Very Long Baseline Polarimetry of Markarian 421 during the broadband campagn in 2011

12th EVN Symposium

Cagliari, 7-10 October 2014

Presented by:

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M.Giroletti, M.Orienti, G.Giovannini, J.L.Gomez, C.Casadio, F.D'Ammando, M.G.Blasi, W.Cotton, P.G.Edwards, L.Fuhrmann, S.Jorstad, M.Kino, Y.Y.Kovalev, T.P.Krichbaum, A.Marscher, D.Paneque, G.Piner and K.Sokolovsky.

Lico+ 2014, A&A, in press.

Blasi+ 2013, A&A 559, 75.

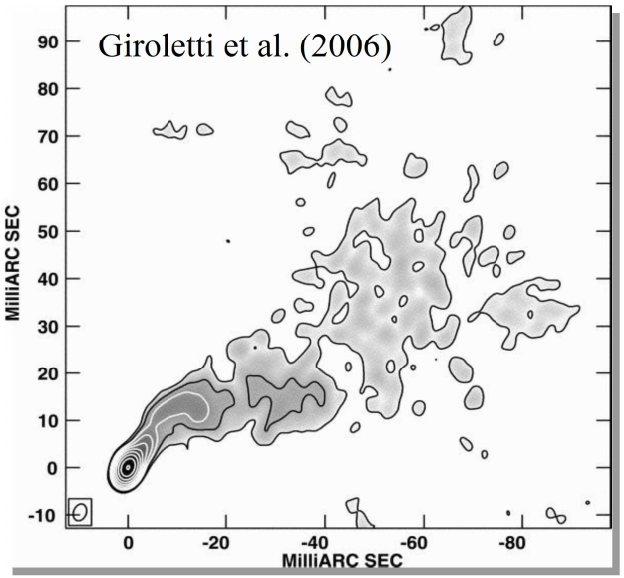
Lico+ 2012, A&A 545, 117.

Markarian 421

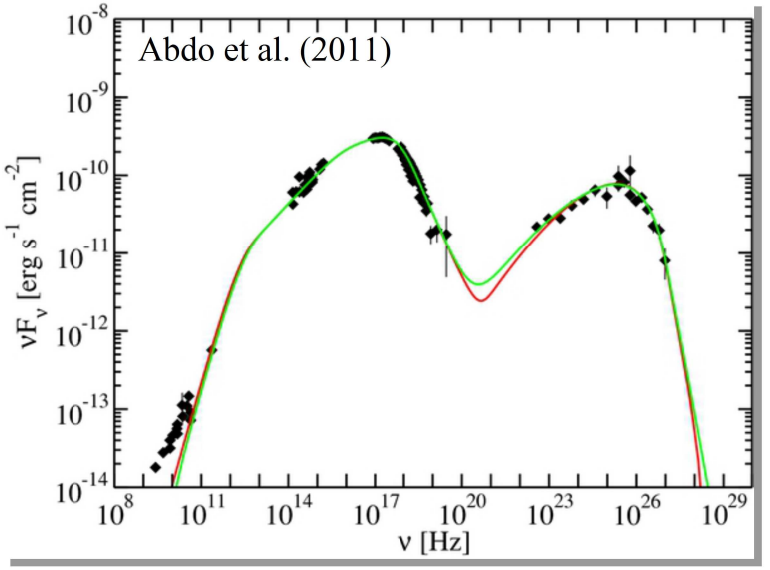
Mrk421 is a near BL Lac object (***z* = 0.031**)

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

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



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

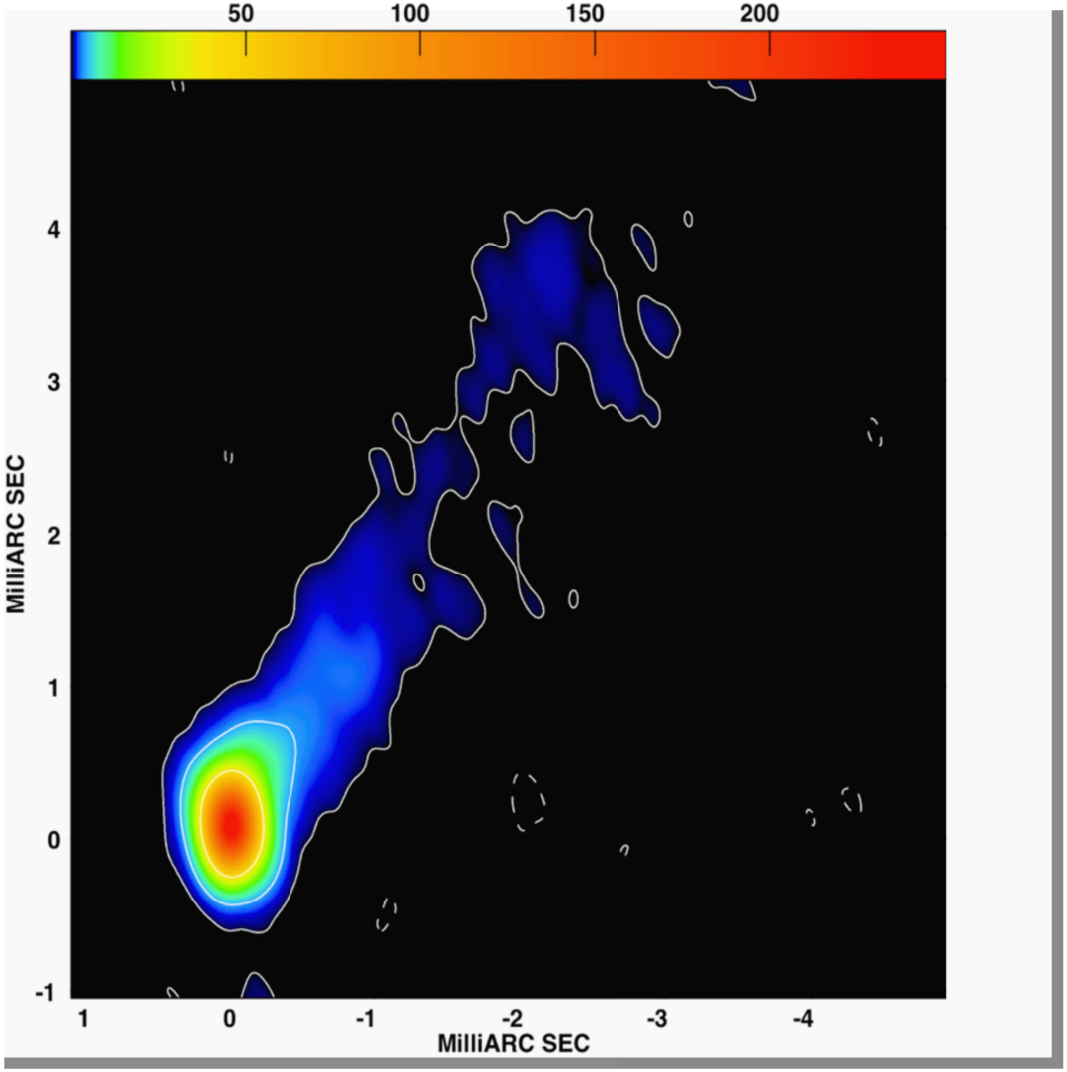
Parsec scale analysis of the polarization structure and properties (core and jet region): fractional polarization, EVPAs, variability, Faraday rotation, limb brightening.

Multifrequency campaign

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

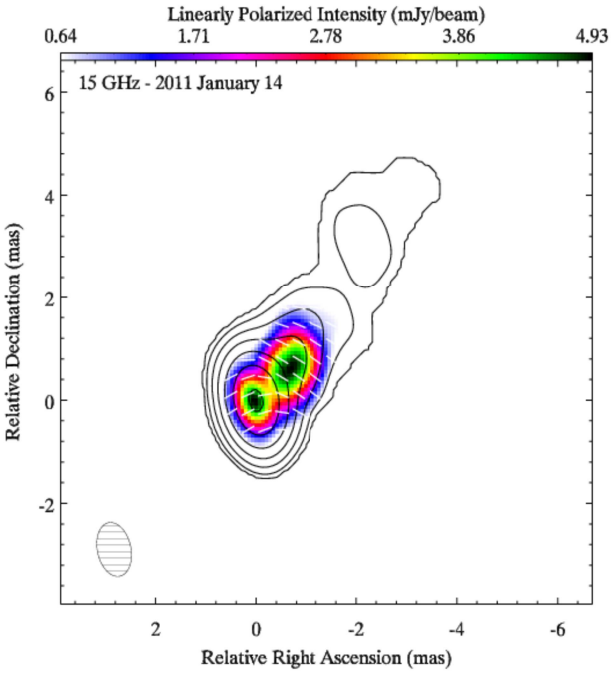
sub-mm (**SMA**), opt./IR (**GASP**), UV/X-ray (**Swift**, **RXTE**, **MAXI**), and γ rays (**Fermi-LAT**, **MAGIC**, **VERITAS**).

43 GHz total intensity image



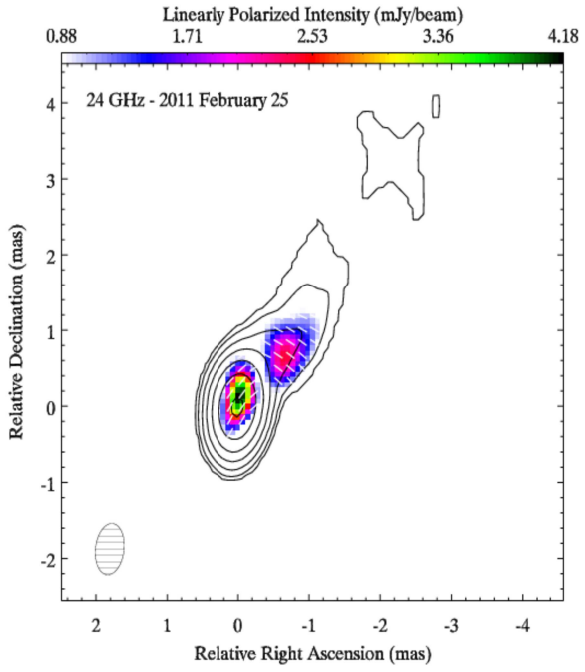
- Jet structure well defined and well-collimated emerging from a compact nuclear region.
- The **jet** is oriented in North-West direction (PA ~-35°), and it extends over an angular distance of ~4.5 mas (about 2.67 pc @ z=0.03).
- The mean **flux density** of nuclear region is ~350 mJy.
- Detected only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

Polarized intensity images



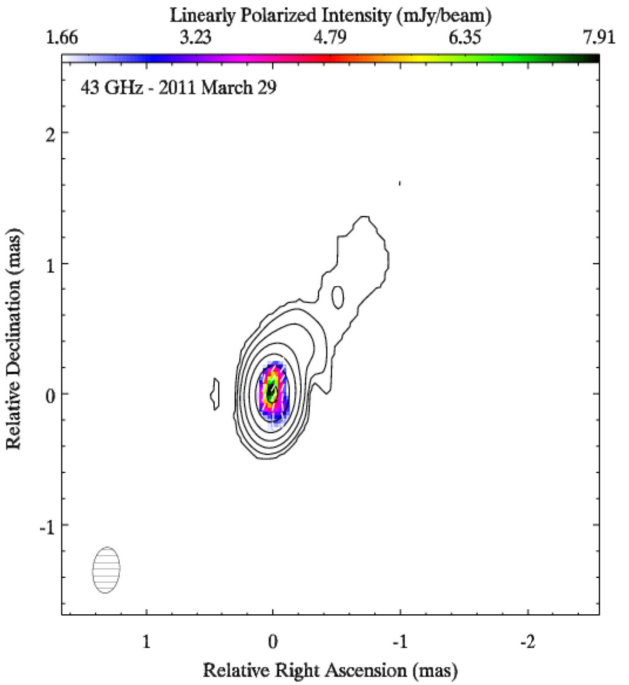
15GHz

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.

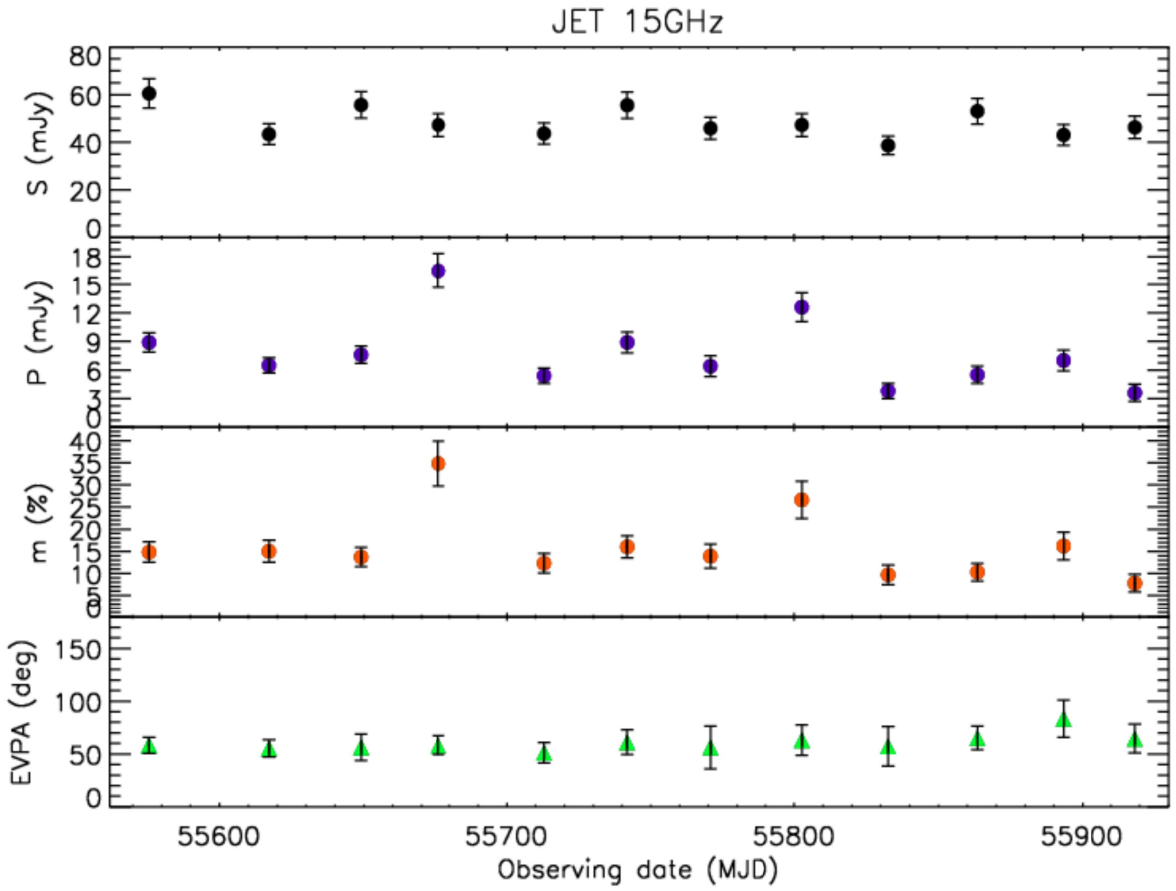
Polarization parameters for the jet region at 15 GHz

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).

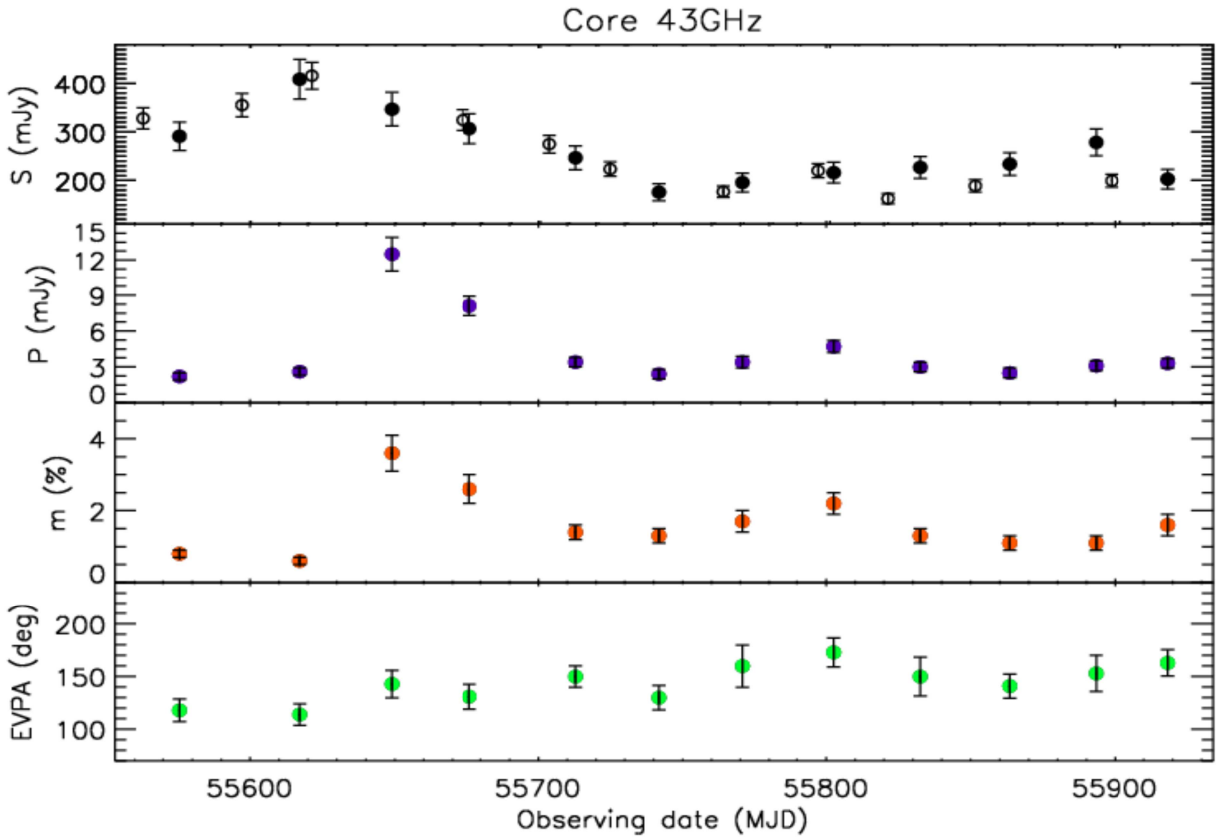
Polarization parameters for the core region at 43 GHz

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).

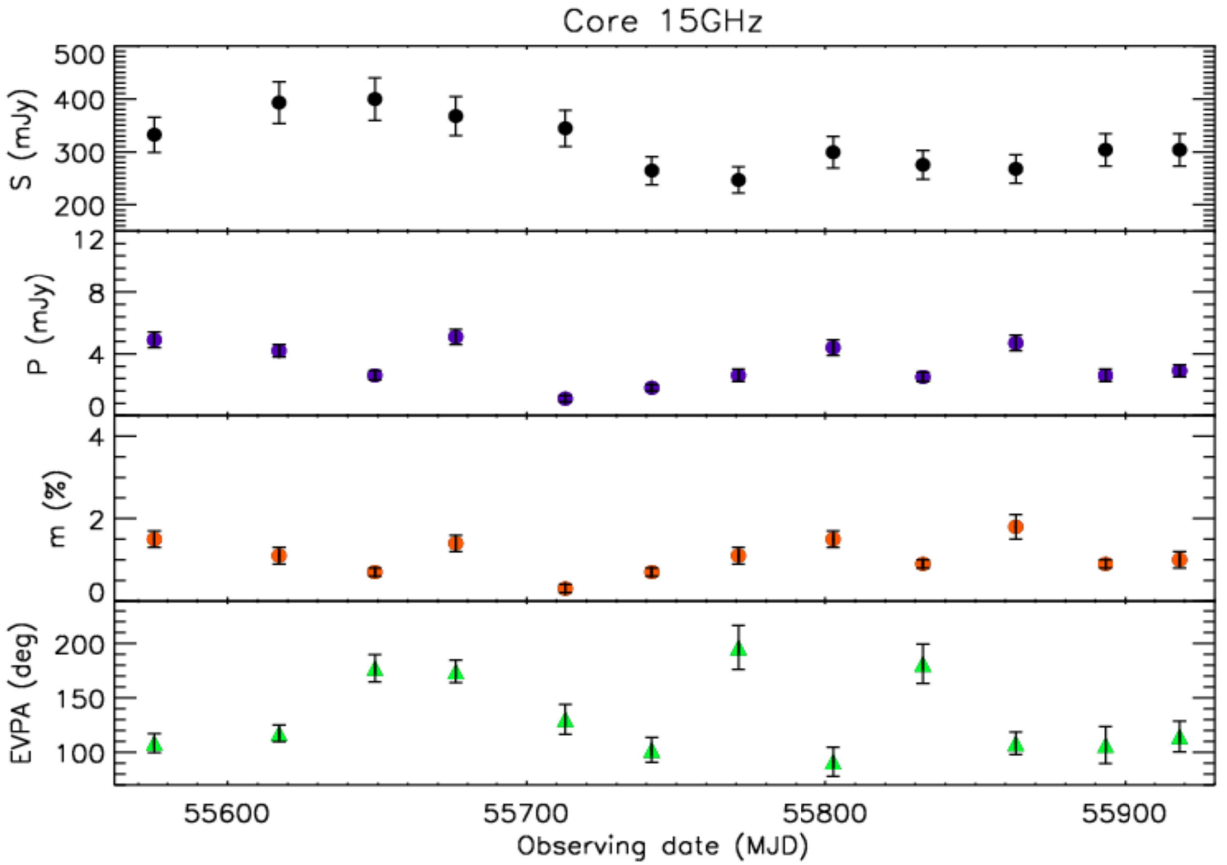
Polarization parameters for the core region at 15 GHz

Total intensity emission

Polarized emission

Fractional polarization

EVPAs

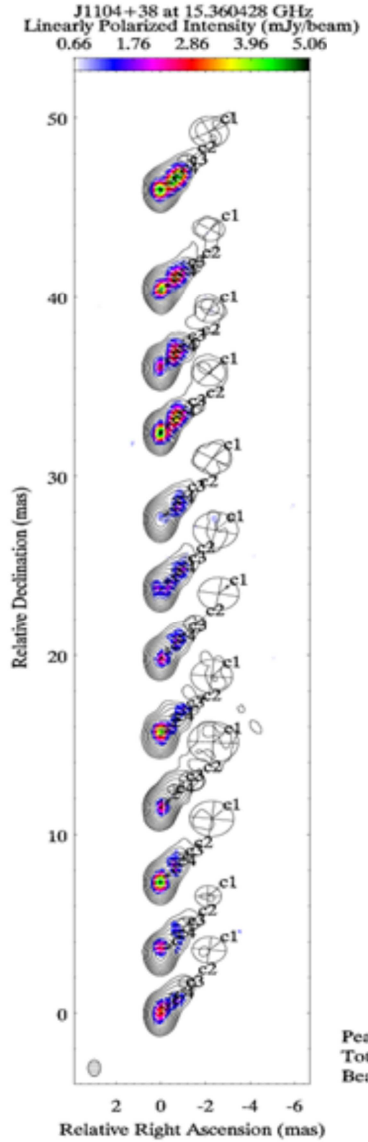


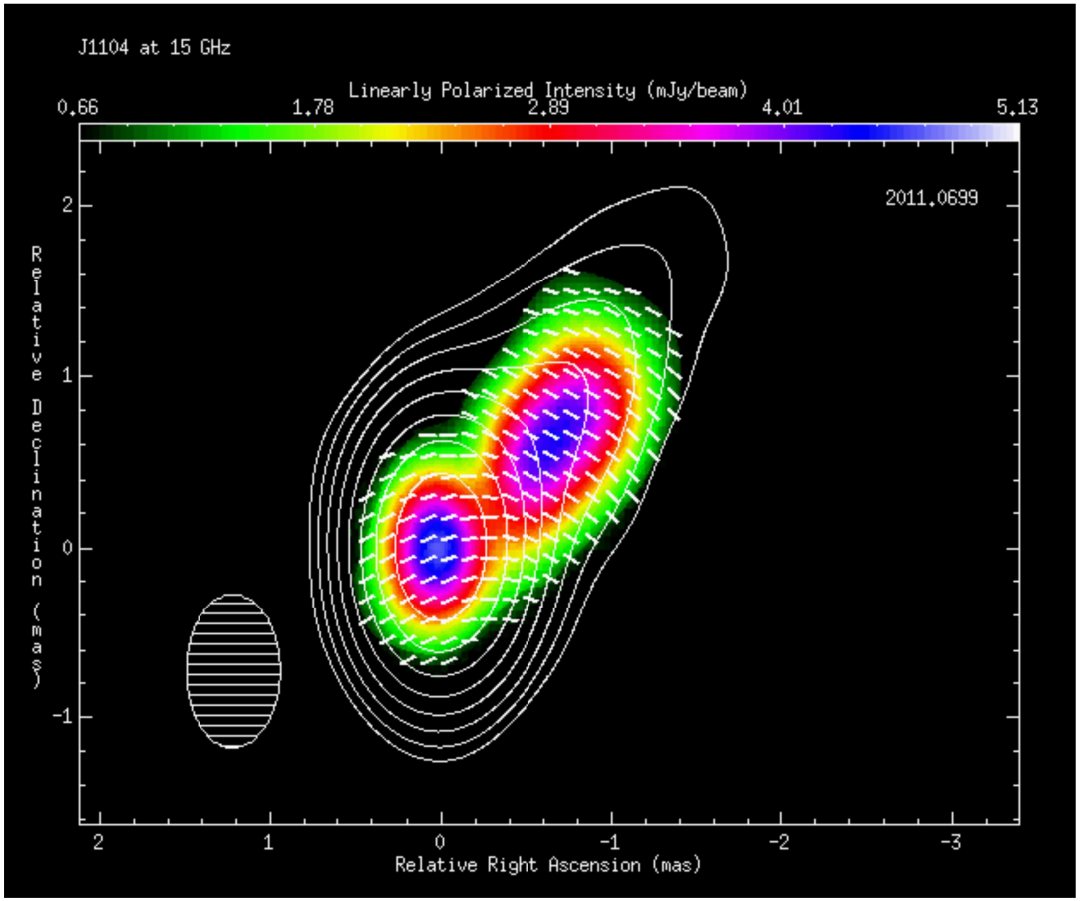
Lico+ 2014, A&A, in press.

- There is a main peak in the total intensity lightcurve.
- The polarized flux is not extremely variable.
- 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!**

15 GHz EVPA time evolution





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 **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

⇩

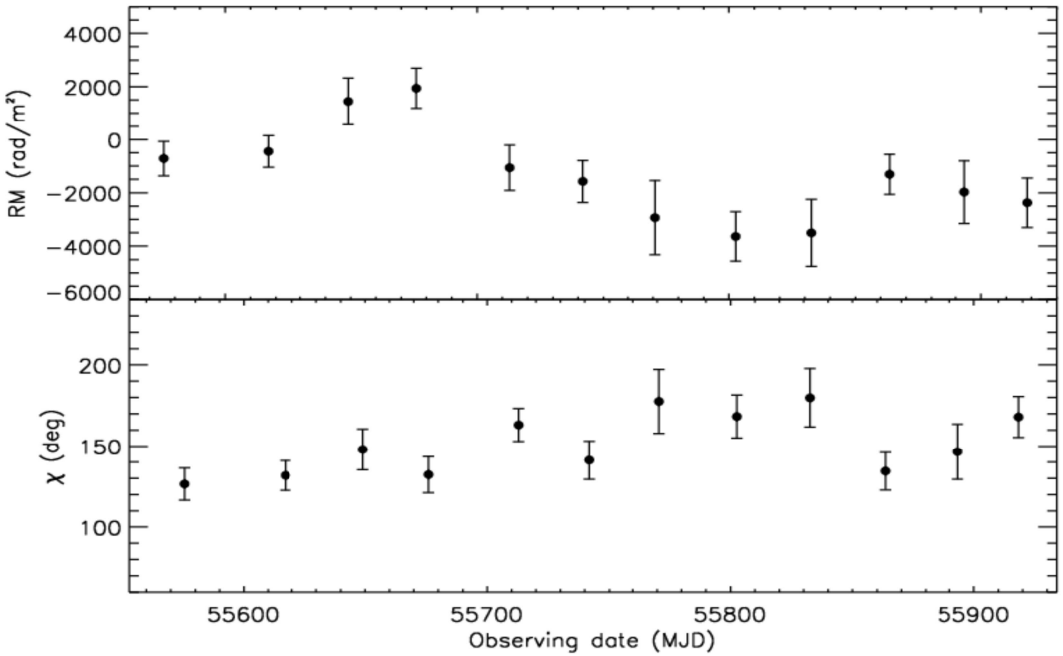
- Transverse shock.

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

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

Faraday rotation analysis

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



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

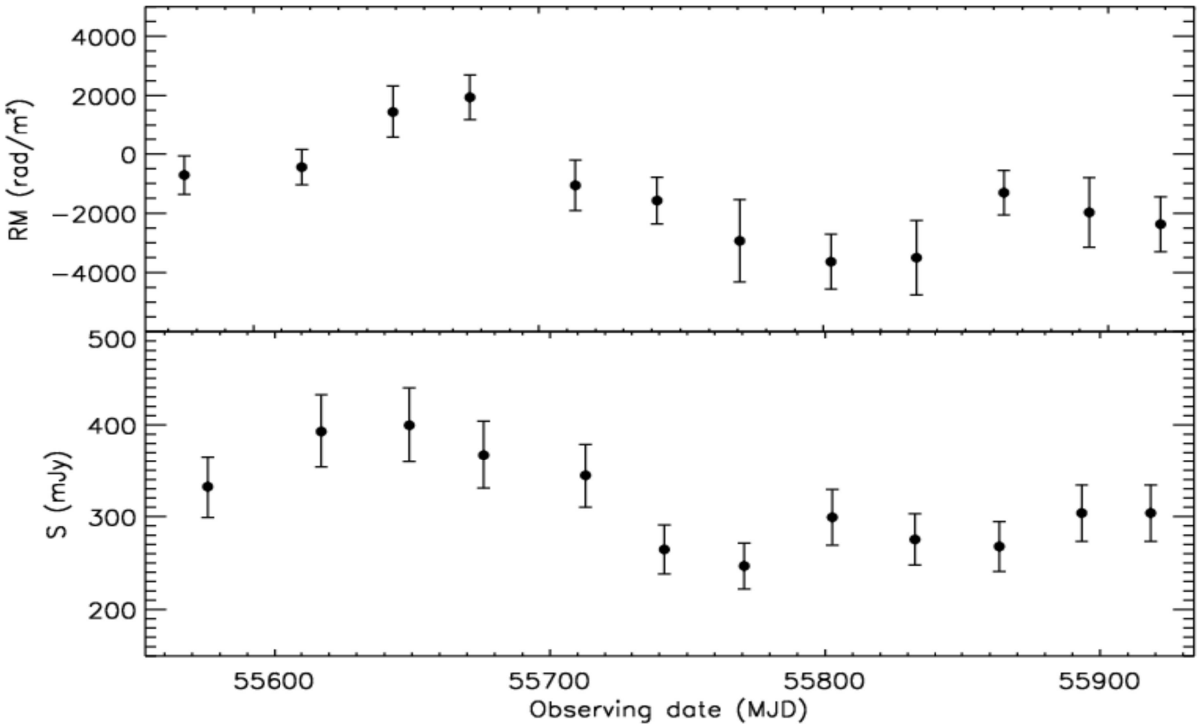
Higher variability at longer wavelenghts

- Intrinsic polarization angle less variable with respect the 15 GHz trend (Fvar=0.10±0.04).

reflects the 43 GHz trend.

RM vs. accretion rate

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



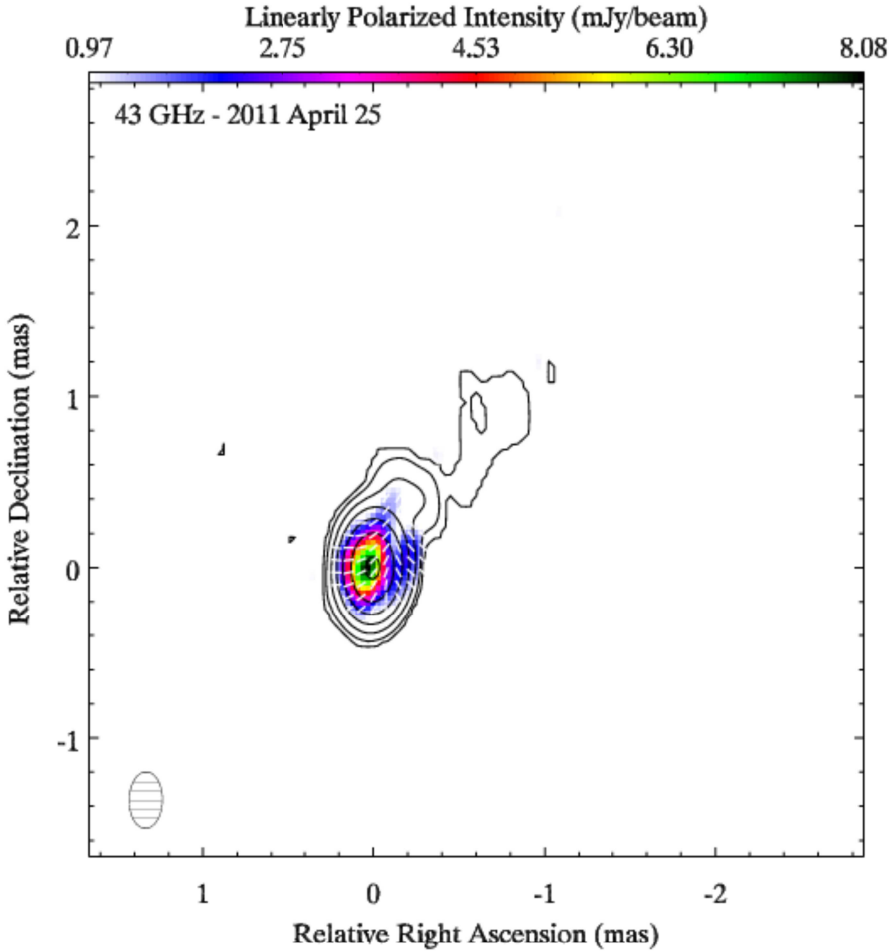
⇦ RM time evolution

⇦ 15 GHz Tot int light curve

RM and core flux density → similar trend ⇨ Faraday screen not so far from the radio core!

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 degree of polarization 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 et al. 2014, A&A, in press.
arXiv:1410.0884

→ including γ-ray analysis!

Thanks for your attention!

D-terms method for EVPA relative rotation: 15 GHz

Instrumental contribution to the polarization

In general, to obtain the absolute orientation of the EVPAs in VLBI observations, a comparison with quasi simultaneous single dish or JVLA observations is required.

⇩

Lack of polarization calibrators with stable EVPAs on (sub)milliarcsecond-scale.

The method consists in the comparison of the D-terms parameters for each antenna in consecutive epochs, obtaining the relative rotation both in right (R) and left (L) circular polarization.

⇩

The phase difference of the D-terms provide the phase offset in R and L between two epochs.

EVPAs: absolute rotation

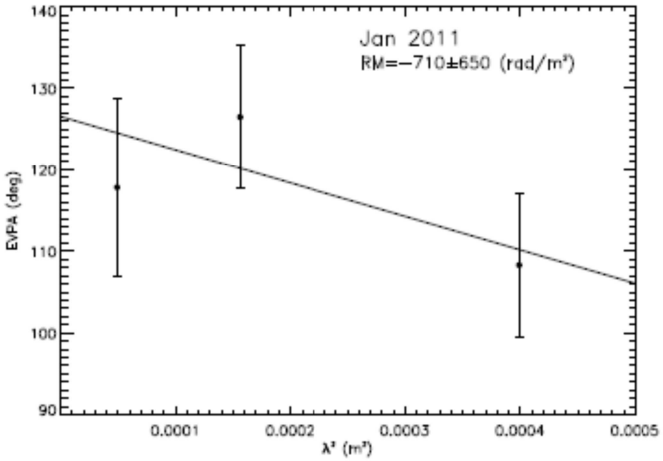
(Lico+ 2014, A&A, in press.)

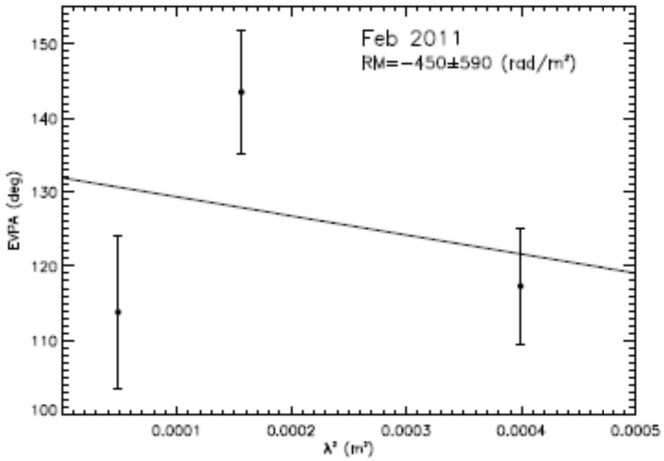
Epoch	ΔJVLA	ΔD-Terms	Refant
Jan	-21.7		PT
Feb	-21.7	0	PT
Mar	**-21.7**	0	PT
Apr	-21.7	0	PT
May	-21.7	0	PT
Jun	**22.2**	45	OV
Jul	22.2	0	OV
Aug	85.2	63	KP
Sep	157.2	72	PT
Oct	157.2	0	PT
Nov	**25.5**	45	OV
Dec	-19.5	-45	PT

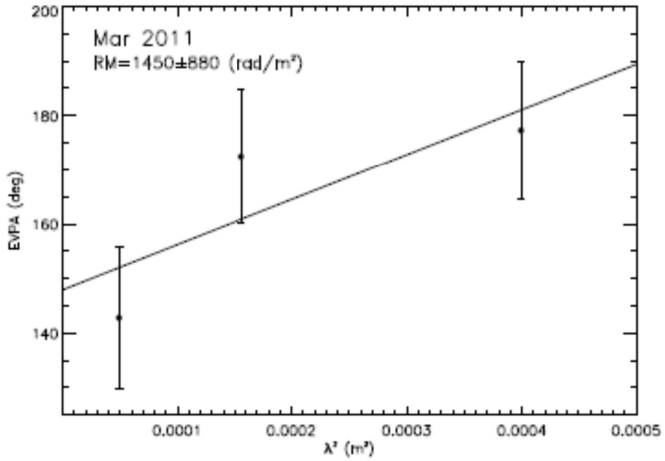
Final rotation

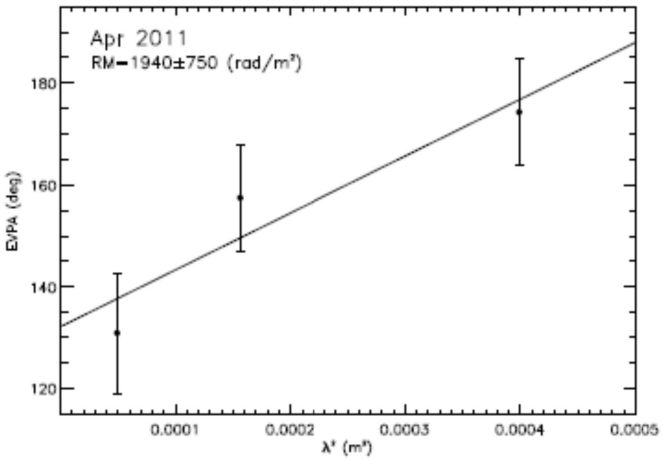
Relative rotation

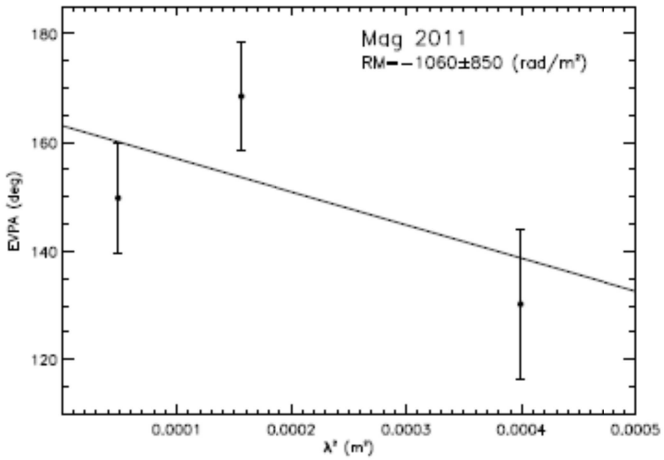
RM fits Jan-Jun

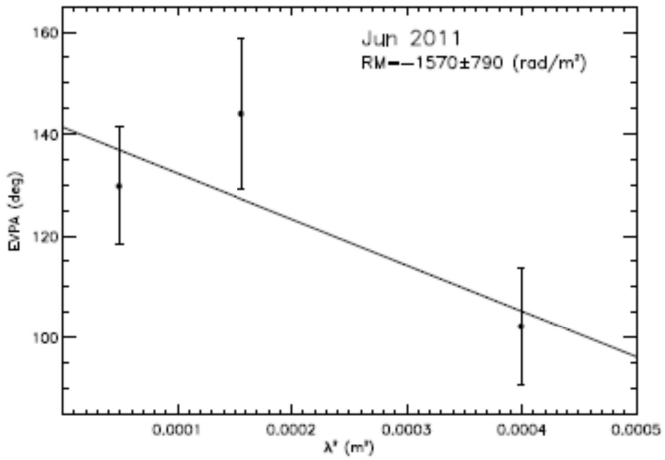




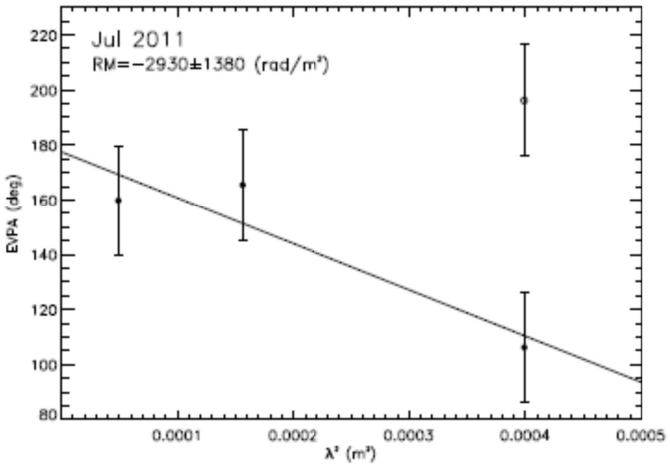


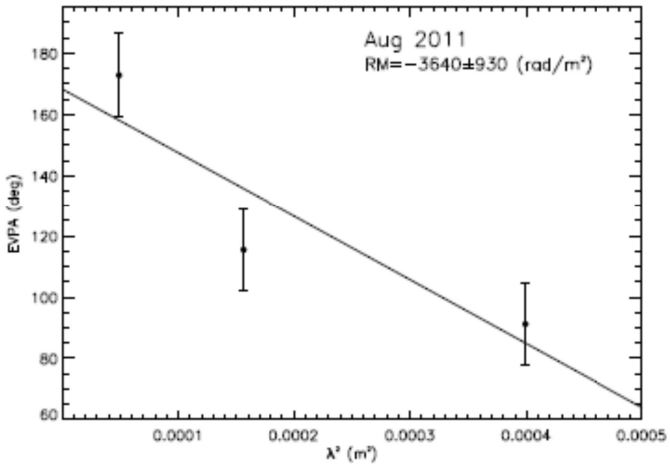


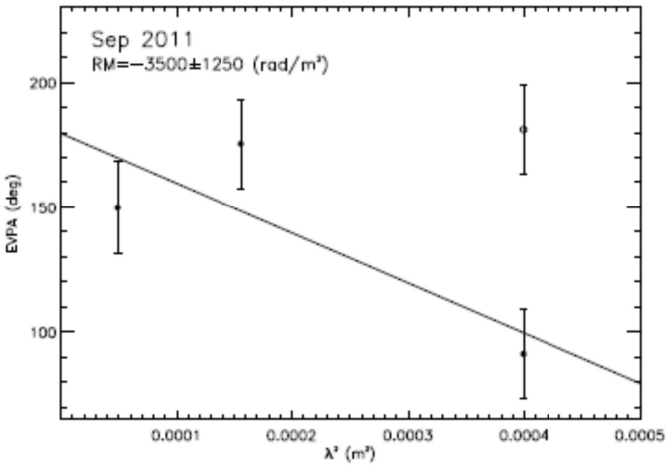


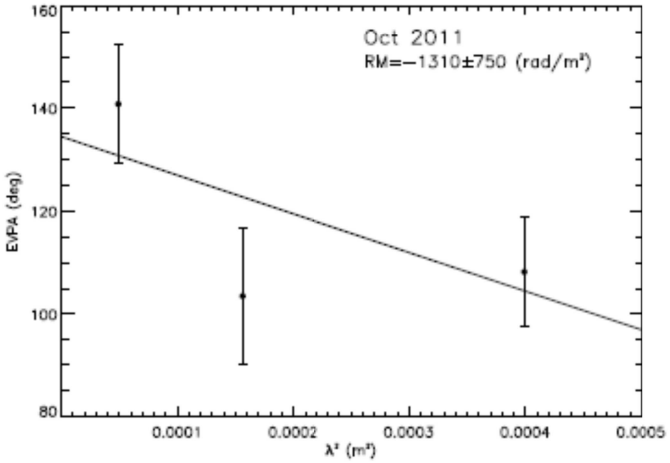


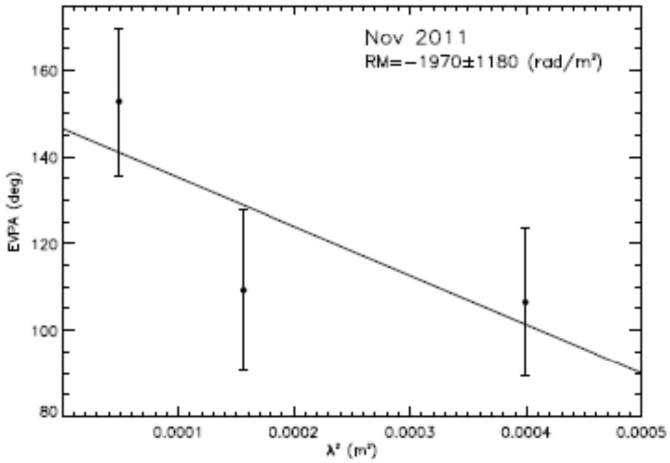
RM fits Jul-Dec

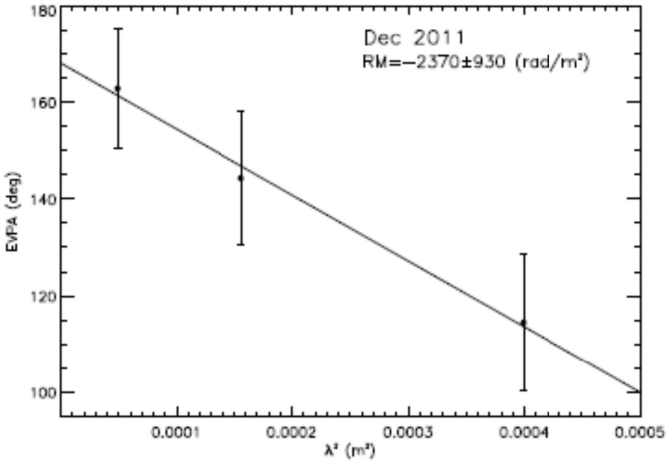




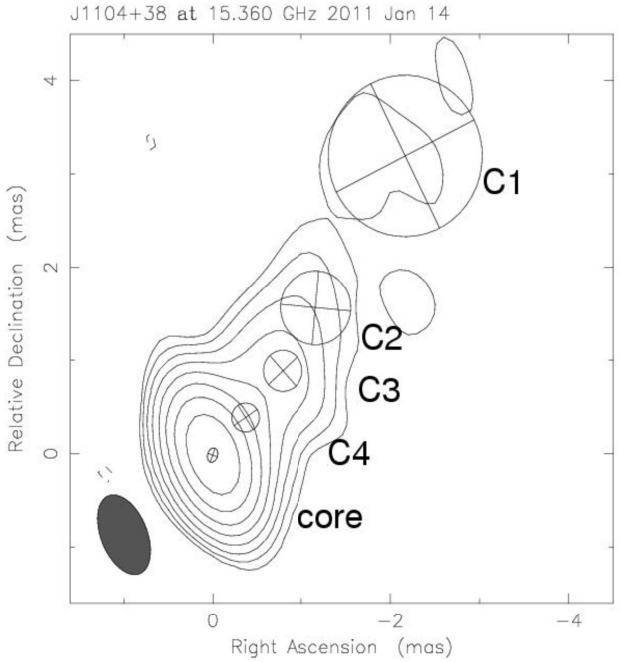






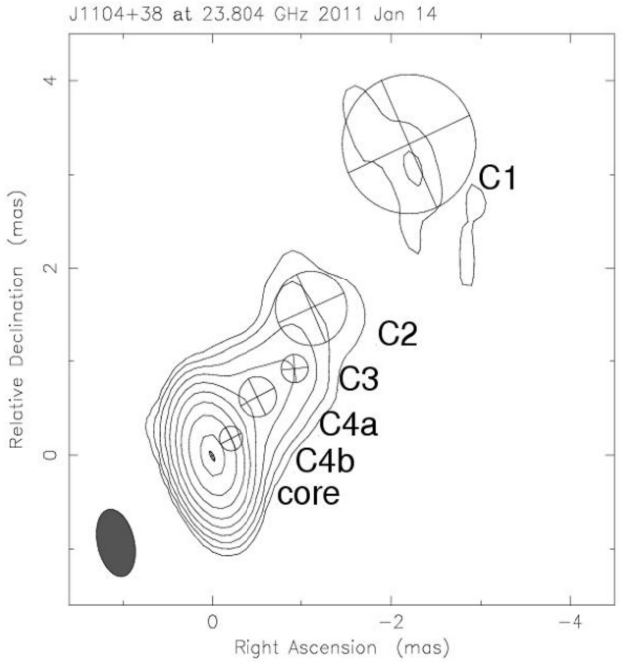


Total intensity images



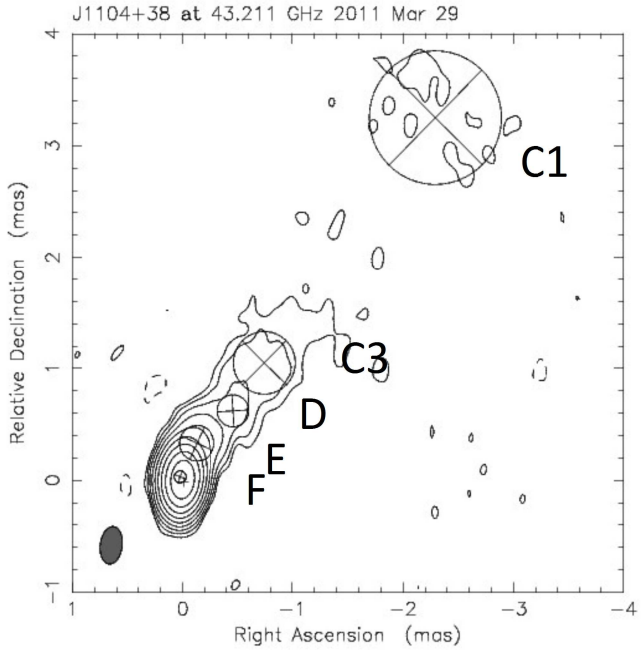
15GHz

Beam: 0.92mas x 0.54mas



24GHz

Beam: 0.58mas x 0.35mas



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