High-precision VLBI astrometric measurements using SFPR observations of BLLAC.

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Outline of the talk

• Motivation: Determination of core shift.

• Sample of sources observed by VLBA.

• Astrometric Technique applied to BL Lac. Is a new approach to the Source Frequency Phase Transfer (SFPR).

• Preliminary results.
Motivation: Study the nature of core jets.

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.

Hada et al. 2011.

Marscher et al. 2008.
Sample of sources observed by VLBA.

BL Lac, 3C120, 3C273, CTA102, 0716+714, 3C111 and some other sources Mrk421, 4C+21.35, 1633+382, 3C279, and 3C454.3.

γ-ray emitting AGN at 1.3, 5, 8.4, 15, 22, 43 and 86 GHz.
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$\gamma$-ray emitting AGN at 1.3, 5, 8, 15, 22, 43 and 86 GHz.

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
Sample of sources observed by VLBA.

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Observation Strategy

Usual phase-reference block

Ionospheric block

Calibrator 1
Target
50 sec
30 sec

Calibrator 2
Target
50 sec
35 sec

Low freq.
5, 8, 15, 22 GHz

Target 1.3 GHz
Target new C-band wide rec.

Target 22 GHz

4.3 GHz
7.6 GHz
Sample of sources observed by VLBA.

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**Observation Strategy**

- **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: 22 GHz, 30 sec
  - Target: 86 GHz, 30 sec

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  - Target: 1.3 GHz
  - Target: wide band at 5 GHz
  - Target: 22 GHz

- **Frequency-phase-transfer block**
  - Target: 22 GHz
  - Target: 43 GHz
  - Target: 86 GHz

- **Ionospheric block**
  - Target: 1.3 GHz
  - Target: wide band at 5 GHz
  - Target: 22 GHz
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 (22GHz) band.

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

- \( \delta \tau_{trop}(t) \): Tropospheric contribution
- \( \delta \tau_{iono}(v,t) \): Ionospheric contribution
- \( \delta \tau_{struc}(v,t) \): Source structure contribution
- \( \delta \tau_{ast}(v,t) \): Astrometric contribution
- \( \delta \tau_{inst}(v,t) \): Instrumental contribution

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Rioja & Dodson (2011)
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This term is not relevant in this kind of sources.

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

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

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Instrumental contribution

Rioja & Dodson (2011)

This term is not relevant in this kind of sources.

Includes the core shift

We have to calibrate

\( \delta \tau_{inst}(\nu, t) \),  \( \delta \tau_{trop}(t) \),  \( \delta \tau_{iono}(\nu, t) \)
**Instrumental contributions**

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

Calculating instrumental contributions in a scan and using this to calibrate all the experiment.
**Instrumental contributions**

\[ \delta \tau_{\text{inst}}(\nu,t) \]

Calculating instrumental contributions in a scan and using this to calibrate all the experiment.

**Ionospheric contributions**

\[ \delta \tau_{\text{iono}}(\nu,t) \]

The delay varies with \( \lambda^2 \)

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This is the novel part of this technique
Instrumental contributions

\[ \delta \tau_{\text{inst}}(\nu, t) \] Calculating instrumental contributions in a scan and using this to calibrate all the experiment.

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.
We have obtained TEC values.

We have calculated a new table at each frequency that contain the ionospheric corrections.
SN Tables with ionospheric corrections

Example for HN antenna

K band- 22 GHz

L band- 1.3 GHz

WC band 4.3- 7.6 GHz

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SN Tables with ionospheric corrections

K band- 22 GHz

WC band

Example for HN antenna
SN Tables with ionospheric corrections

Example for HN antenna

K band- 22 GHz

WC band

L band- 1.3 GHz

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We have determined ionospheric corrections from TEC values.

We want to test if these corrections have removed the ionospheric terms.
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We want to test if these corrections have removed the ionospheric terms.

We have applied the solution tables obtained to the data.

Recalculate TEC values.
We have determined ionospheric corrections from TEC values.

We want to test if these corrections have removed the ionospheric terms.

Tec Residual are

\[ \sim 0.2 \text{ TECU} \]

Except for MK and SC
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Doing more iterations could improve this calibration.
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Tec Residual are

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Except for MK and SC

Doing more iterations could improve this calibration.

Most of the ionospheric contribution has been removed.
Tropospheric contributions

\[ \delta \tau_{iono}(v,t) \]

We have to calculate the tropospheric contribution with a GFF in Aips.

We have removed all the contributions

\[ \delta \tau_{inst}(v,t) \quad \delta \tau_{trop}(t) \quad \delta \tau_{iono}(v,t) \]
Map obtained at 22 GHz

Map without autocalibration steps.
Calibrating data at 43 GHz

\[ \delta \tau_{\text{inst}}(v, t) \rightarrow \text{Fring in Aips} \]

\[ \delta \tau_{\text{iono}}(v, t) \rightarrow \text{We know TEC values} \]
Calibrating data at 43 GHz

\[ \delta \tau_{\text{inst}}(v,t) \quad \rightarrow \quad \text{Fring in Aips} \]

\[ \delta \tau_{\text{iono}}(v,t) \]

\[ \delta \tau_{\text{trop}}(t) \quad \text{The tropospheric phase contributions are proportional to the observing frequency} \]

Frequency-phase-transfer

\[ \phi \tau_{\text{trop}}(v_1) \cdot R = \phi \tau_{\text{trop}}(v_2) \]

\[ R = \frac{v_{\text{high}}}{v_{\text{low}}} \]

\[ \phi \tau_{\text{trop}}(22\text{GHz}) \cdot R = \phi \tau_{\text{trop}}(43\text{GHz}) \]
• Instrumental contribution obtained from a Fring for 43 GHz data.
• Ionospheric contributions obtained from TEC calculations from the fit of the data at L (1.3 GHz), WC and K (22 GHz) band.
• Tropospheric contribution calculated from 22 GHz data.

This map is obtained without any autocalibration.
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This is work in progress

We have to improve some points:
• Iterations to obtain a better ionospheric determination.
• Better tropospheric calibrations using autocalibrated solutions at low frequency.

We have a detection at 43 GHz !!!

That implies that we have successfully remove at a first order term the ionospheric and tropospheric contributions.

This is a 43 GHz image referred to 22 GHz image.

We can measure the core shift between the two frequencies.

We didn’t use an external calibrator to do this calibration.
Summary

• Multiwavelength observations suggest that at mm wavelength the core may correspond to a recollimation shock.

• To test this we are performing astrometric observations of a sample of $\gamma$-ray emitting AGN at 1.3, 5, 8.4, 15, 22, 43 and 86 GHz with VLBA.

• We are using a new approach to the Source Frequency Phase Transfer technique for astrometry in which the ionospheric contribution is determined from the ionospheric block with observations at L (1.3 GHz), WC and K (22GHz) band.
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- Combine this with frequency phase transfer at higher frequencies allow us to obtain a reliable calibration of the 43 GHz data.
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• This work is in progress and we expect to obtain astrometric solutions at 86 GHz.
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L-band (1.3 GHz) instrumental delays calibrated

L-band (1.3 GHz), ionospheric contribution calibrated
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We have to calculated the tropospheric contribution with a GFF

L-band (1.3 GHz) instrumental delays calibrated

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L-band (1.3 GHz), instrumental delays calibrated

L-band, instrumental, ionospheric and tropospheric contribution calibrated
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Calibrating data at 43 GHz

\( \delta \tau_{\text{inst}}(\nu, t) \) → Fring in Aips

Table with ionospheric calibration at 22 GHz

Table with ionospheric calibration at 43 GHz