Magnetic field studies in BL Lacertae throught Faraday rotation and a novel astrometric tecnique.

Sol N. Molina

Instituto de Astrofísica de Andalucía. (IAA-CSIC)

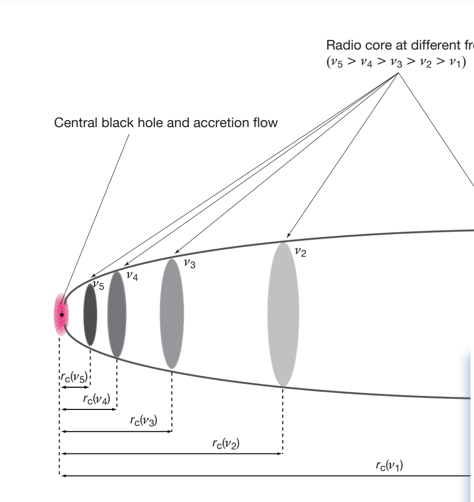
José L. Gómez (IAA-CSIC)
Richard Dodson (ICRAR)
María Rioja (ICRAR, IGN)

Motivation: Study the nature of core jets.

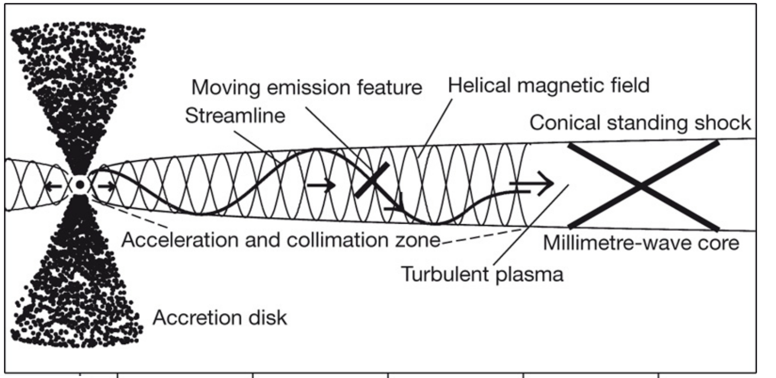
One of the main questions to answer in jets is the nature of the core.

The location at which the jet becomes optically thin. Therefore its position shifts with observing frequency.

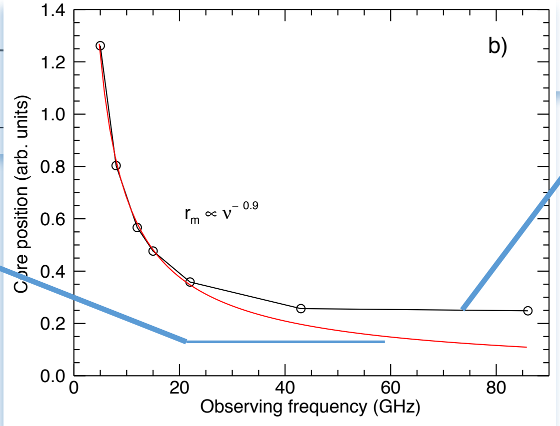
The radio core is a recollimation shock in the jet at a fixed location.



Hada et al. 2011.



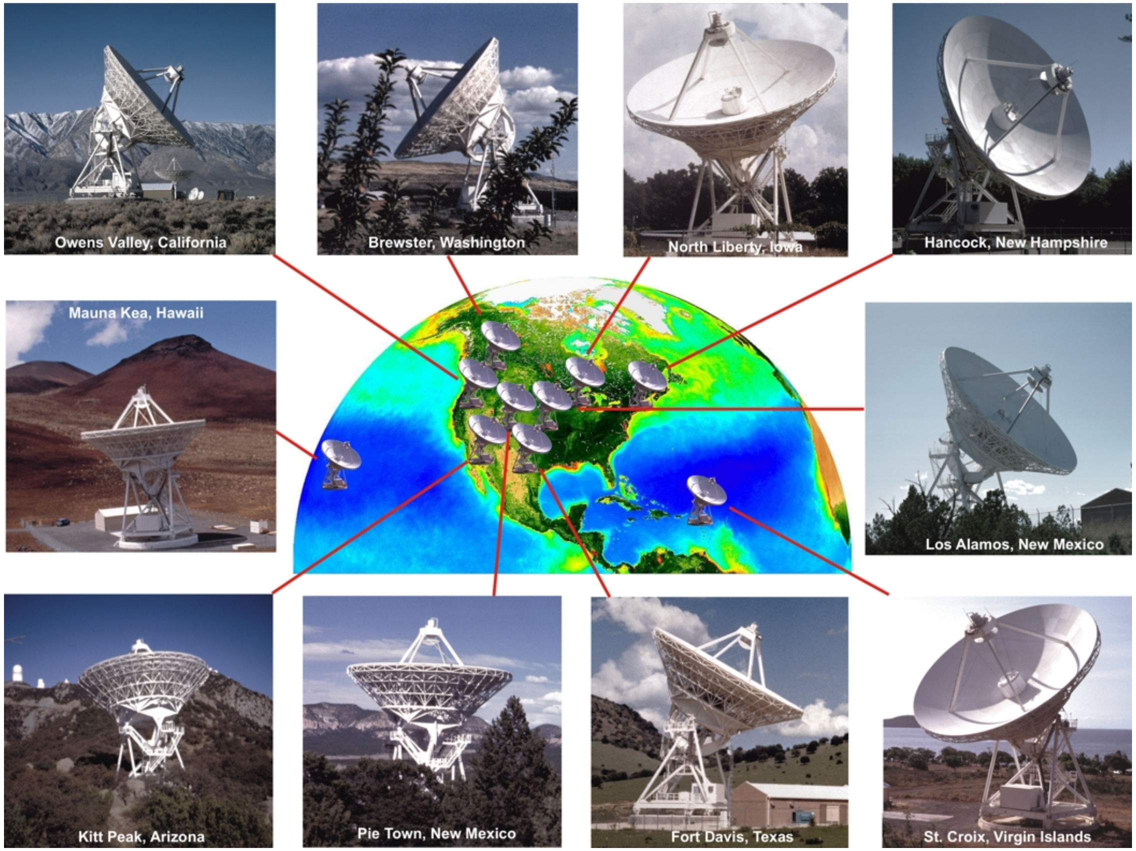
Marscher et al. 2008.



It is necessary to have astrometric measurements at mm wavelenght

Astrometric program with the VLBA

- Sample of sources observed in this program: BL Lac, 3C120, 3C273, CTA102, 0716+714, 3C111.
- γ-ray emitting AGN observed at 1.3, 5, 8.4, 15, 22, 43 and 86 GHz.

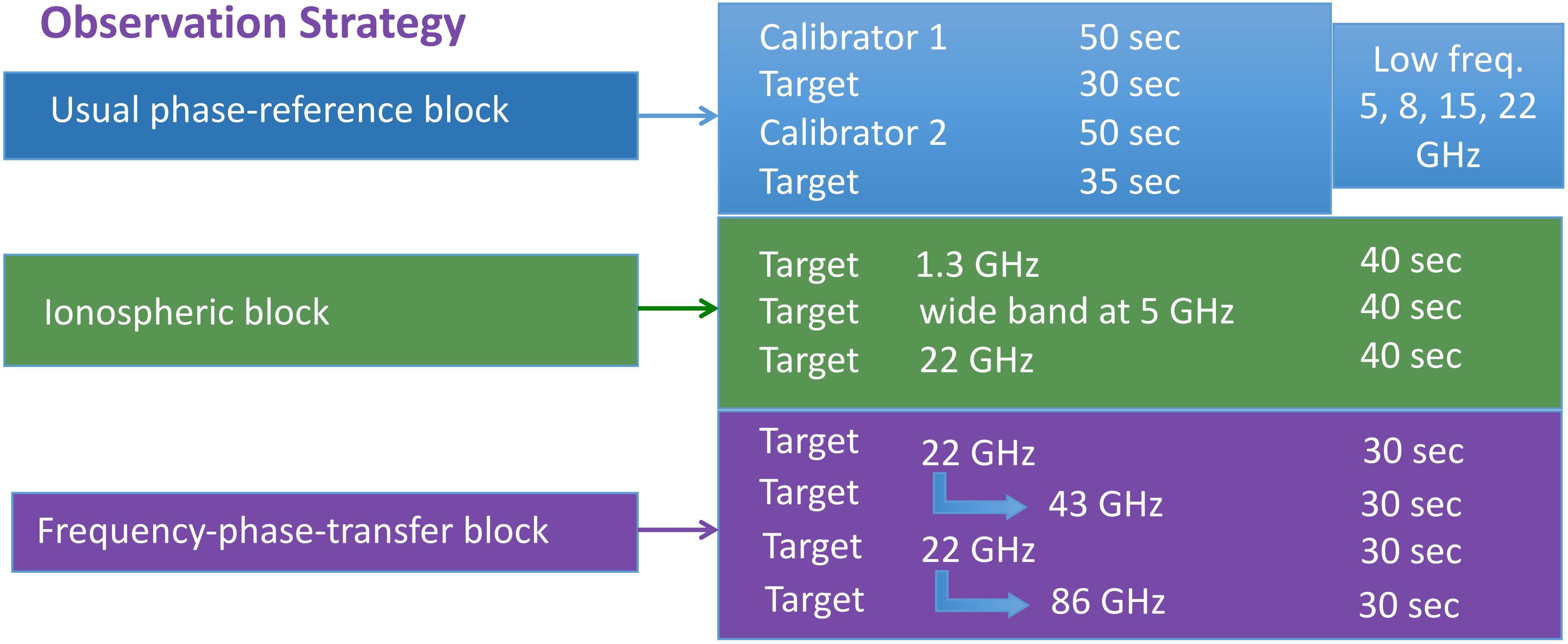


VLBA antennas. Credit NRAO/VLBA

Astrometric program with the VLBA

- Sample of sources to study: BL Lac, 3C120, 3C273, CTA102, 0716+714, 3C111.
- γ-ray emitting AGN at 1.3, 5, 8.4, 15, 22, 43 and 86 GHz.
- This method does not require a calibrator at high frequencies.

Observation Strategy



Usual phase-reference block

Calibrator 1	50 sec
Target	30 sec
Calibrator 2	50 sec
Target	35 sec

Low freq. 5, 8, 15, 22 GHz

Ionospheric block

Target	1.3 GHz	40 sec
Target	wide band at 5 GHz	40 sec
Target	22 GHz	40 sec

Frequency-phase-transfer block

Target	22 GHz	30 sec
Target	43 GHz	30 sec
Target	22 GHz	30 sec
Target	86 GHz	30 sec

Astrometric Technique applied to BL Lac.

Is a new approach to the Source Frequency Phase Transfer (SFPR) in which the ionospheric contribution is determine from the L (1.3 GHz), WC and K (22GHz) band.

$$\delta\tau(\nu,t)=\delta\tau_{trop}(t)+\delta\tau_{iono}(\nu,t)+\delta\tau_{struc}(\nu,t)+\delta\tau_{ast}(\nu,t)+\delta\tau_{inst}(\nu,t)$$

Rioja & Dodson (2011)

This term includes the structure of the source.

Includes the core shift

We have to calibrate

$\delta\tau_{trop}(t)$ Tropospheric contribution

$\delta\tau_{iono}(\nu,t)$ Ionospheric contribution

$\delta\tau_{inst}(\nu,t)$ Instrumental contribution

Instrumental contributions

$\delta\tau_{inst}(\nu,t)$ Calculating instrumental contributions with a bright calibrator.

Ionospheric contributions → This is the novel part of this technique

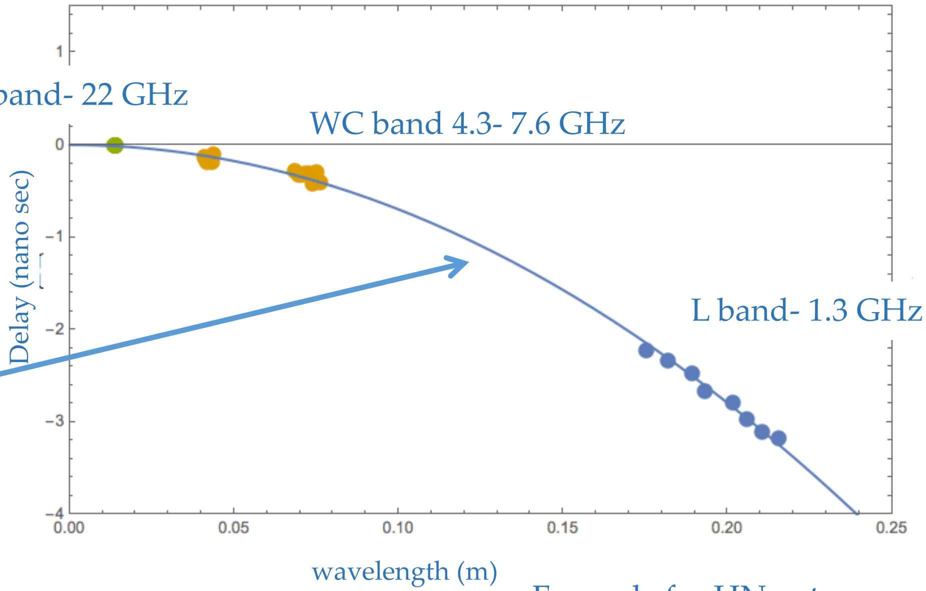
$\delta\tau_{iono}(\nu,t)$ → The delay varies with λ^2

$$\delta\tau_{iono} = c + m\lambda^2$$

↓

Tec (Total electron content)

We have developed a program to fit the data.



Example for HN antenna

Tropospheric contributions

$\delta\tau_{trop}(t)$ → From 5 to 22 GHz

We have to calculate the tropospheric contribution with the usual cm astrometry with the calibrator.

$\delta\tau_{trop}(t)$ → At 43 and 86 GHz

Frequency-phase-transfer

The tropospheric phase contributions are proportional to the observing frequency

$$\phi\tau_{trop}(\nu_1)\bullet R = \phi\tau_{trop}(\nu_2)$$

$$\hookrightarrow \phi\tau_{trop}(22GHz)\bullet R = \phi\tau_{trop}(43GHz) \qquad R = \frac{\nu^{high}}{\nu^{low}}$$

$$= \phi\tau_{trop}(86GHz)$$

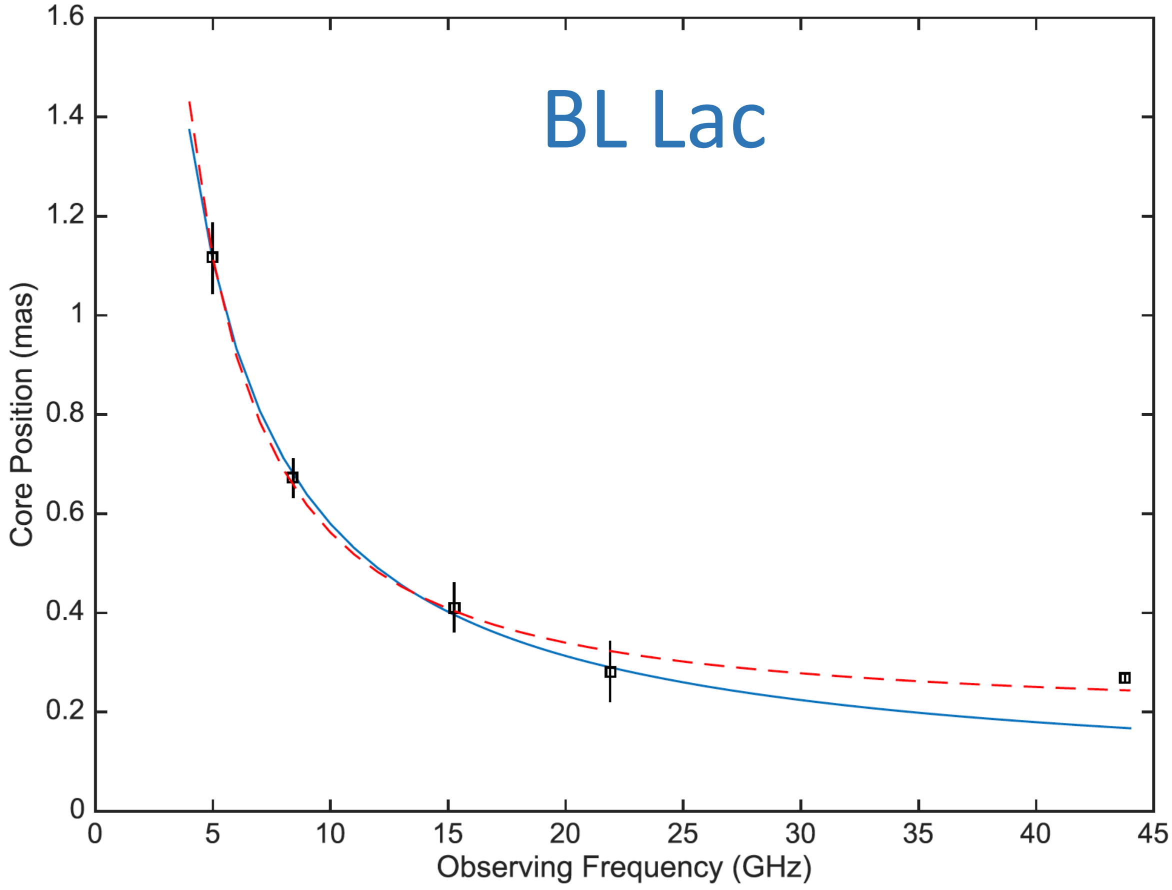
Rioja et al. 2015

Results at higher frequencies

Core shift
between
43 and 22 GHz:

-8 ±5 μas right ascension
20 ±6 μas declination

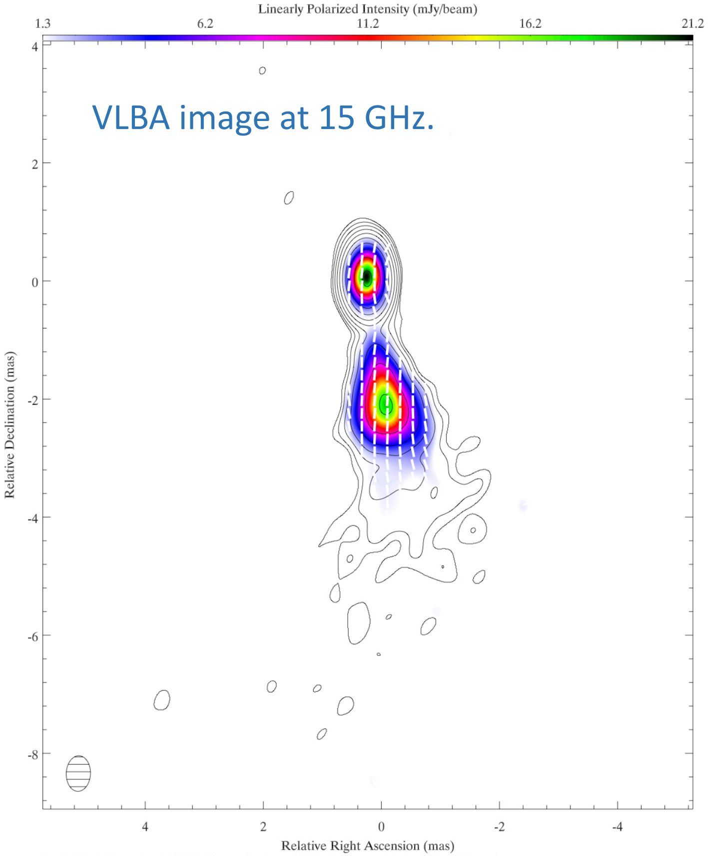
This result is in agreement with Gómez et al. 2016



Dodson et al. 2017

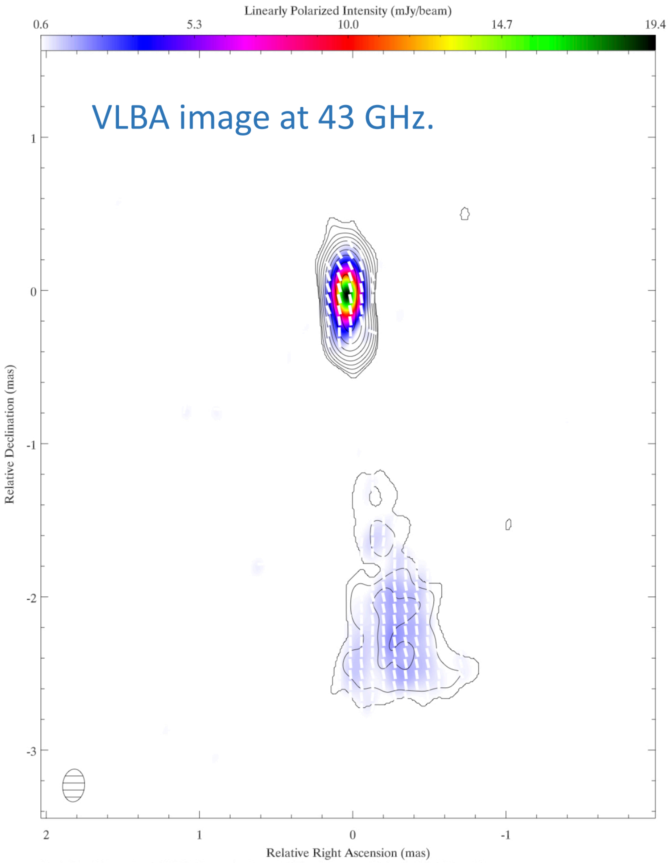
VLBA images of BLLAC with polarization

BL Lac is a blazar at z=0.06 and the jets is pointing at us with a viewing angle of ~8º (Jorstad et al. 2005)



VLBA image at 15 GHz.

Peak Total Intensity 4.3766 Jy/beam (noise at 8.75 mJy/beam - Noise Pol. 6.0% peak)
Total Intensity Contours 0.20,0.39,0.78,1.53,3.02,5.96,11.74,23.15,45.65,90% of peak
Beam FWHM 0.60x0.41 mas at -2.41 deg.

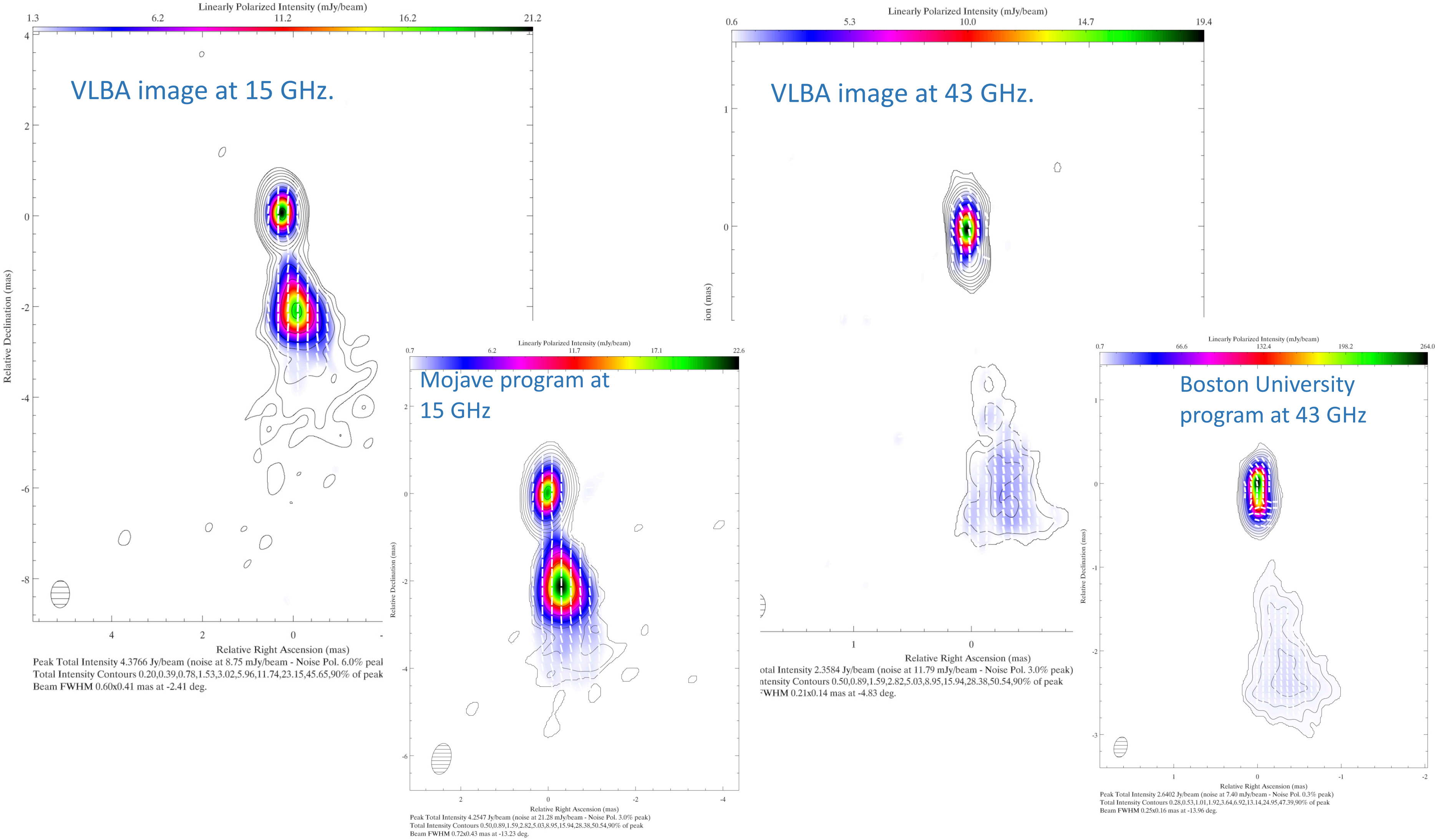


VLBA image at 43 GHz.

Peak Total Intensity 2.3584 Jy/beam (noise at 11.79 mJy/beam - Noise Pol. 3.0% peak)
Total Intensity Contours 0.50,0.89,1.59,2.82,5.03,8.95,15.94,28.38,50.54,90% of peak
Beam FWHM 0.21x0.14 mas at -4.83 deg.

VLBA images of BLLAC with polarization

BL Lac is a blazar at z=0.06 and the jets is pointing at us with a viewing angle of ~8º (Jorstad et al. 2005)



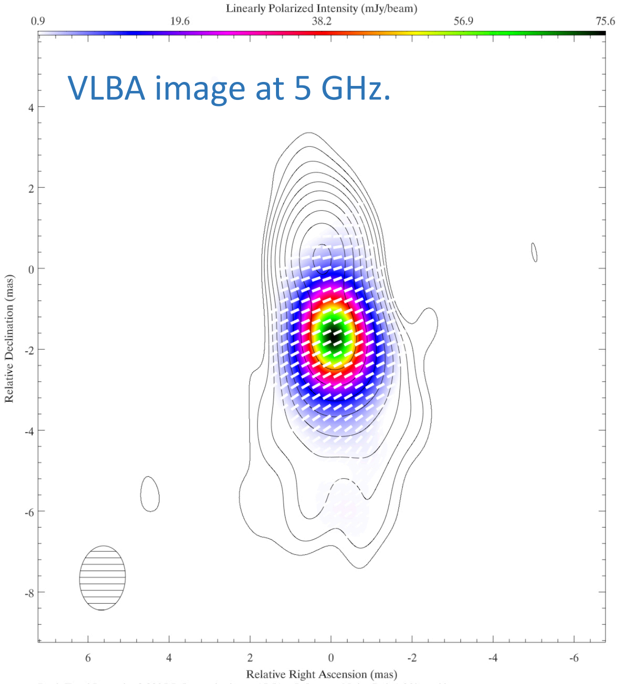
VLBA image at 15 GHz.

VLBA image at 43 GHz.

Mojave program at 15 GHz

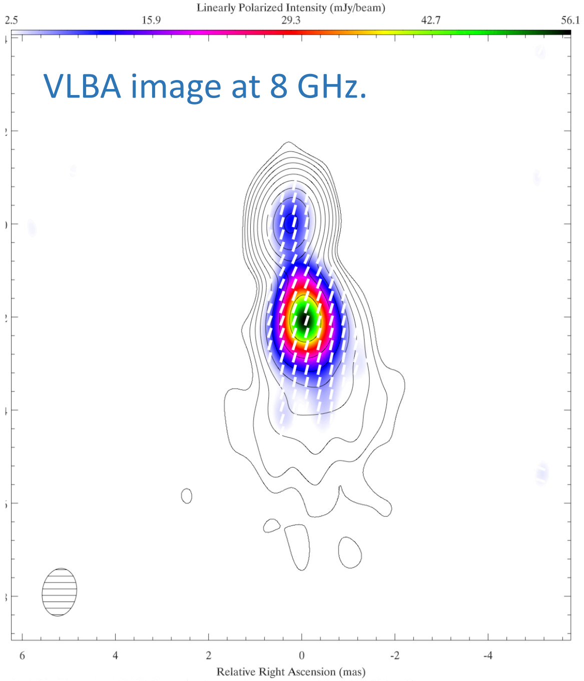
Boston University program at 43 GHz

VLBA images of BLLAC with polarization



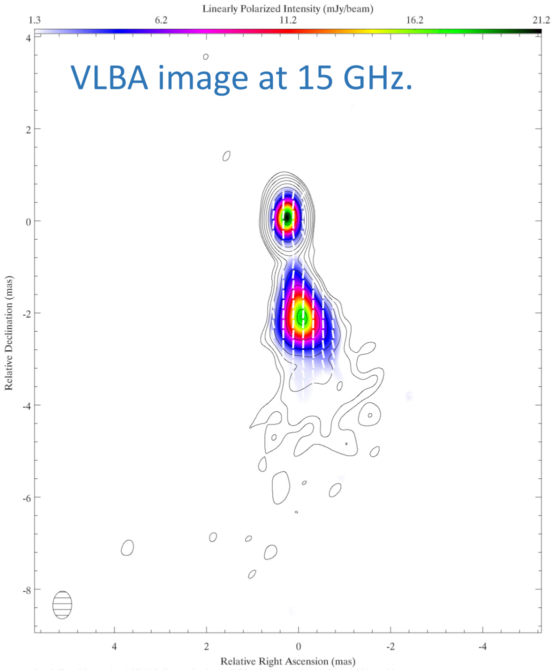
VLBA image at 5 GHz.

Peak Total Intensity 2.8205 Jy/beam (noise at 15.51 mJy/beam - Noise Pol. 1.2% peak)
Total Intensity Contours 0.55,0.97,1.71,3.01,5.30,9.34,16.45,28.99,51.08,90% of peak
Beam FWHM 1.59x1.13 mas at -3.76 deg.



VLBA image at 8 GHz.

Peak Total Intensity 4.8245 Jy/beam (noise at 14.47 mJy/beam - Noise Pol. 4.5% peak)
Total Intensity Contours 0.30,0.57,1.07,2.01,3.78,7.13,13.44,25.34,47.75,90% of peak
Beam FWHM 1.03x0.73 mas at -8.72 deg.

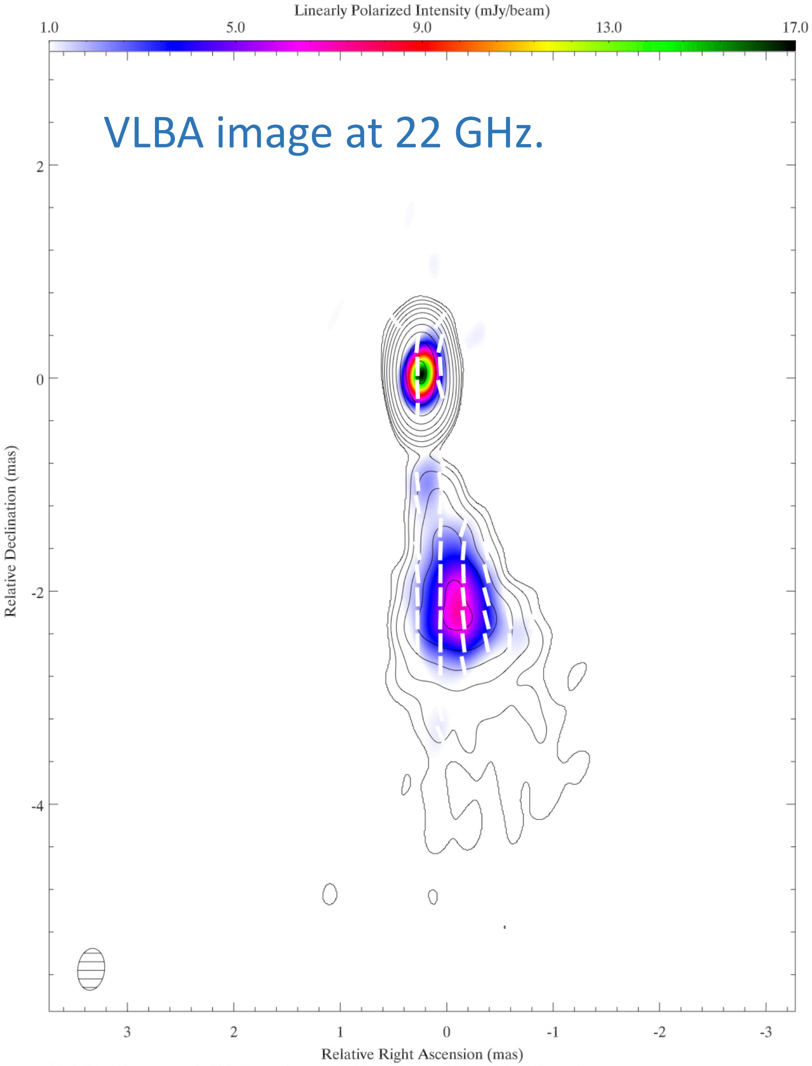


VLBA image at 15 GHz.

Peak Total Intensity 4.3766 Jy/beam (noise at 8.75 mJy/beam - Noise Pol. 6.0% peak)
Total Intensity Contours 0.20,0.39,0.78,1.53,3.02,5.96,11.74,23.15,45.65,90% of peak
Beam FWHM 0.60x0.41 mas at -2.41 deg.

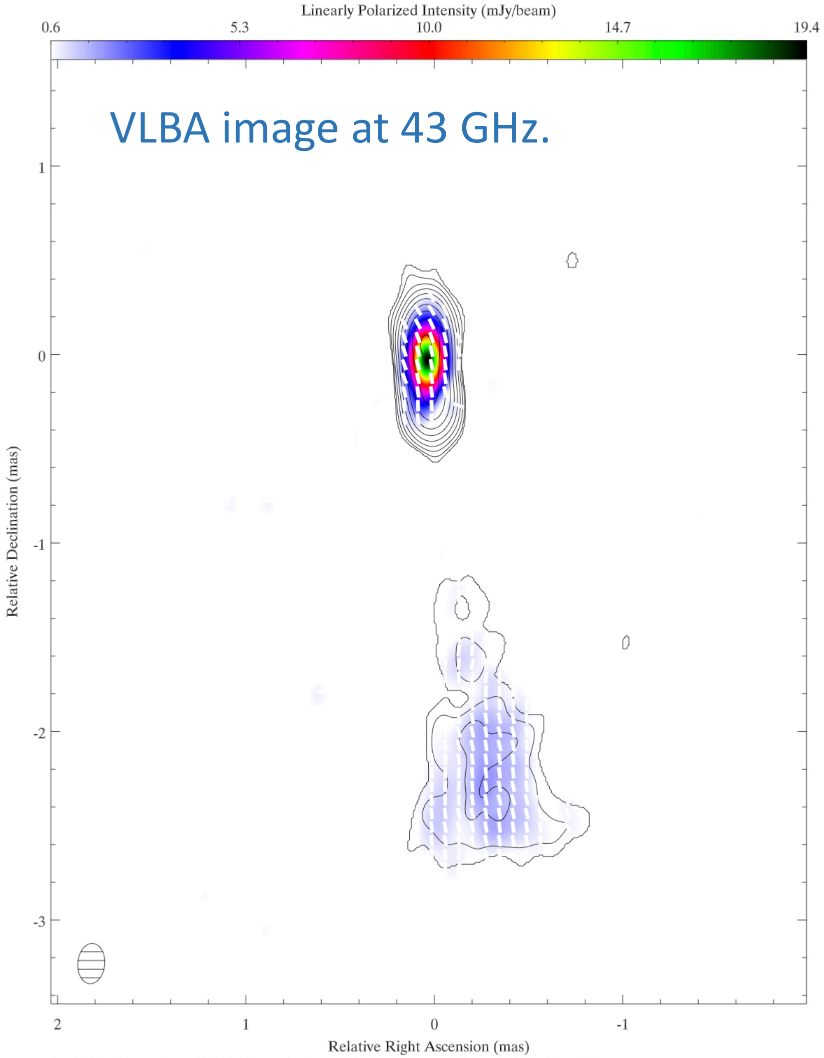
BL Lac have a galactic rotation measure of -156.1 rad.m^{-2} that we have taken into account (Taylor et al. 2009).

VLBA images of BLLAC with polarization



VLBA image at 22 GHz.

Peak Total Intensity 3.3289 Jy/beam (noise at 4.99 mJy/beam - Noise Pol. 6.0% peak)
Total Intensity Contours 0.15,0.31,0.62,1.27,2.58,5.24,10.67,21.72,44.21,90% of peak
Beam FWHM 0.39x0.25 mas at -6.70 deg.

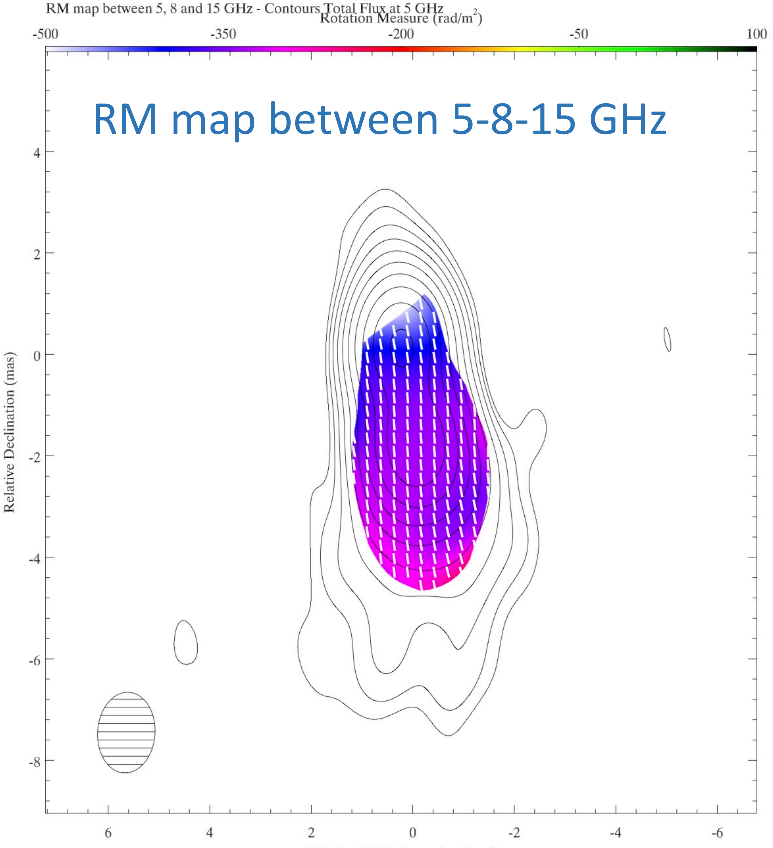


VLBA image at 43 GHz.

Peak Total Intensity 2.3584 Jy/beam (noise at 11.79 mJy/beam - Noise Pol. 3.0% peak)
Total Intensity Contours 0.50,0.89,1.59,2.82,5.03,8.95,15.94,28.38,50.54,90% of peak
Beam FWHM 0.21x0.14 mas at -4.83 deg.

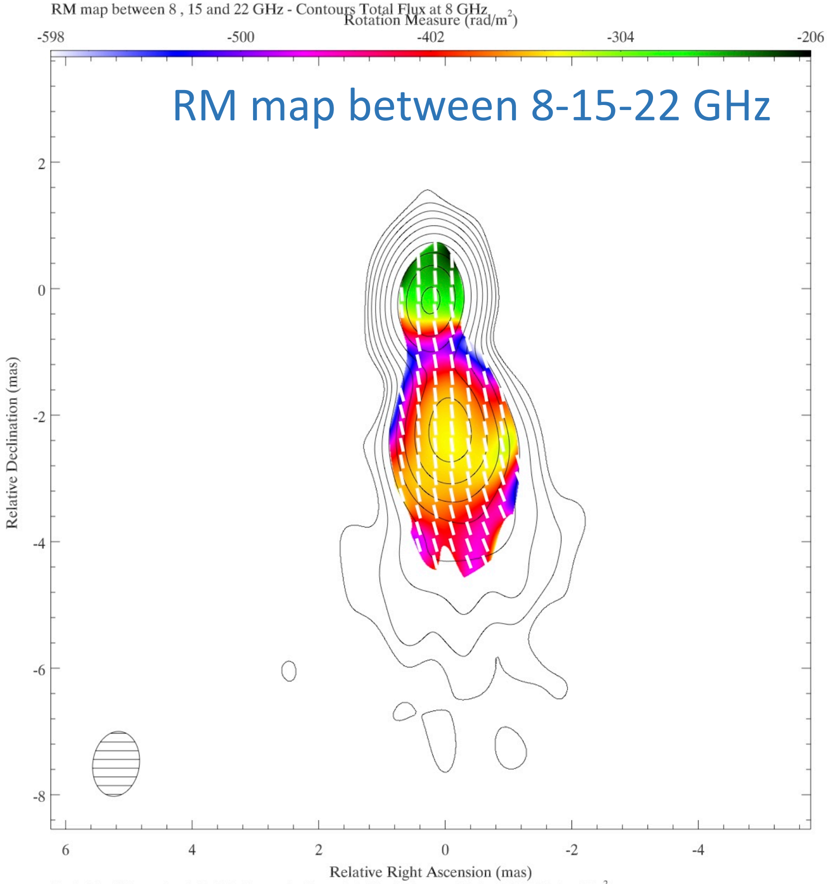
Rotation Measure Maps

$\chi_{obs} = X_0 + RM . \lambda^2$


RM map between 5, 8 and 15 GHz - Contours Total Flux at 5 GHz

RM map between 5-8-15 GHz

Peak Total Intensity 2.8205 Jy/beam (noise at 15.51 mJy/beam - Noise RM -500.0 rad/m^2)
Total Intensity Contours 0.55,0.97,1.71,3.01,5.30,9.34,16.45,28.99,51.08,90% of peak
Beam FWHM 1.59x1.13 mas at -3.76 deg.

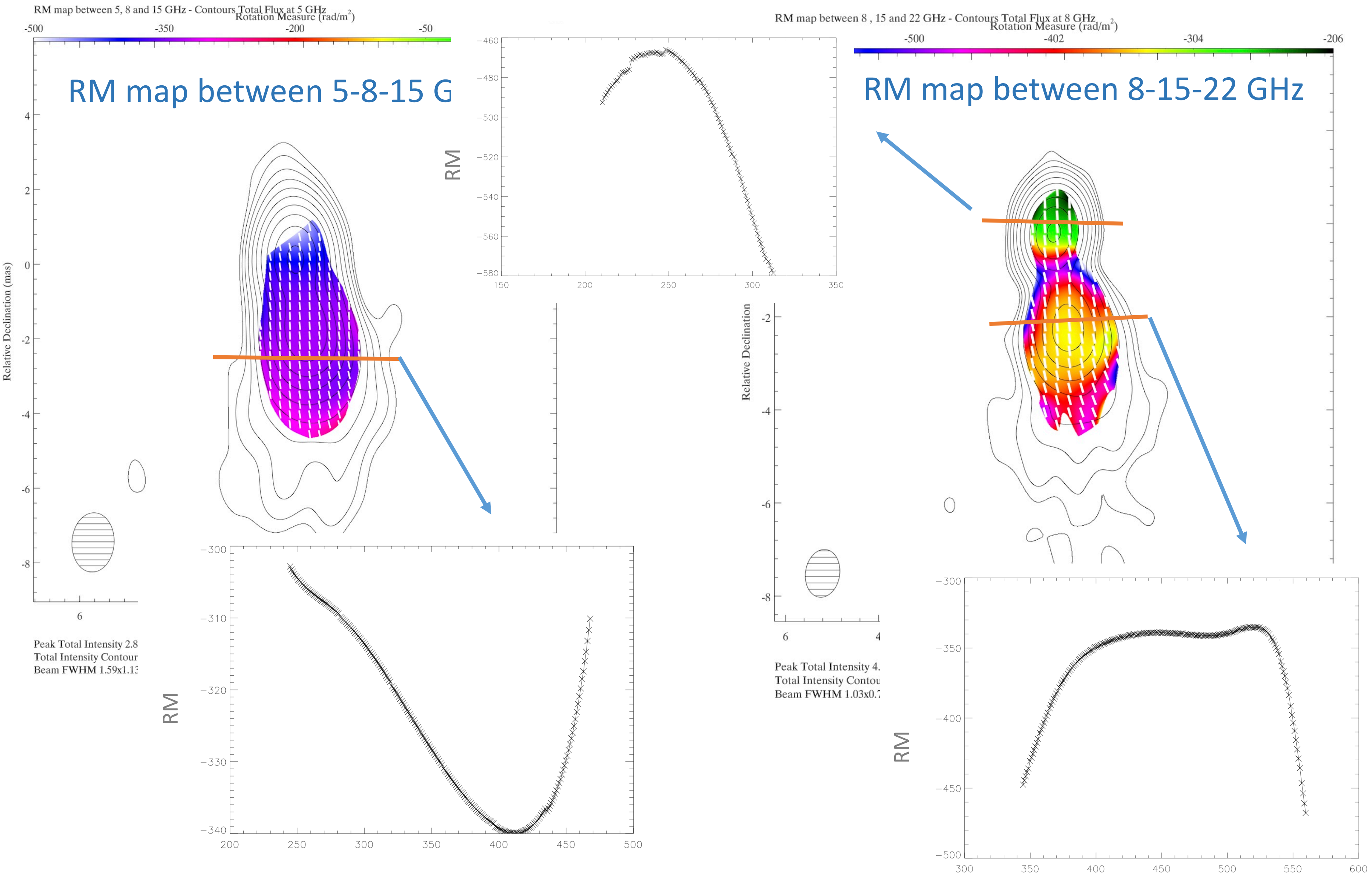

RM map between 8 , 15 and 22 GHz - Contours Total Flux at 8 GHz

RM map between 8-15-22 GHz

Peak Total Intensity 4.8245 Jy/beam (noise at 14.47 mJy/beam - Noise RM 289.9 rad/m^2)
Total Intensity Contours 0.30,0.57,1.07,2.01,3.78,7.13,13.44,25.34,47.75,90% of peak
Beam FWHM 1.03x0.73 mas at -8.72 deg.

Rotation Measure Maps

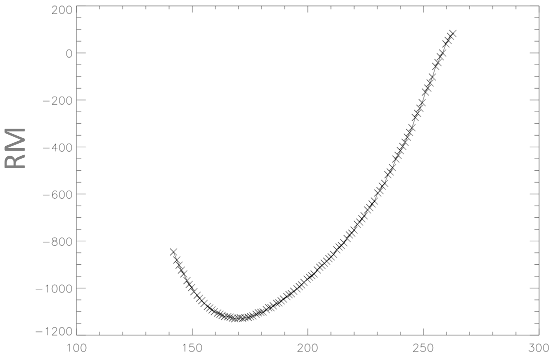
χ_{obs} = X_0 + RM . λ^2

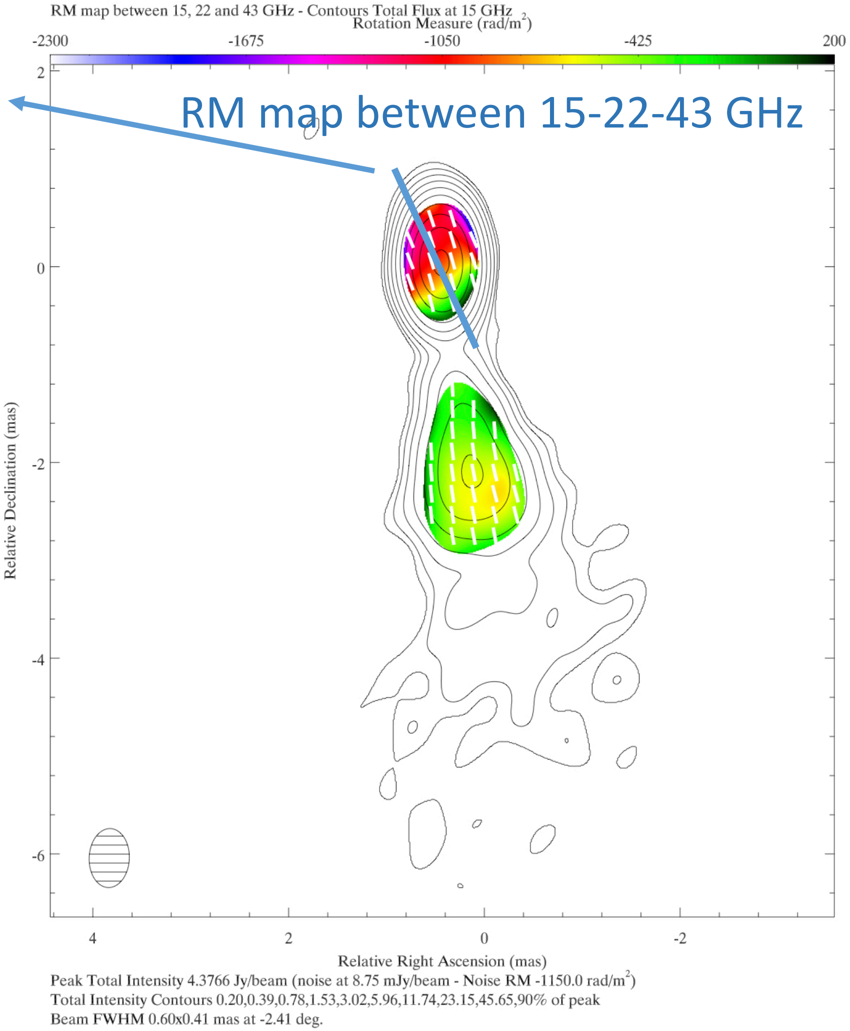


RM map between 5-8-15 G

RM map between 8-15-22 GHz

Rotation Measure Maps



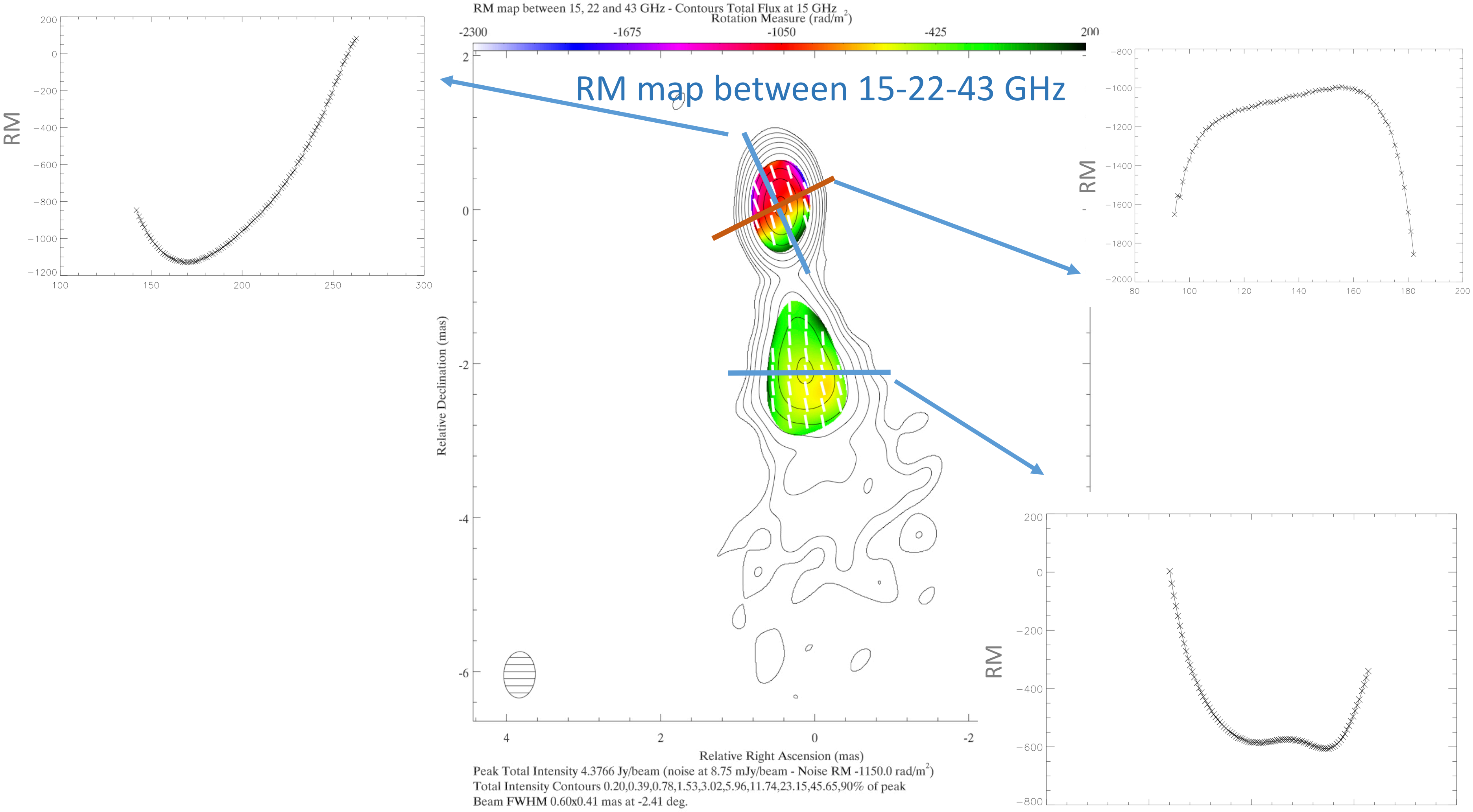

RM map between 15, 22 and 43 GHz - Contours Total Flux at 15 GHz

RM map between 15-22-43 GHz

Peak Total Intensity 4.3766 Jy/beam (noise at 8.75 mJy/beam - Noise RM -1150.0 rad/m^2)
Total Intensity Contours 0.20,0.39,0.78,1.53,3.02,5.96,11.74,23.15,45.65,90% of peak
Beam FWHM 0.60x0.41 mas at -2.41 deg.

Molina et al. 2017 (in prep.)

Rotation Measure Maps

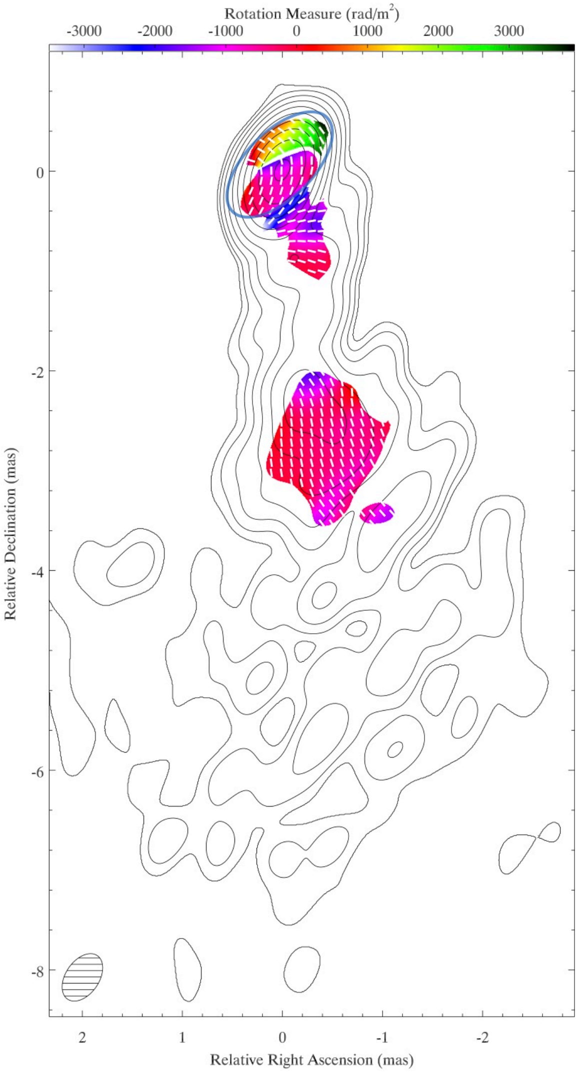


RM map between 15-22-43 GHz

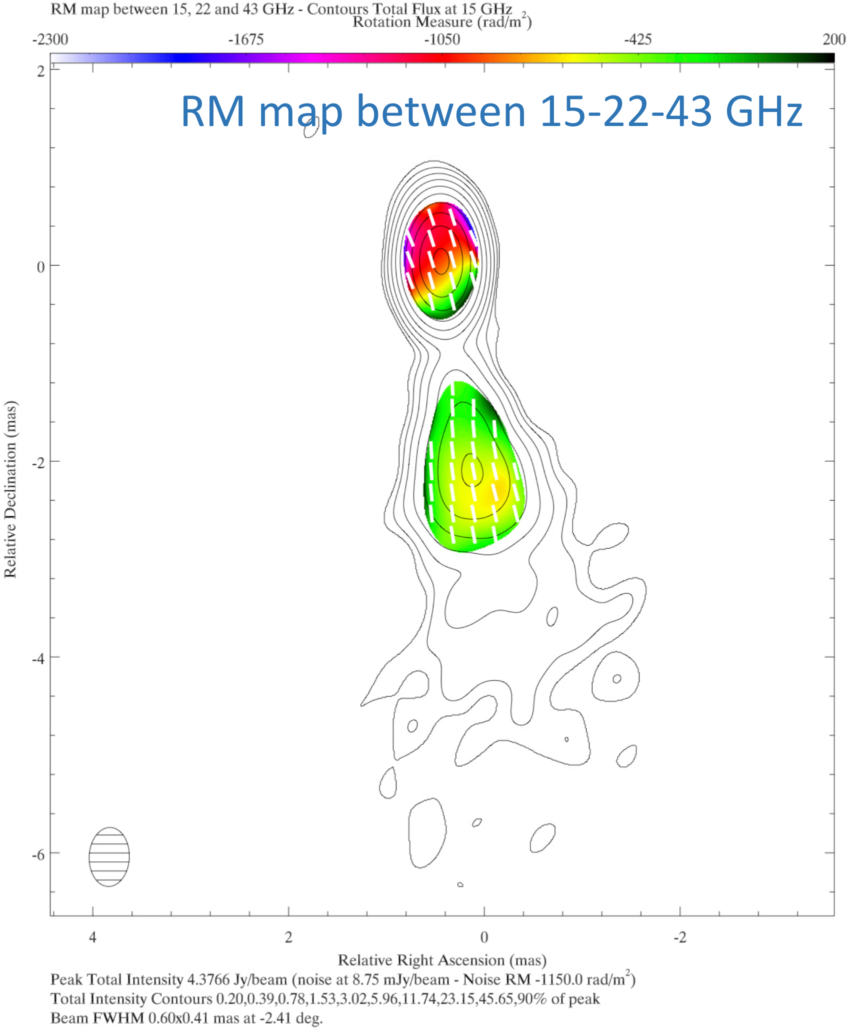
Peak Total Intensity 4.3766 Jy/beam (noise at 8.75 mJy/beam - Noise RM -1150.0 rad/m^2)
Total Intensity Contours 0.20,0.39,0.78,1.53,3.02,5.96,11.74,23.15,45.65,90% of peak
Beam FWHM 0.60x0.41 mas at -2.41 deg.

Molina et al. 2017 (in prep.)

Rotation Measure Maps



Gómez et al. 2016



RM map between 15-22-43 GHz

Molina et al. 2017 (in prep.)

Summary

- Sample of sources observed with the VLBA.
- Astrometric Technique applied to BL Lac. This technique does not require a calibrator at high frequencies
- We have measured a core shift between 22-43 GHz lower than expected suggesting that the core is a recollimation shock.
- BL Lac rotation measure maps showing structures in agreement with a helical magnetic field.
- Future work: extend this kind of studies to the remaining sources in the sample