The Innermost Regions of Relativistic Jets and Their Magnetic Fields

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Multi-frequency study of the TeV blazar Markarian 421 with VLBA observations

Presented by:

Rocco Lico

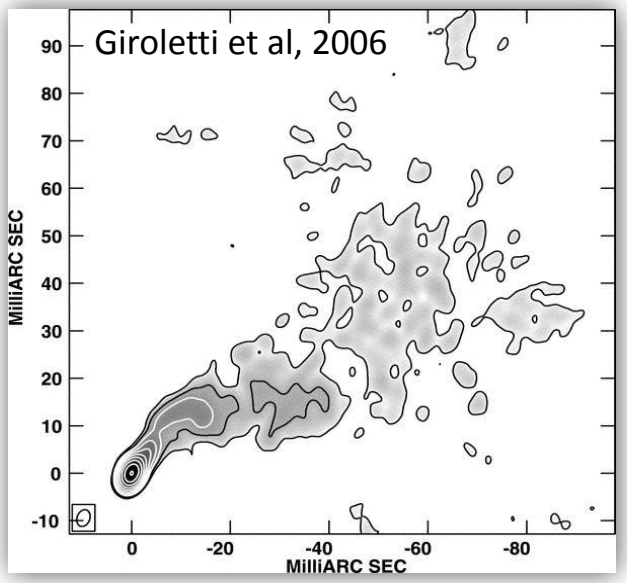
M.Giroletti, M.Orienti, G.Giovannini, M.G.Blasi, J.L.Gomez, C.Casadio, and many others.

Markarian 421

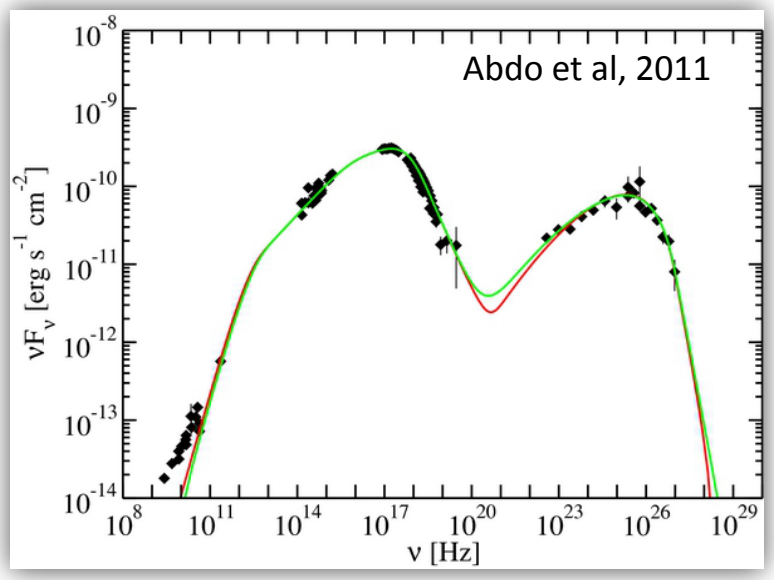
Mrk421 is a near BL Lac object (***z* = 0.031**)

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

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



It shows a 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.
- Multi-wavelength study by Abdo et al.

It is the first extragalactic object revealed in TeV band

Data set

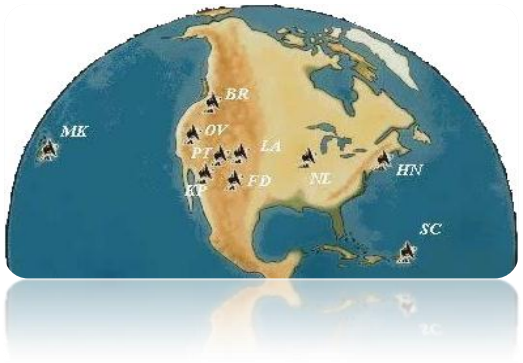
The source was observed, in total and in polarized intensity, once per month throughout the entire 2011, for a total of 12 epochs at 15, 24 and 43 GHz.

Main Goals

To make a detailed structural and physical analysis of the source on parsec scale: proper motion analysis, Doppler factor, flux density variations, spectral index, polarization...

VLBA

(Very Long Baseline Array)



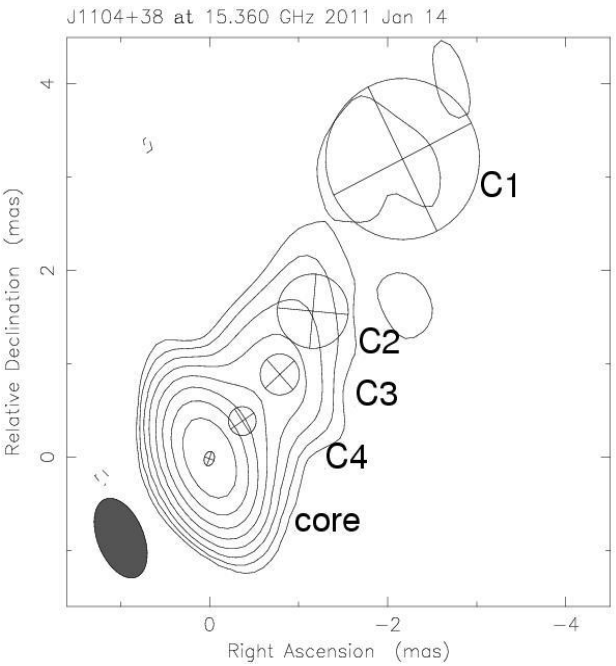
Multifrequency campaign

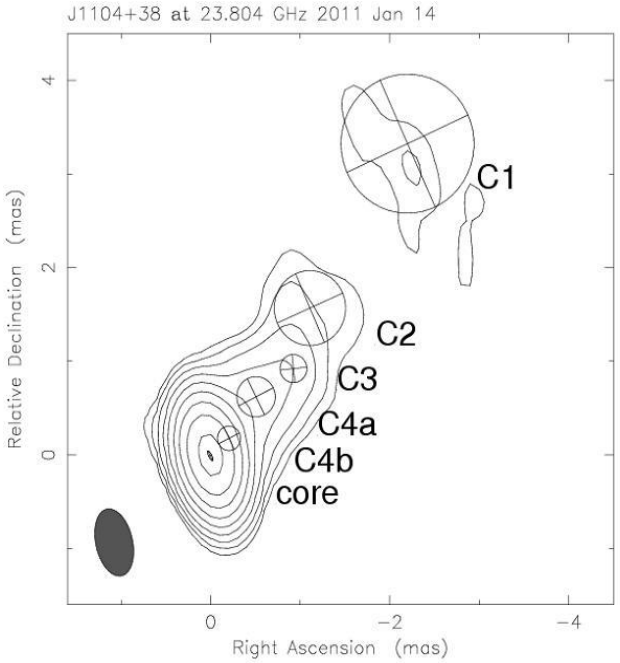
This study is part of an ambitious multifrequency campaign, with observations in:

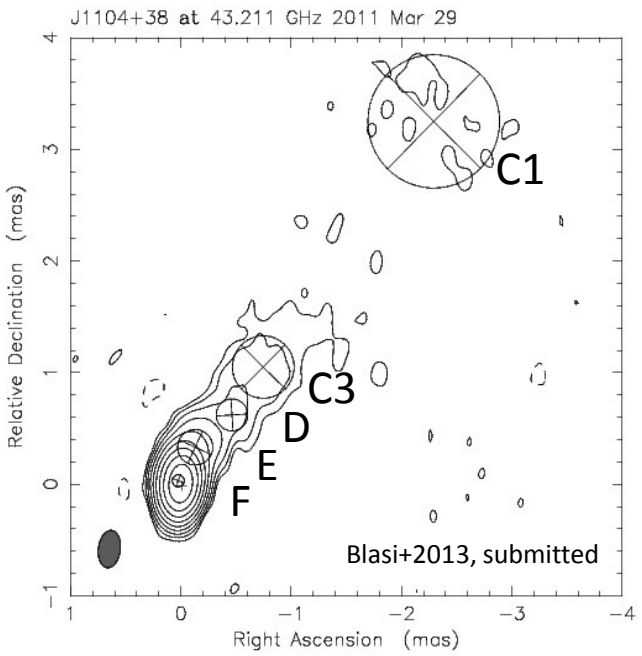
sub-mm (**SMA**), optical/IR (**GASP**), UV/X-ray (**Swift, RXTE, MAXI**), and γ rays (**Fermi-LAT, MAGIC, VERITAS**).

- Extension of Abdo et al. project (2011).

Maps







15GHz

Beam: 0.92mas x 0.54mas

24GHz

*Beam: 0.58*mas x 0.35mas

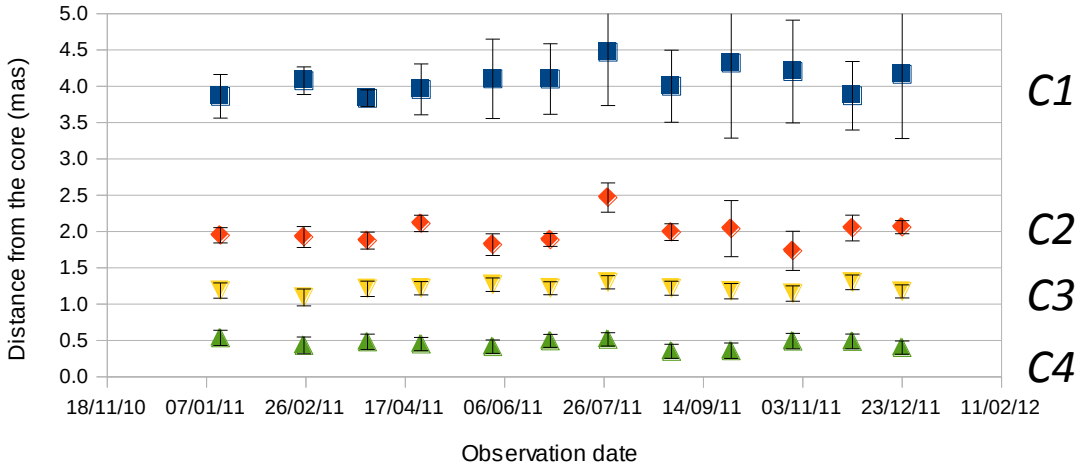
43GHz

Beam: 0.42mas x 0.27mas

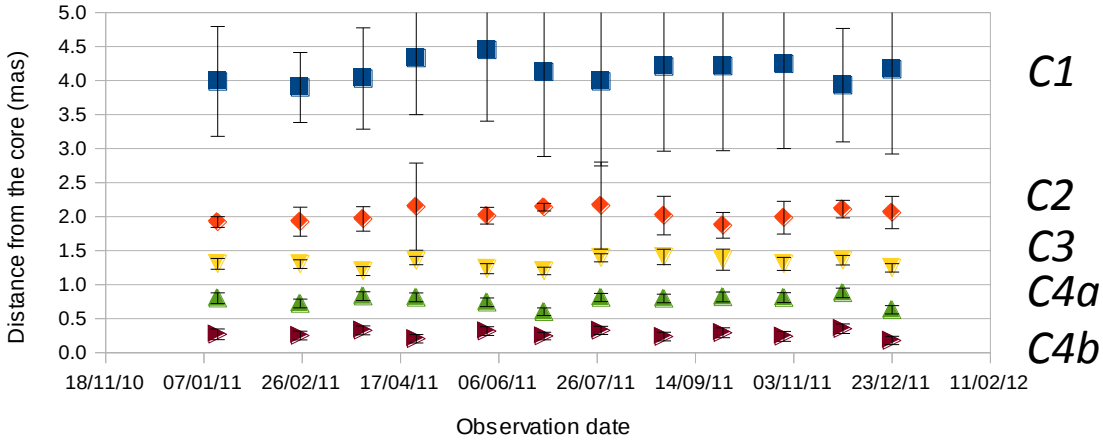
- It shows a jet structure well defined and well-collimated emerging from a compact nuclear region.
- The **jet** is oriented in North-West direction (PA ~ -35°), and it extends over an angular distance of about 4.5 mas (about 2.67 pc @ z=0.03).
- The **flux density** of nuclear region at 15 GHz is ~ 350 mJy

Structural analysis: modelfit for 15 and 24 GHz data

15GHz



24GHz



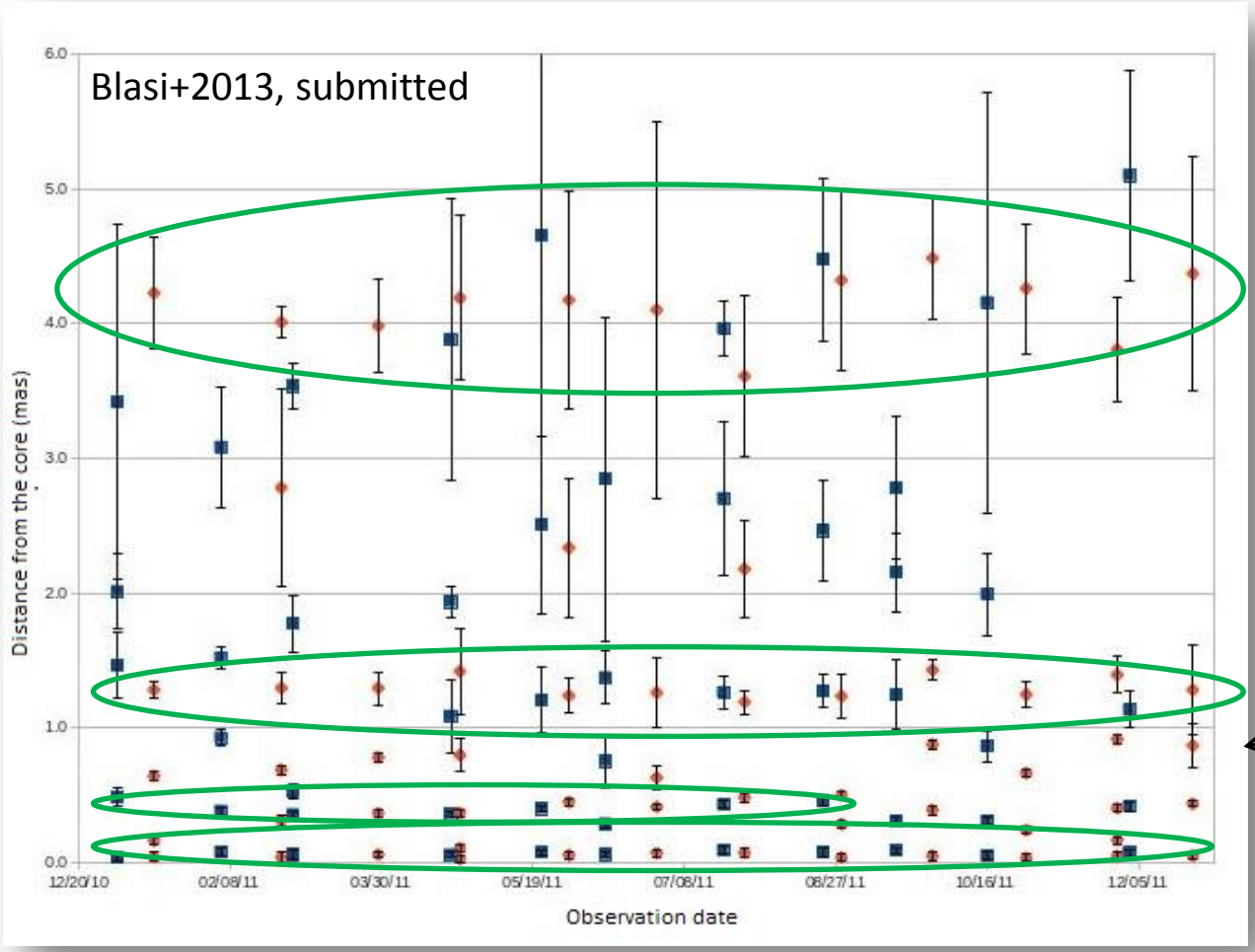
- Data points occupy well defined places in this plane, consistent with the identification of individual components.
- The identification is confirmed from flux density variation analysis.

- The components cover an area of ~5mas (the closest to the core is at ~0.43 mas, the most distant is at ~4.6 mas).

All components appear essentially stationary

Structural analysis: modelfit for 43 GHz data

43GHz

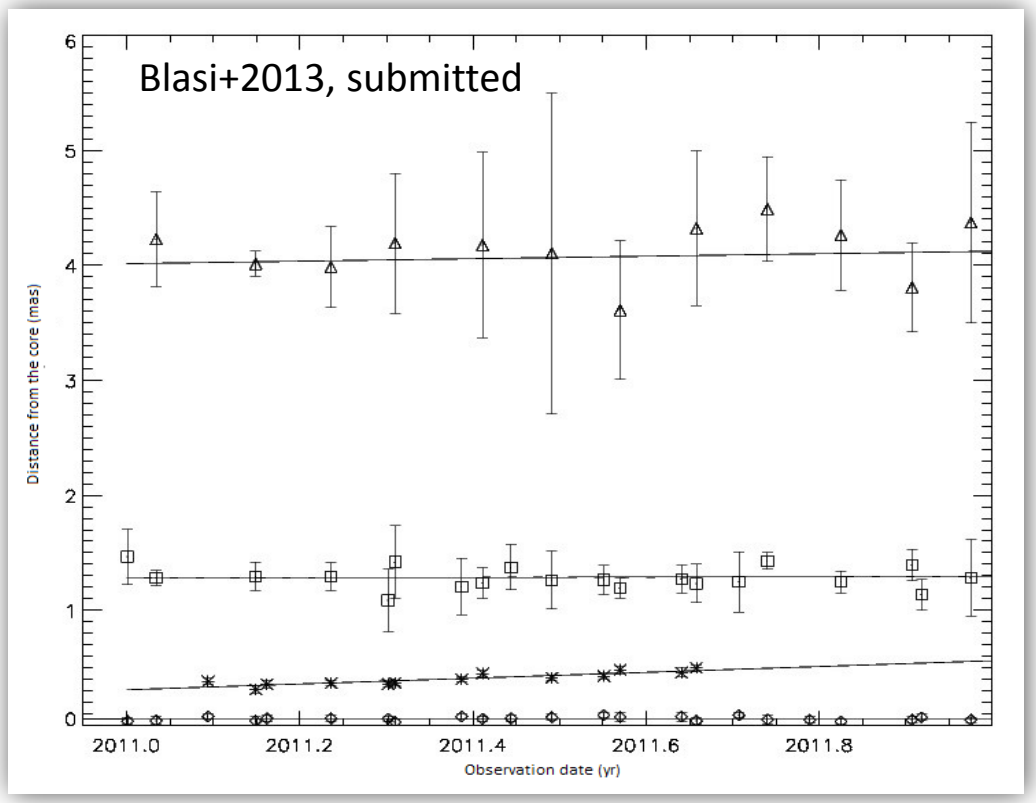


Red Diamonds represent our 43 GHz data.

Blue squares represent 43 GHz date provided by Boston University.

All components appear essentially stationary

Proper motion analisys



C1

C3

D

E

Linear fit to the position vs time component by component.

Apparent speed		
COMP.	**B_{app}**	
	15+24 GHz	**43 GHz**
C1	0.34 ± 0.24	0.24 ± 0.25
C2	0.16 ± 0.20	
C3	0.10 ± 0.11	0.04 ± 0.08
C4a	0.01 ± 0.17	
C4b	0.03 ± 0.10	
D		0.46 ± 0.08
E		0.003 ± 0.038

We only detect subluminal motion

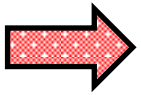
CAVEAT: the modelfit with Gaussian components is a mathematical representation, they may not exactly correspond to real physical structures!

θ and β limits from jet-counterjet brightness ratio

$$\frac{B_J}{B_{cJ}} = R = \left(\frac{1+\beta cos\theta}{1-\beta cos\theta}\right)^{2+\alpha}$$

We obtain: **R > 254.8** and **βcosθ > 0.80**

Assuming that the pattern velocities are representative of the bulk velocity



The previous values obtained for β_{app} are compatible with **θ~4.8°** and **β~0.81**, which yield **δ=3.0**

Brightness Temperature

$$T_{\rm B,var} = 1.548 \times 10^{-32} \frac{\Delta S_{\rm max} d_L^2}{\nu^2 \tau^2 (1+z)} \sim 2.1 \times 10^{10}\ {\rm K}$$

$$T_{\rm B} = 1.22 \times 10^{12} \frac{S(1+z)}{ab\nu^2} \sim 10^{11}\ {\rm K}$$

Relativistic radio jet with marginal effects of beaming

Interpretative framework

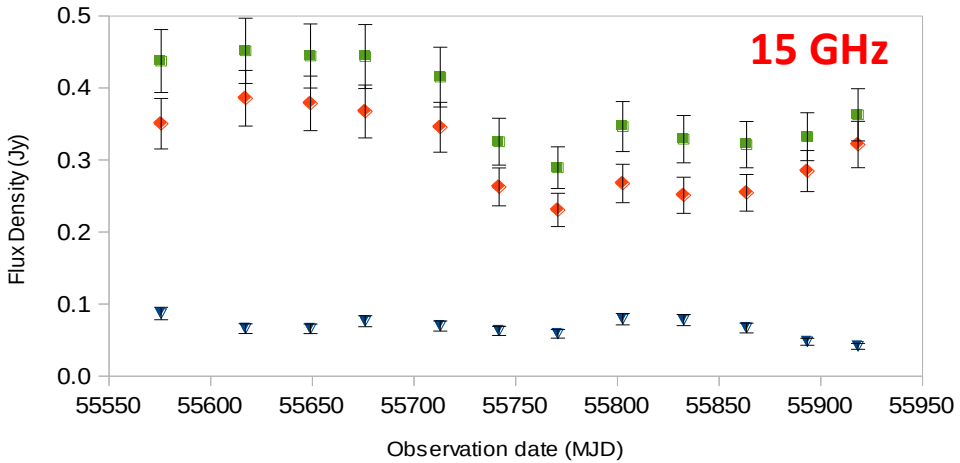
$\delta_{HE} = \delta_{Radio}$ ➡ **RULED OUT**

- Combining **high δ** implied by the high-energy observations with **stationary components** from radio observations, then **very small viewing angles** are obtained (**θ<1°**).
  - ↳ But such small viewing angles imply unreasonable number of parent objects (e.g. Piner & Edwards 2005)
- Jet counter-jet ratio, core dominance, brightness temperature do not require significant beaming in the radio jet.

$\delta_{HE} \neq \delta_{Radio}$

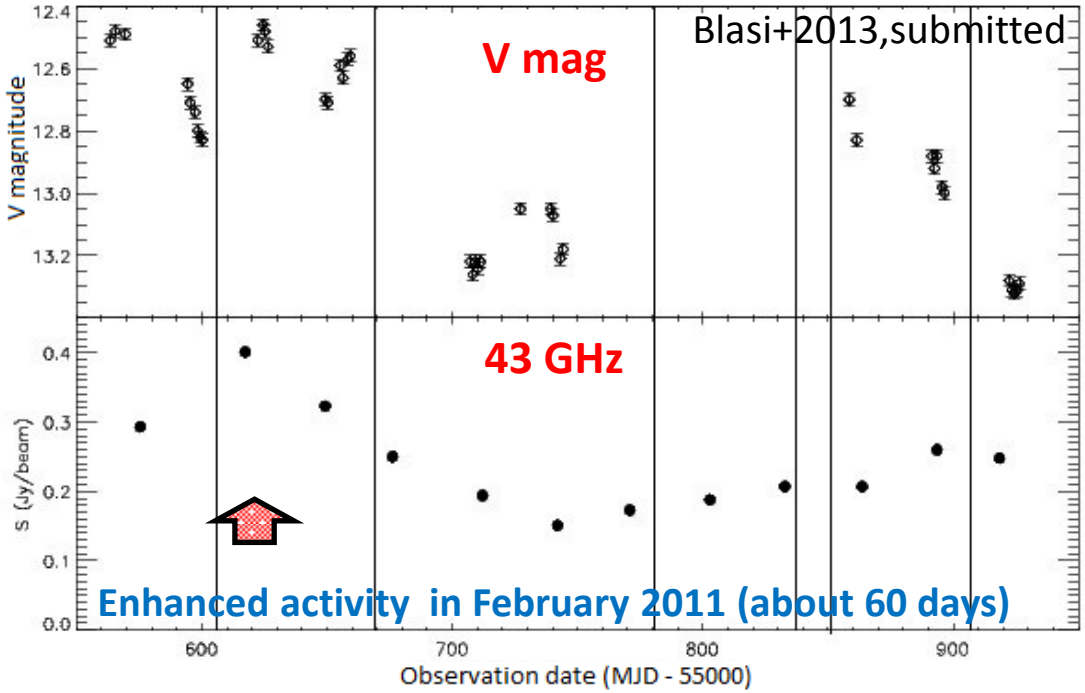
- **DOPPLER FACTOR CRISIS**
  - ❖ **Deceleration.**
  - ❖ **Spine/Layer Model**. ➡ Fast inner spine, surrounded by a slower layer
    - ↳ Supported by limb brightened structure (Piner & Edwards 2005).

Light curves



Green: total flux density
Red: core flux density
Blue: total flux – core flux

Core dominated source

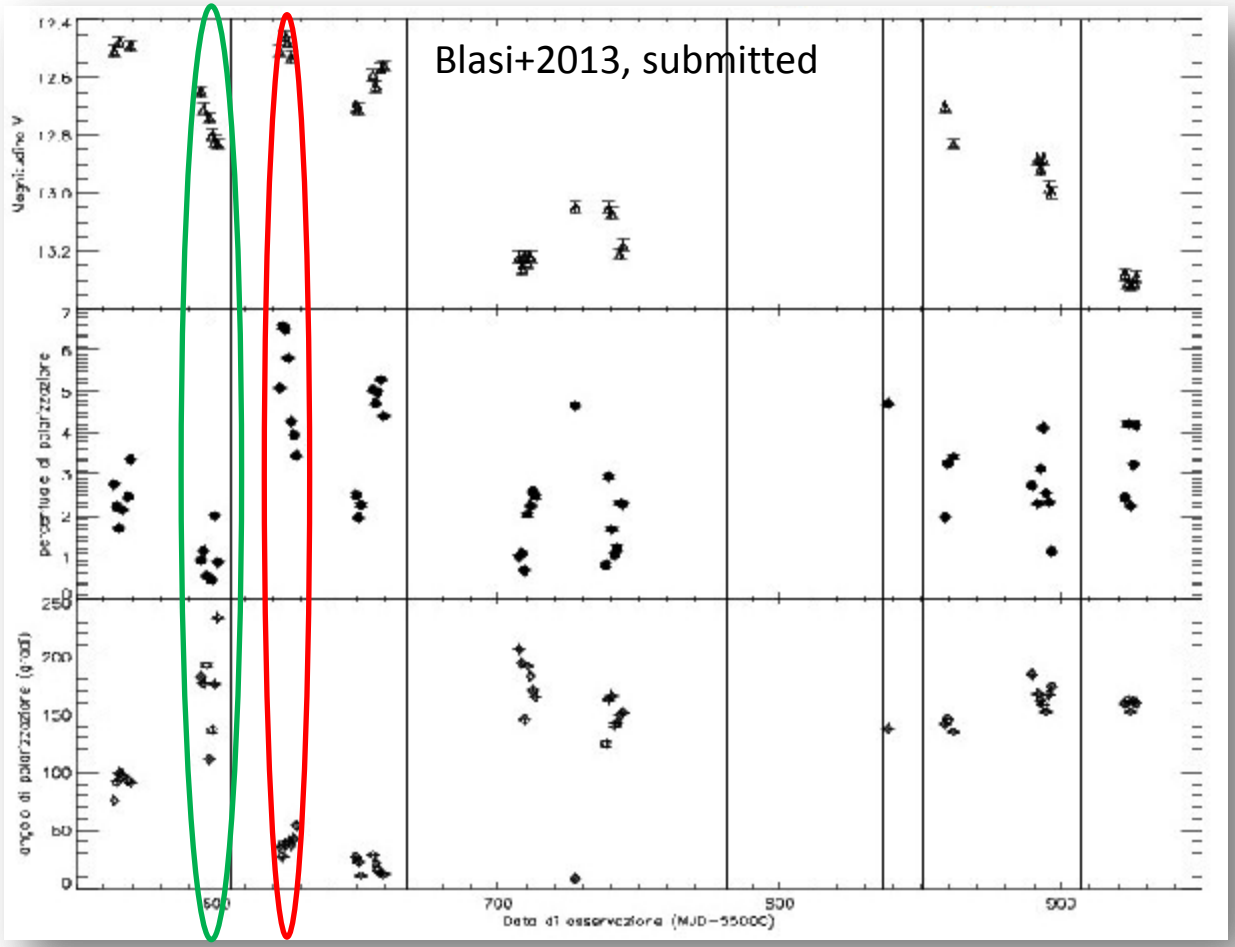


V-band data from Steward observatory (University of Arizona)

43 Ghz data (VLBA)

Co-spatiality: optical and radio emission seem to be originated in the same emission region.

Enhanced activity and MWL behavior



V magnitude

Before: DECREASES

After: INCREASES

Polarization percentage

Before: LOW

After: HIGH

Polarization angle

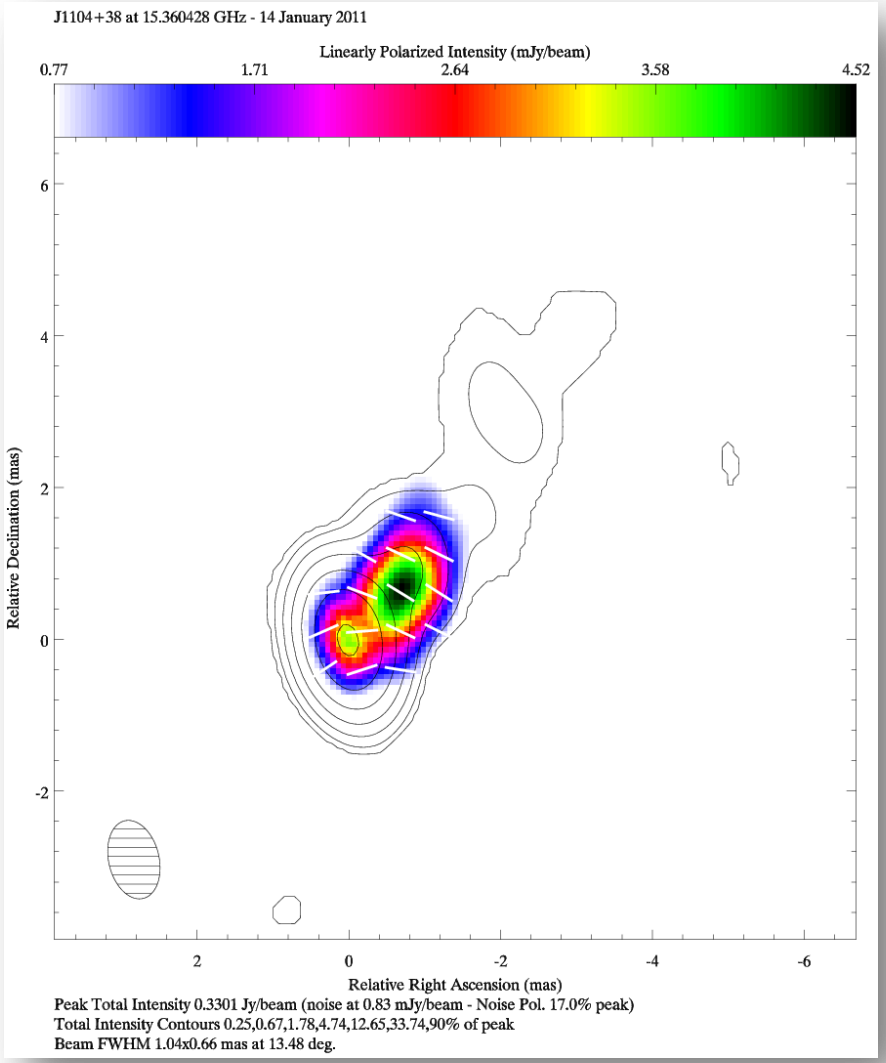
Before: LARGE SCATTER

After: SMALL SCATTER

Possible transition from a disordered magnetic field to a more ordered magnetic field

This activity is caused by a variation in the central region (no Knots were revealed after the event).

Preliminary analysis on VLBI polarization: 15 GHz



EVPAs: absolute rotation

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	70.5	-45	PT

Final rotation

Relative rotation

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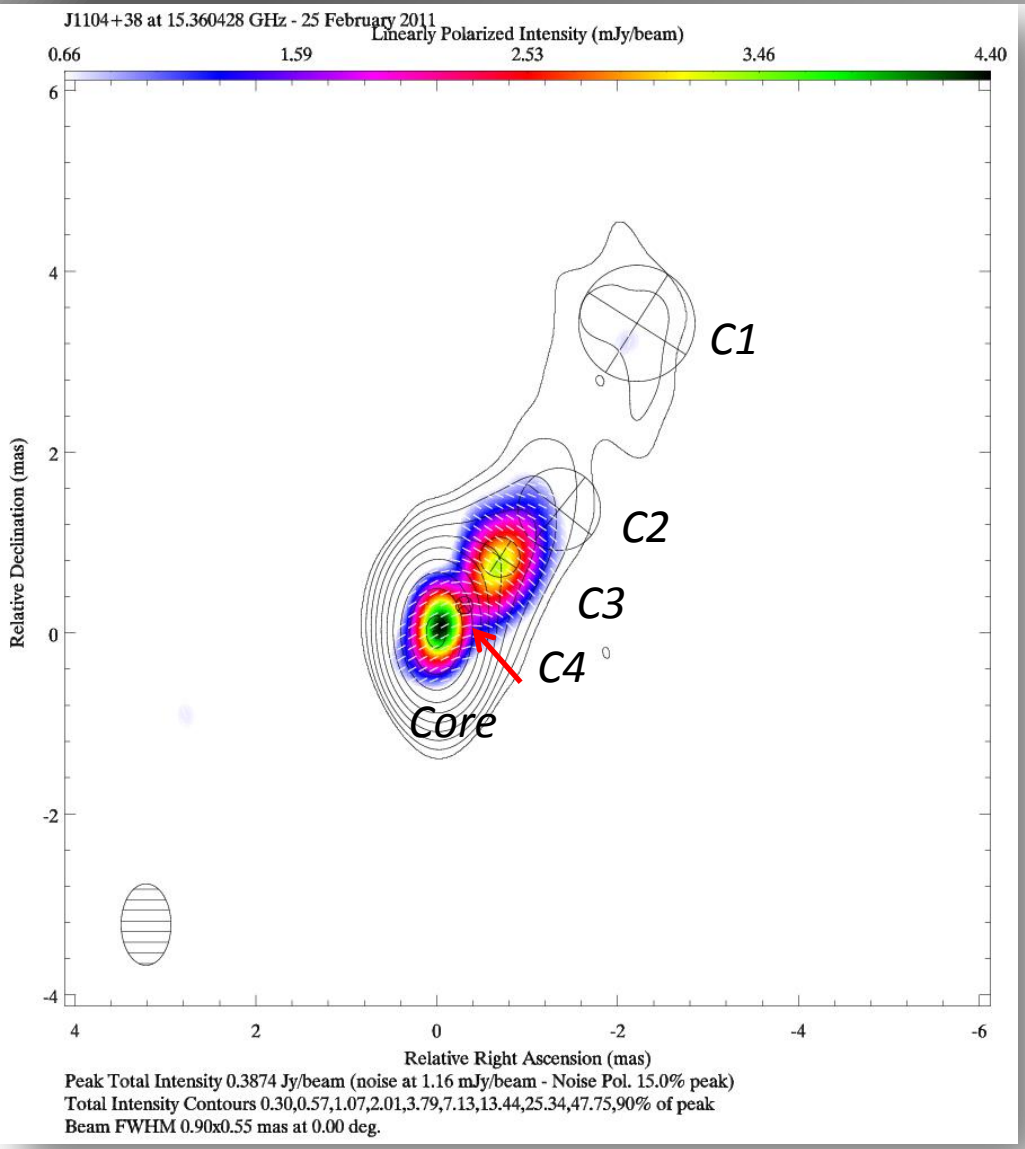
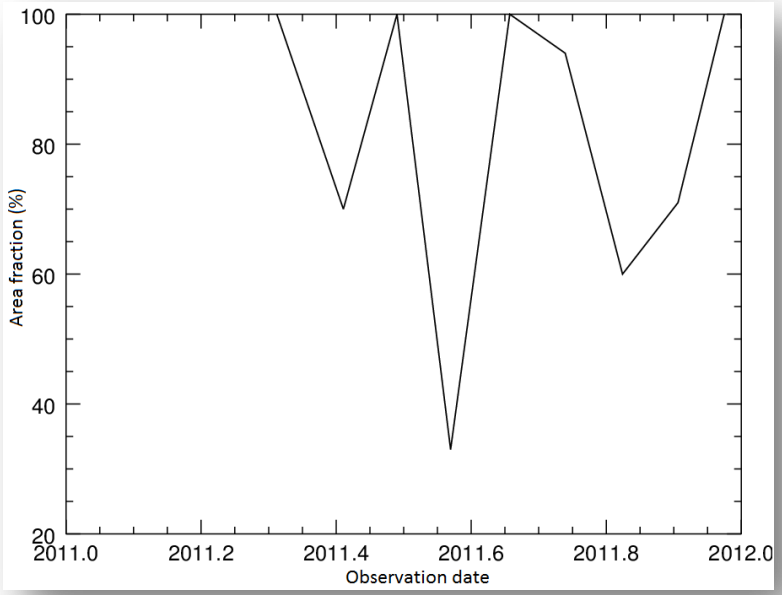
Polarization on jet's components



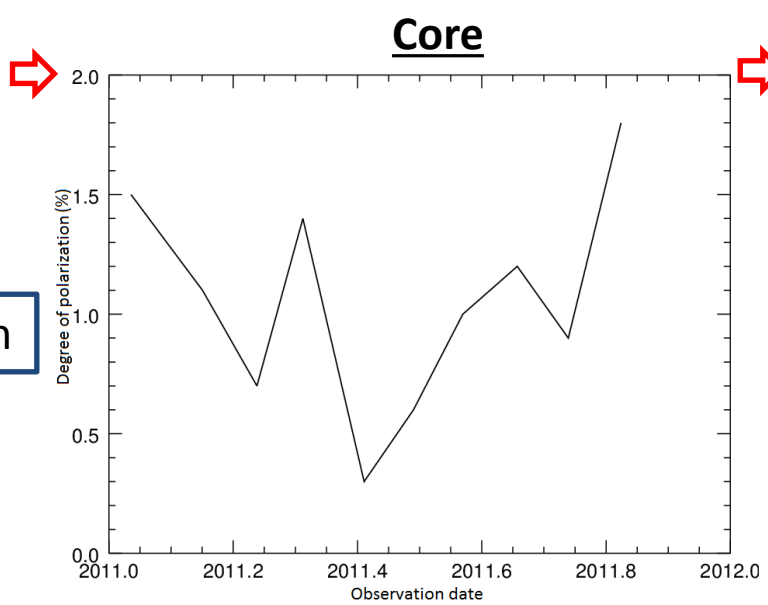
Fraction of C4 component's area with polarization.

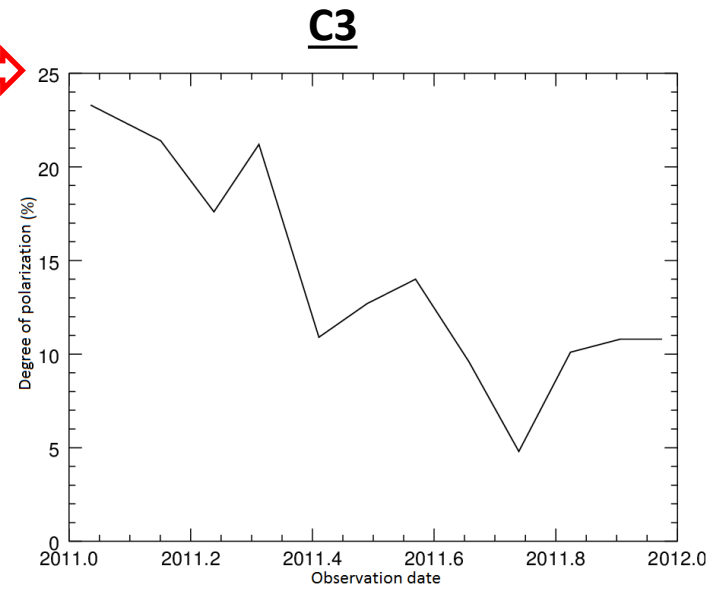


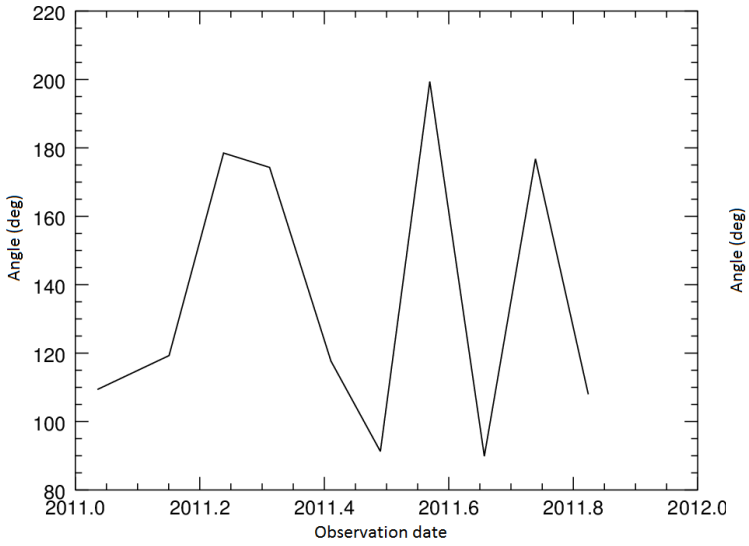
Some preliminary results

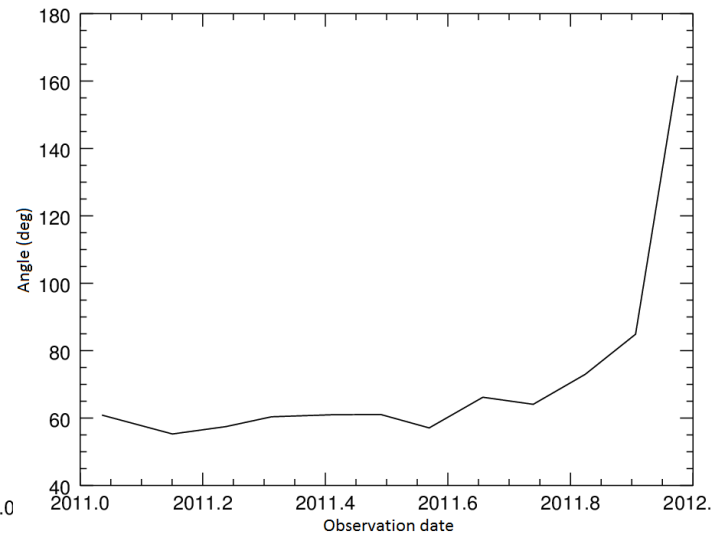
Degree of polarization

EVPAs

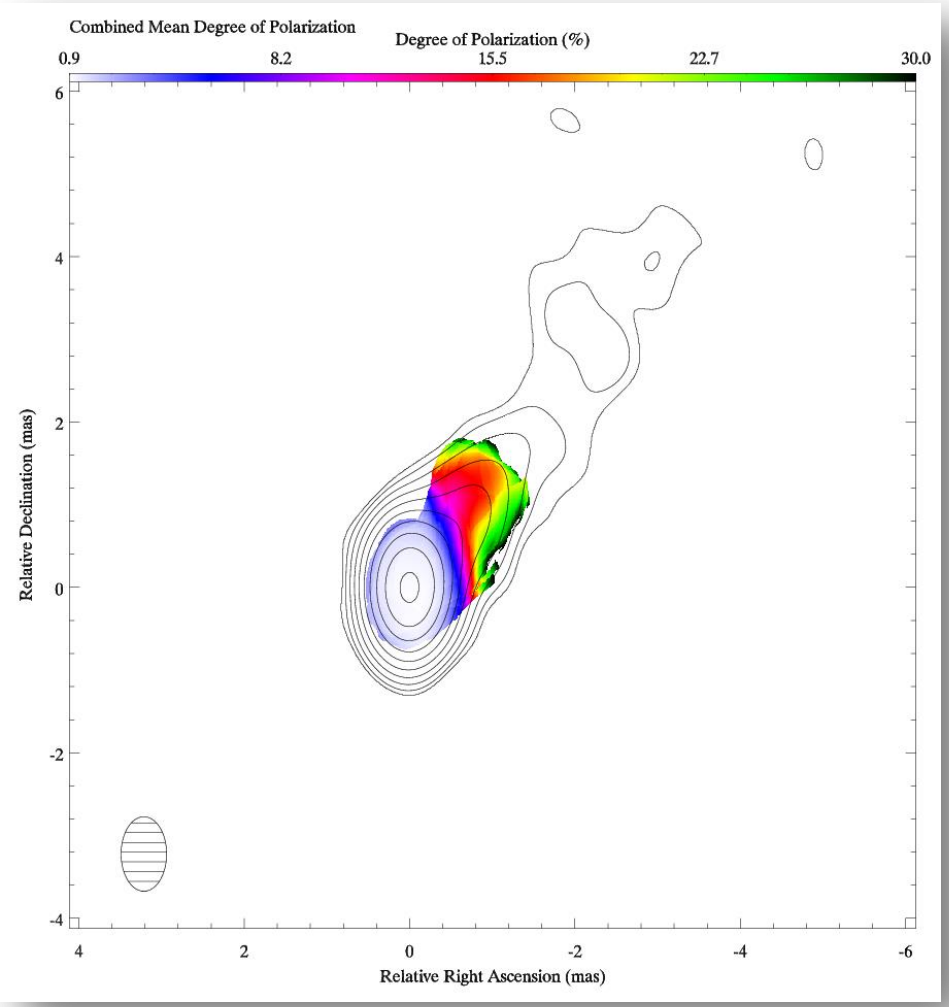




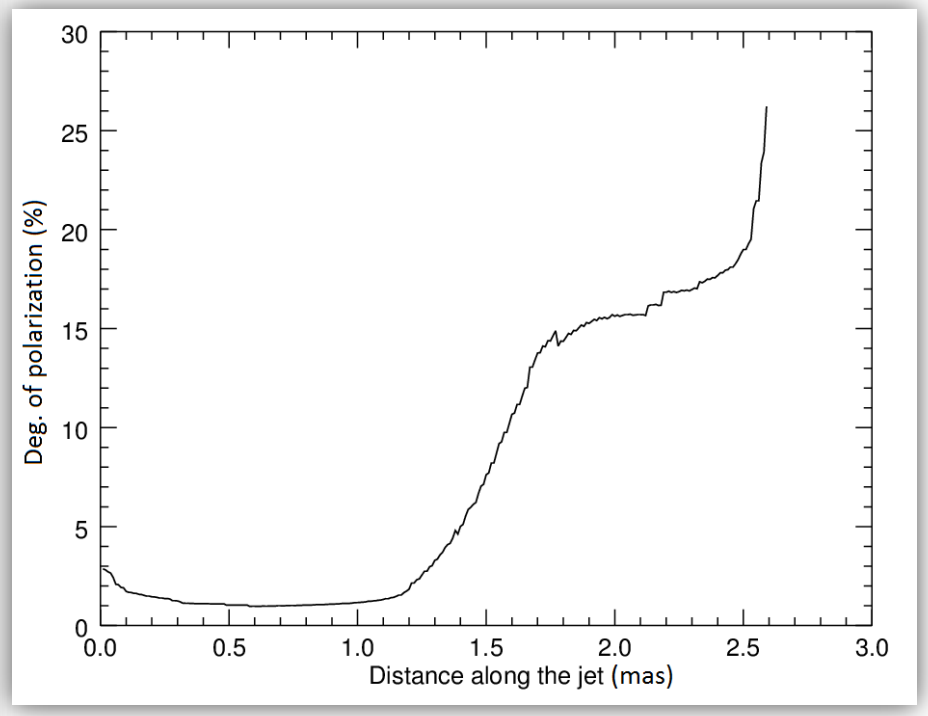




Mean value of the degree of polarization



preliminary!



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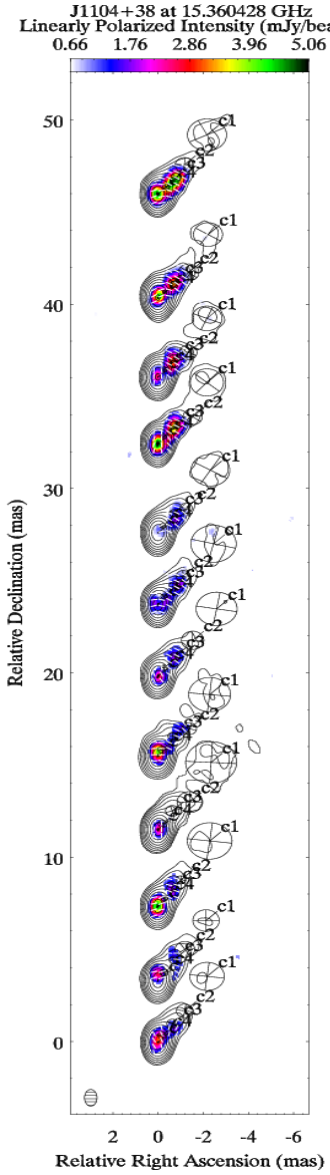
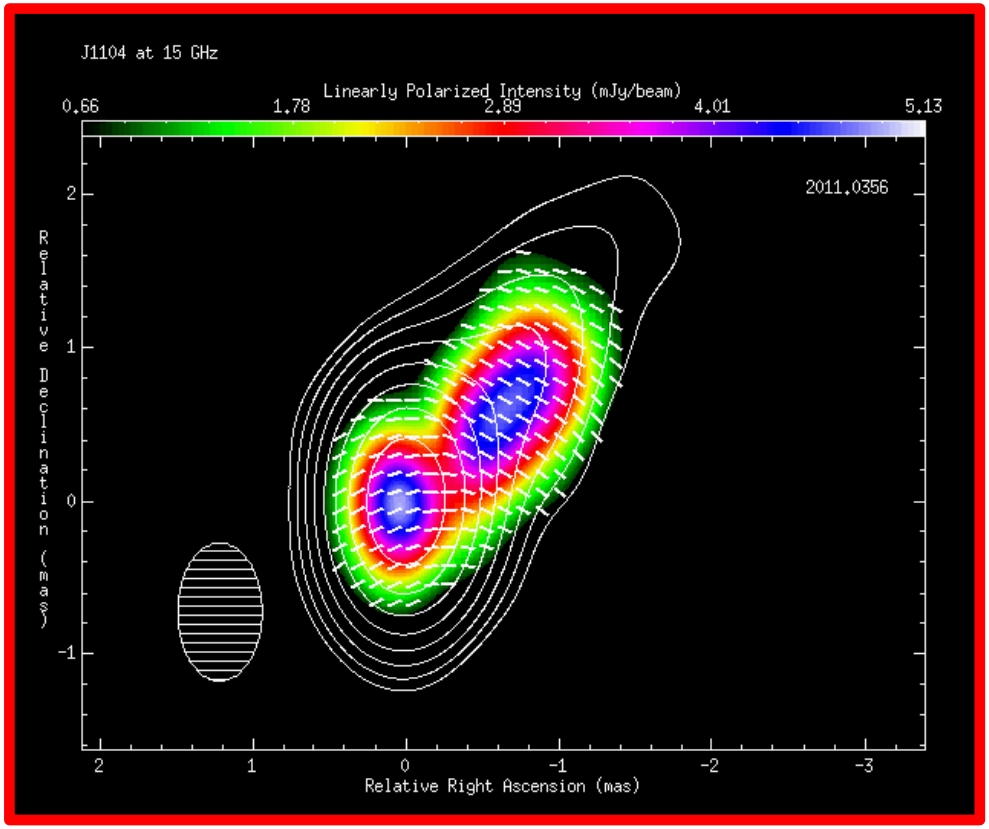
Linearly polarized intensity





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.

Summary and results

- **Relativistic radio jet** with marginal effects of beaming, that already at about 0.6 pc of projected distance from the core shows absence of proper motions, low flux density variability and steep spectral index.
  - Radio images show us the slower structure. (layer?).

- There is a velocity structure in this jet, with:
  - $2° < \theta < 5°$
  - $\beta_{radio} \sim 0.83$ and $\delta_{Radio} \sim 3$
  - $\beta_{HE} \sim 0.99$ and $\delta_{HE} \sim 15$

- For the **core**, we found a mean value for the degree of polarization of ~1%, and for the **C3** component of ~14%.

Thanks
for your attention!