Magnetic field studies in BL Lacertae through Faraday rotation and a novel astrometric technique.

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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.

It is necessary to have astrometric measurements at mm wavelength
Astrometric program with the VLBA

- Sample of sources observed in this program: BL Lac, 3C120, 3C273, CTA102, 0716+714, 3C111.

- \( \gamma \)-ray emitting AGN observed at 1.3, 5, 8.4, 15, 22, 43 and 86 GHz.
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**

| Block                               | Target          | Duration |
|-------------------------------------|-----------------|----------|
| Usual phase-reference block         | Calibrator 1    | 50 sec   |
|                                     | Target          | 30 sec   |
|                                     | Calibrator 2    | 50 sec   |
|                                     | Target          | 35 sec   |
| 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 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 determined from the L (1.3 GHz), WC and K (22 GHz) band.

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

We have to calibrate:

- \( \delta \tau_{\text{trop}}(t) \) Tropospheric contribution
- \( \delta \tau_{\text{iono}}(\nu, t) \) Ionospheric contribution
- \( \delta \tau_{\text{inst}}(\nu, t) \) Instrumental contribution

This term includes the structure of the source.

Includes the core shift.

Rioja & Dodson (2011)
Instrumental contributions

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

Ionospheric contributions

\[ \delta \tau_{\text{iono}}(\nu, t) \]
The delay varies with \( \lambda^2 \)

\[ \delta \tau_{\text{iono}} = c + m \lambda^2 \]

Tec (Total electron content)

We have developed a program to fit the data.

Example for HN antenna
Tropospheric contributions

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

From 5 to 22 GHz

At 43 and 86 GHz

The tropospheric phase contributions are proportional to the observing frequency

\[ \delta \tau_{\text{trop}}(t) \]

\[ \delta \tau_{\text{trop}}(t) \]

\[ \phi \tau_{\text{trop}}(\nu_1) \cdot R = \phi \tau_{\text{trop}}(\nu_2) \]

\[ \phi \tau_{\text{trop}}(22\text{GHz}) \cdot R = \phi \tau_{\text{trop}}(43\text{GHz}) \]

\[ \phi \tau_{\text{trop}}(86\text{GHz}) \]

\[ R = \frac{\nu^{\text{high}}}{\nu^{\text{low}}} \]

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 $\sim 8^\circ$ (Jorstad et al. 2005)
The VLBA images of BLLAC with polarization show BL Lac as a blazar at $z=0.06$ and the jets are pointing at us with a viewing angle of $\sim 8^\circ$ (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

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.

VLBA image at 43 GHz.
Rotation Measure Maps

\[ \chi_{obs} = X_0 + \text{RM} \cdot \lambda^2 \]

RM map between 5-8-15 GHz

RM map between 8-15-22 GHz
Rotation Measure Maps

\[ \chi_{\text{obs}} = \chi_0 + \text{RM} \cdot \lambda^2 \]
Rotation Measure Maps

RM map between 15-22-43 GHz

Molina et al. 2017 (in prep.)
Rotation Measure Maps

RM map between 15-22-43 GHz

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.