetry and the γ-ray connection in Mrk 421 during the broadband campagn in 2011

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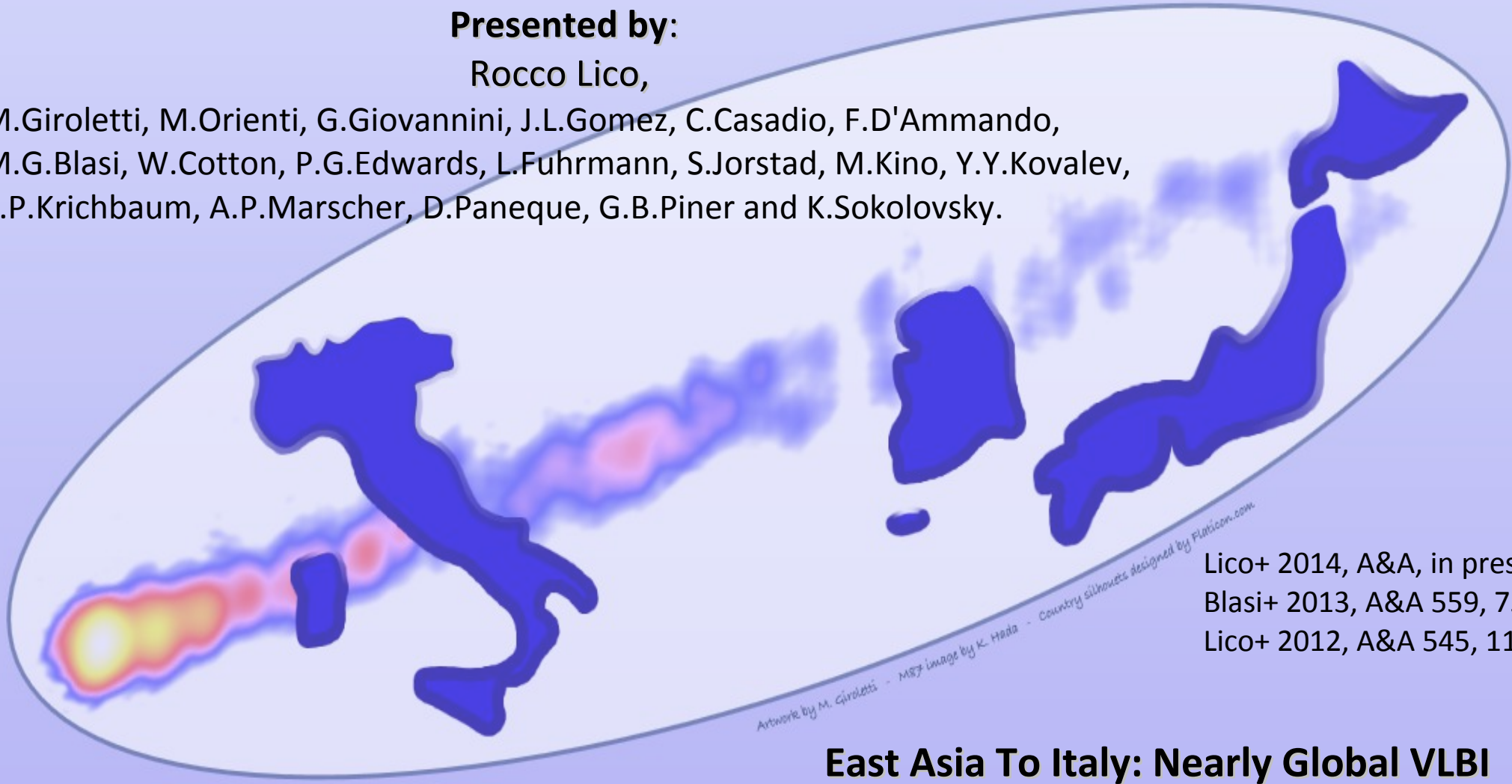


Lico+ 2014, A&A, in press.
Blasi+ 2013, A&A 559, 75.
Lico+ 2012, A&A 545, 117.

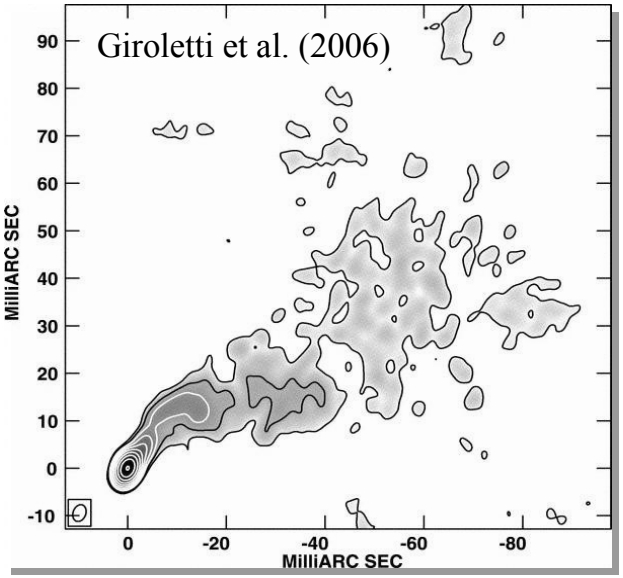
East Asia To Italy: Nearly Global VLBI
Bologna, 13-14 October 2014

Markarian 421

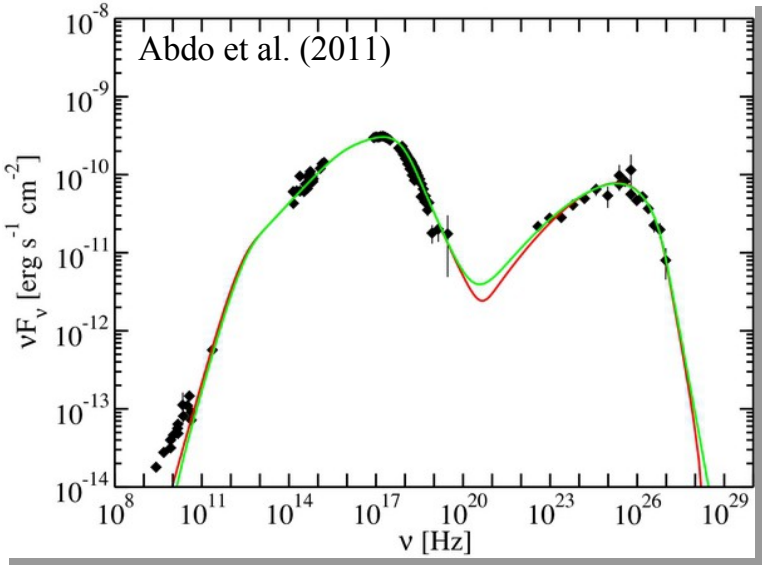
Mrk421 is a near BL Lac object (***z* = 0.031**)

$P_{1.4GHz} \sim 10^{24.27}$ Watt/Hz

$D_{core} \sim 0.06\text{-}0.12$ mas (~1-2x10^{17}cm)



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



- HBL (High-frequency peaked BL Lac).
- Detected by EGRET.
- It is a bright Fermi source (1FHL).
- Multi-wavelength study by Abdo et al.

It is the first extragalactic object revealed in TeV band

Dataset

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

in total and polarized intensity

VLBA
(Very Long Baseline Array)

Main Goals

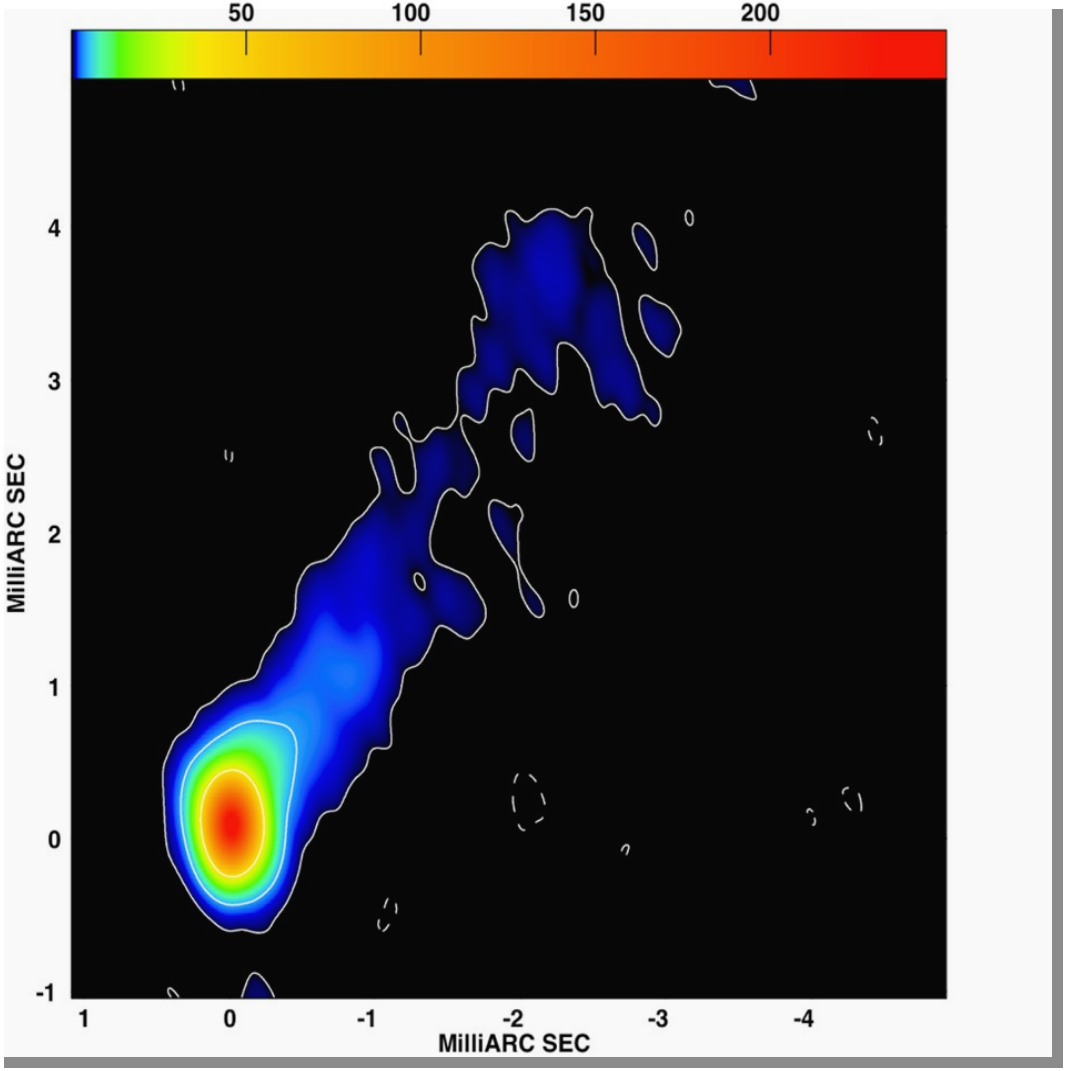
- Parsec scale analysis of the polarization structure and properties (core and jet region).
- Radio vs. γ-ray connection.

Multifrequency campaign

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

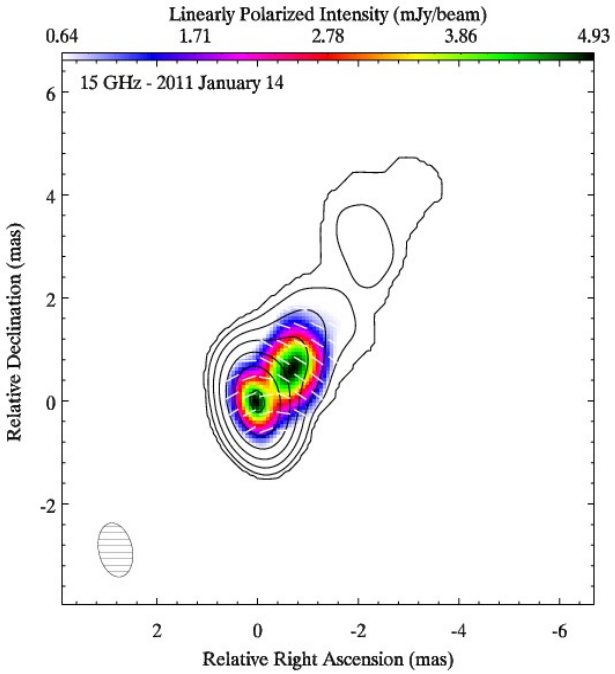
sub-mm (**SMA**), opt./IR (**GASP**), UV/X-ray (**Swift**, **RXTE**, **MAXI**), and γ rays (**Fermi-LAT**, **MAGIC**, **VERITAS**).

43 GHz total intensity image



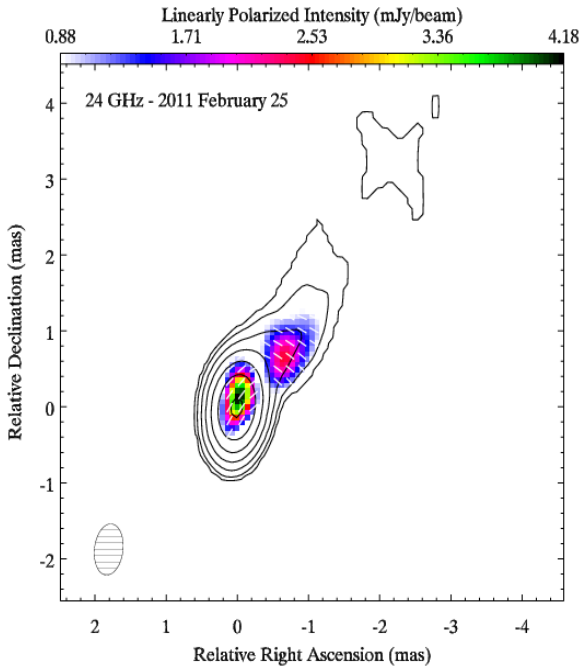
- Jet structure well defined and well-collimated emerging from a compact nuclear region.
- The **jet** is oriented in North-West direction (PA ~-35°), and it extends over an angular distance of ~4.5 mas (about 2.67 pc @ z=0.03).
- The mean **flux density** of nuclear region is ~350 mJy.
- Detected only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

Polarized intensity images



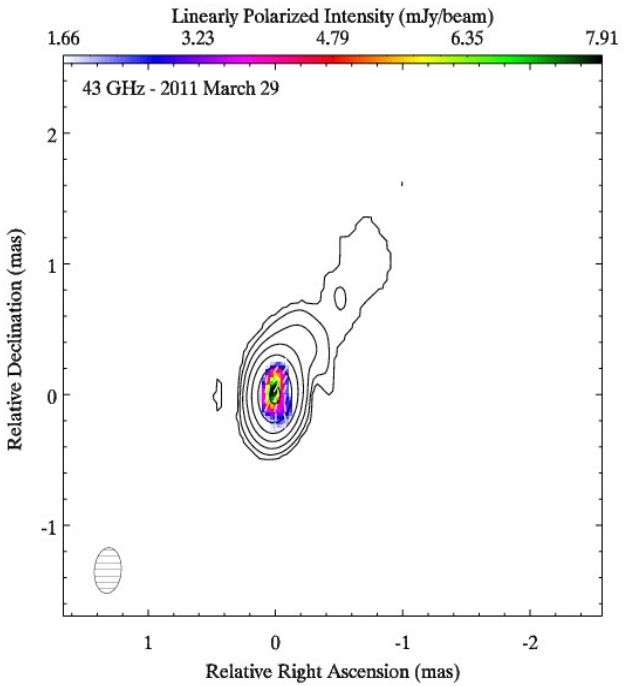
15GHz

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 the time, the frequency and the jet location.

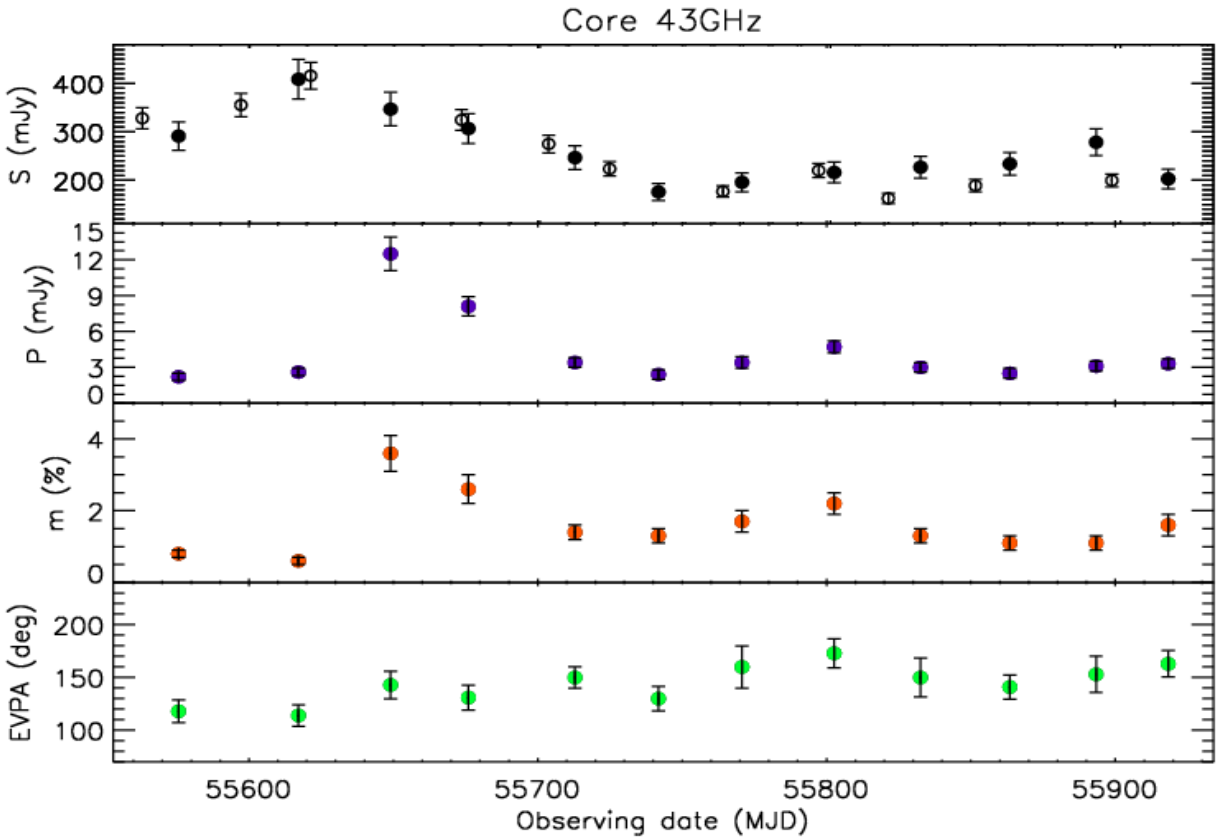
Polarization parameters for the core region at 43 GHz

Total intensity emission

Polarized emission

Fractional polarization

EVPAs



Lico+ 2014, A&A, in press.

- 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).

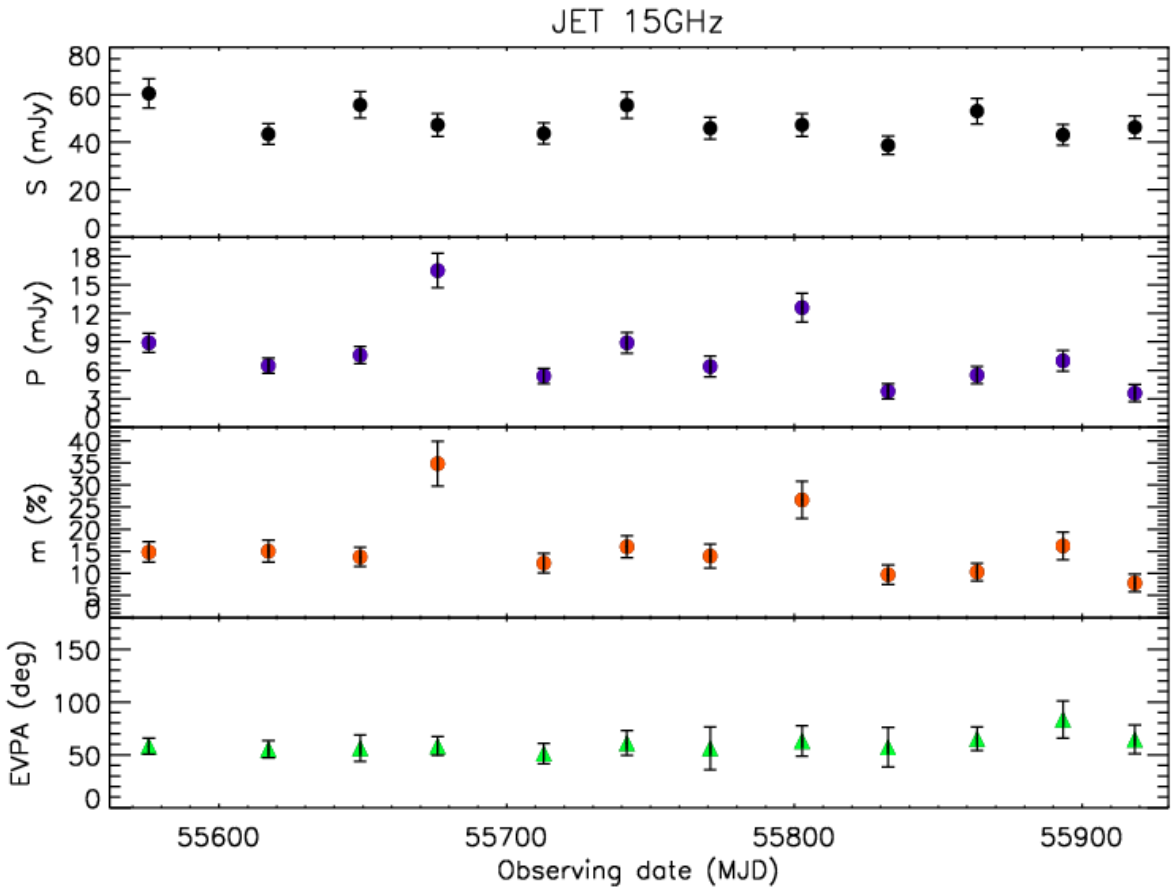
Polarization parameters for the jet region at 15 GHz

Total intensity emission

Polarized emission

Fractional polarization

EVPAs



Lico+ 2014, A&A, in press.

- Total intensity lightcurve not so variable.
- The polarized flux is variable 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).

Interpretative framework

Jet region:

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

⇩

- 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

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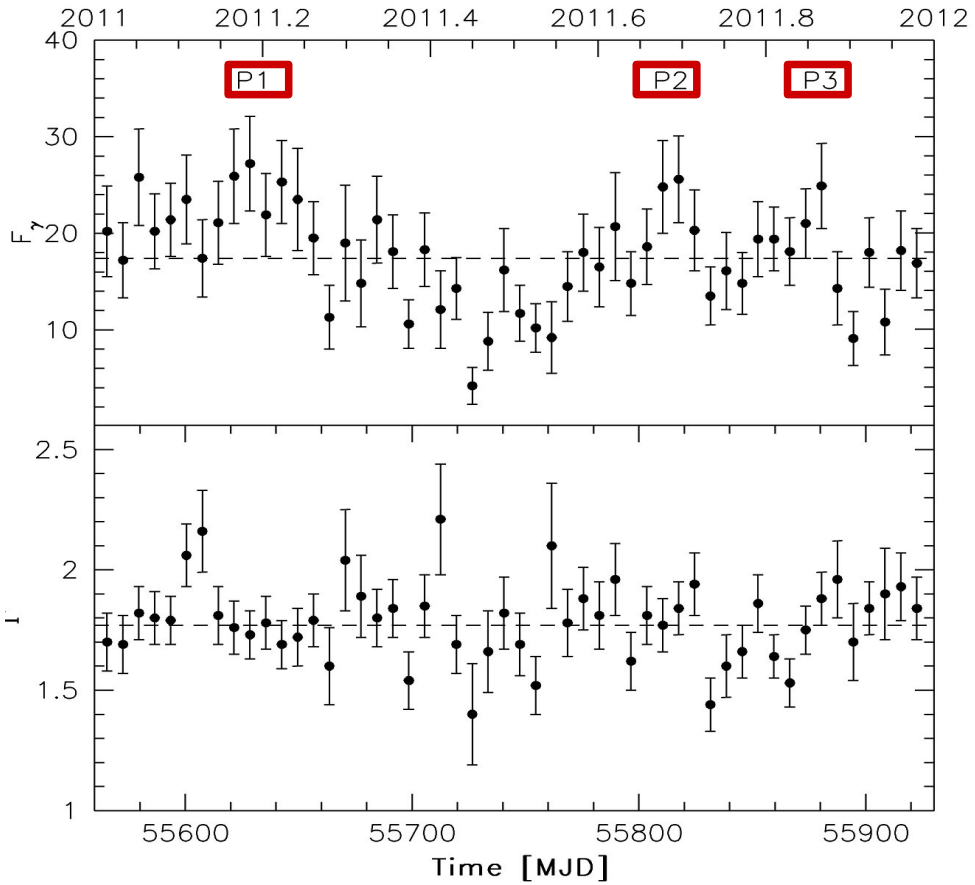
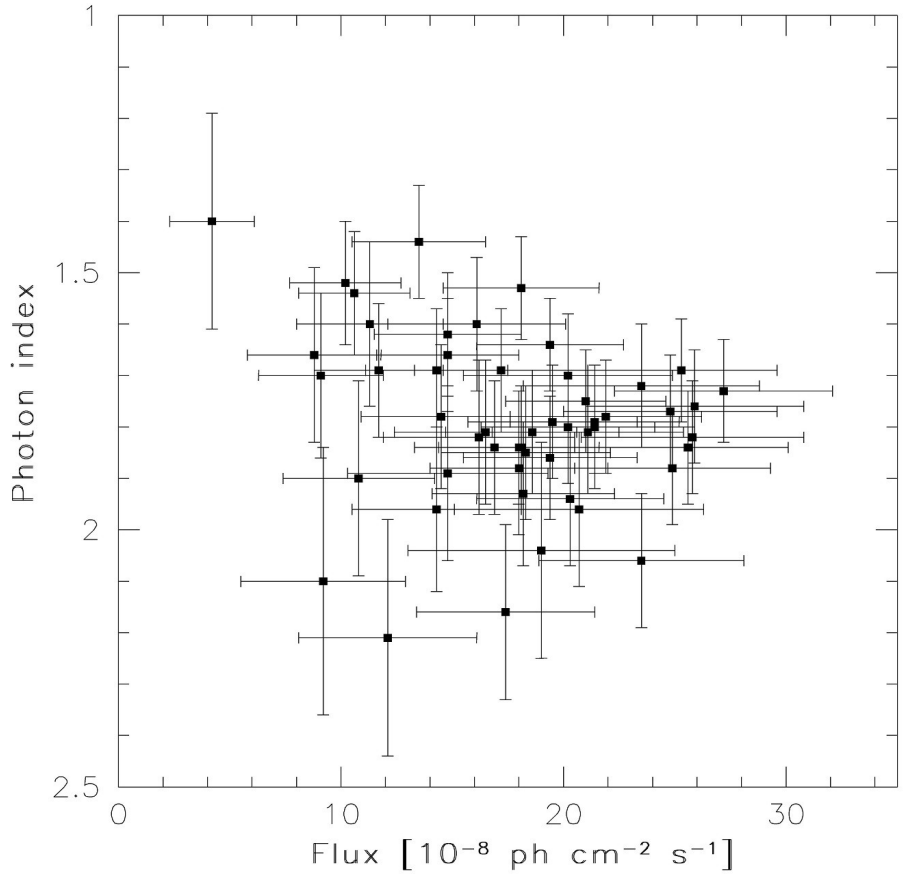
- Transverse shock.

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

γ-ray flux from Fermi-LAT



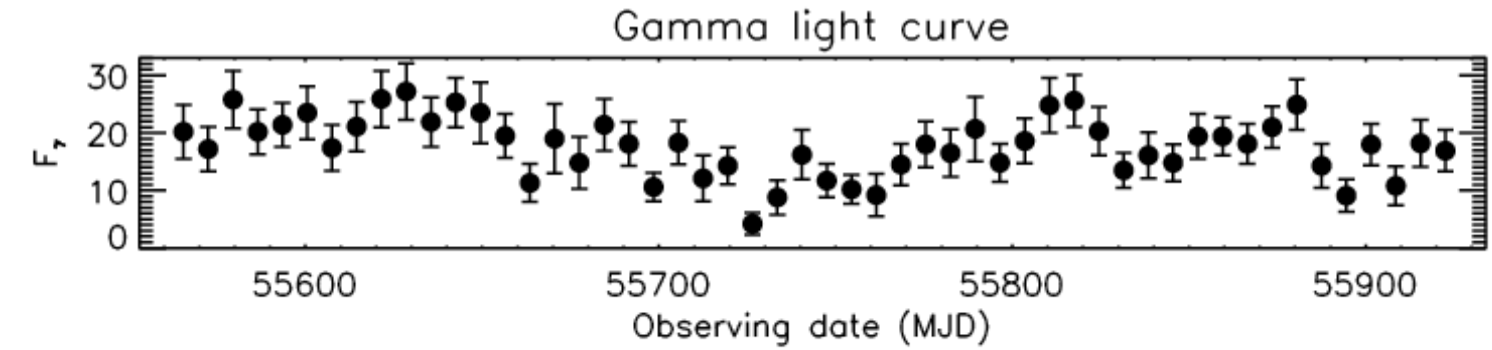


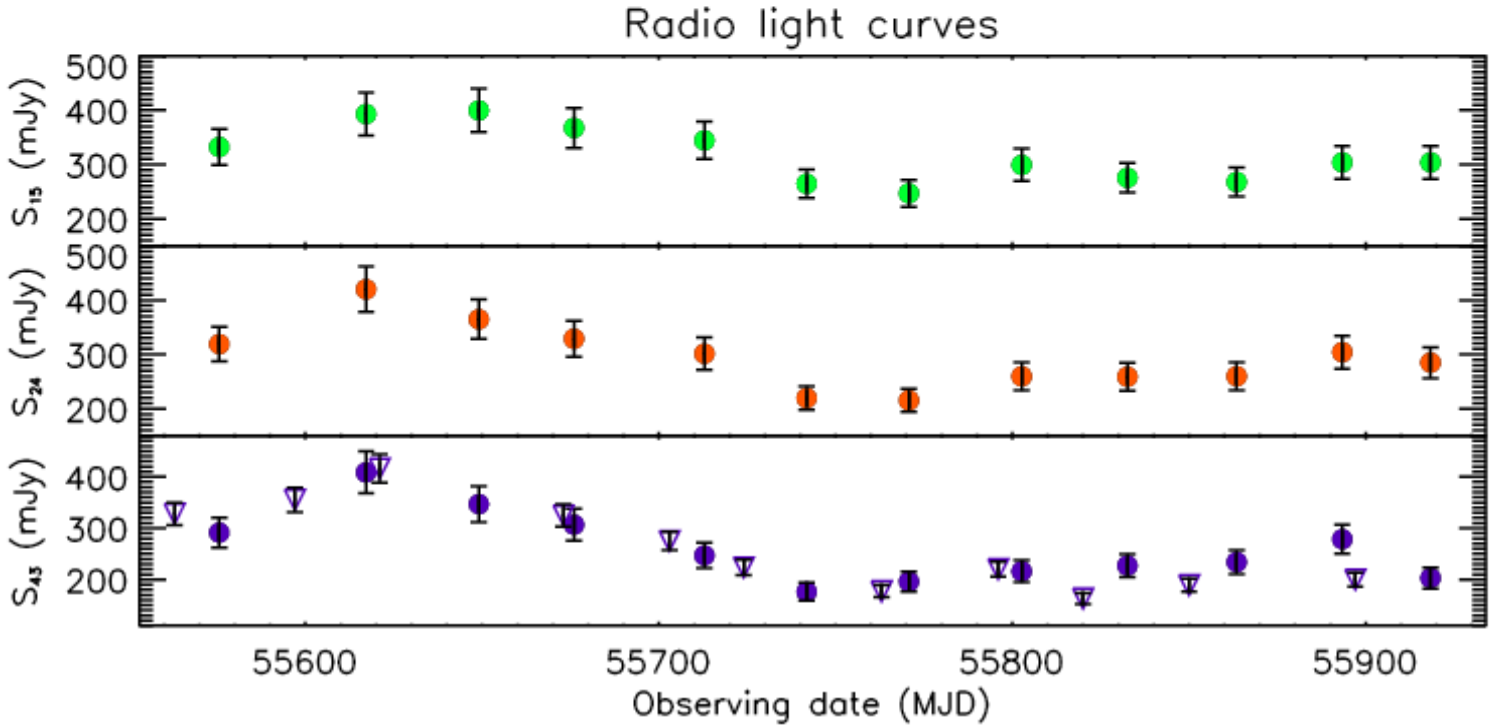
Three main peaks:

- P1: 7 Mar -> (38 ±11) x 10-8 ph cm-2 s^{-1}
- P2: 8 Sep -> (37 ± 12) x 10-8 ph cm-2 s^{-1}
- P3: 13 Nov -> (30 ±9) x 10-8 ph cm-2 s^{-1}

- Photon index varies between 1.4 and 2.2
- No significant hardening during enhanced activity
- No obvious relation between photon index and γ-ray flux

γ-ray vs. radio ligth curves





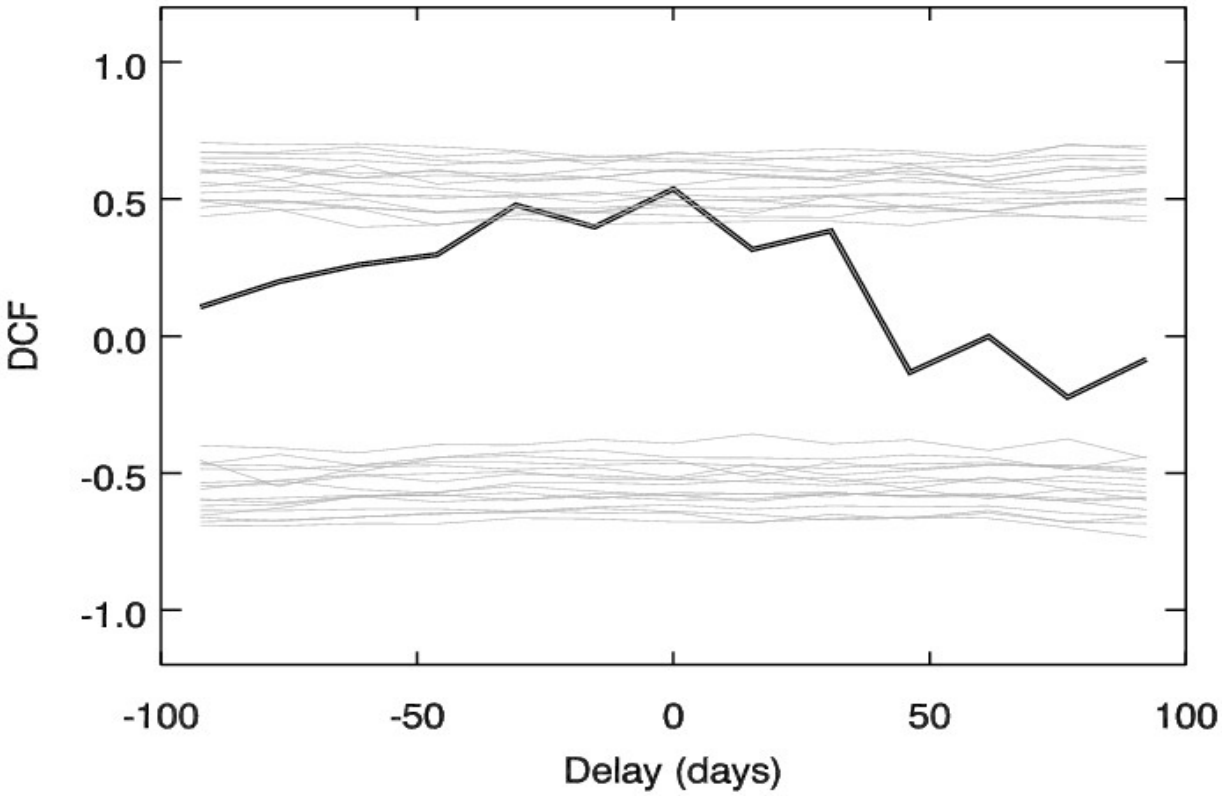
• The P1 γ-ray peak seems to be related to the main radio peak (2011 Feb 25).

15 GHz

24 GHz

43 GHz

Discrete Correlation Function



Pearson correlation coefficient

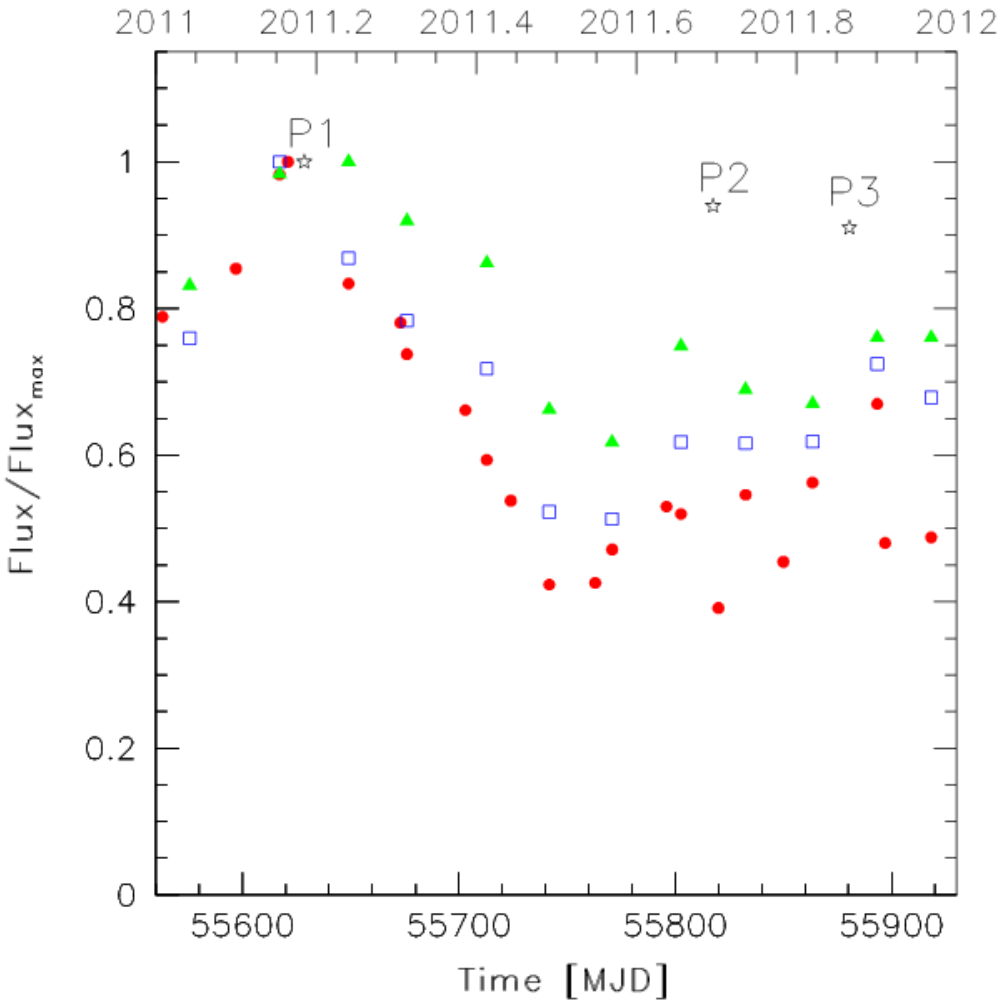
- $r_{15GHz-\gamma} = 0.44$
- $r_{24GHz-\gamma} = 0.42$
- $r_{43GHz-\gamma} = 0.46$

$r_{DCF} = 0.54$

(Edelson & Krolik, 1988)

- ✔ We investigated the delay over a range of ±100 days, with a bin of 15 days → higherst value for zero delay.
- ✔ The gray curves are obtained from different combinations of different Power Spectral Density ($\mathrm{PSD} \propto f^{-\beta}$) slopes, with a confidence level >99.7%.

Normalized light curves



Circles: 43 GHz data
Squares: 24 GHz data
Triangles: 15 GHz data
☆: Stars: γ-ray peaks

The radio and the first gamma-ray peak occur close in time.

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This may indicate that they originate in the same region, where the emission is not opaque at the radio frequencies.

Summary

- The source shows polarized emission (core and jet region).
- EVPAs have different behavior with the time, the frequency and the jet location.

Core region:

- Fractional polarization about 1%.
- Stable EVPAs at 43 GHz → ~150° (i.e. parallel to the jet) → transverse magnetic field.

Jet region:

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

- Correlation between radio and γ-ray light curves (r_{DCF}=0.54) for a zero delay.
- After the enhanced activity:
  - Rapid increase in the polarized flux density.
  - The fractional polarization increase -> 3.6%.

Lico et al. 2014, A&A, in press.
arXiv:1410.0884

Thank You!