Astron. Astrophys. 318, L32–L34 (1997)

ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

Baseline errors in European VLBI Network measurements III. The dominant effect of instrumental polarization.

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Received 10 September 1996 / Accepted 14 November 1996

Abstract. In this paper, we compare the results of a VLBI observation involving 7 European telescopes with the model by Massi et al. 1996 for the contribution of the instrumental polarization to the closure phase. The excellent agreement found between model predictions and data proves that the systematic error present in European VLBI data is in fact due to the high instrumental polarization of some of the telescopes and can be removed by data processing.

Key words: Methods: analytical- Methods: data analysis- Techniques: interferometric - Instrumentation: interferometers

1. Introduction

Observations with the European VLBI-Network at 6 cm have shown that the standard deviation of the closure phase on a significant sample of measurements, is almost one order of magnitude higher than expected from the associated thermal noise (Massi et al, 1996). This fact is a clear indication that there are still systematic errors in the experimental technique and/or data reduction procedures. The consequence is a significant degradation of the quality of the final image: theoretically detectable weak features are lost because of the increased "noise" level. Here we demonstrate that the instrumental polarization is responsible for these residual errors in observations with the European VLBI Network.

2. Contribution of the instrumental polarization to the closure phase

Massi et al. (1996) pointed out that the error in the closure phase might mainly be due to the instrumental polarization (D) at the telescope sites. This effect has been assumed in the past to be completely negligible,because affects observations of unpolarized sources only in the second order. This is certainly true for telescopes in which the instrumental polarization is so low that a second order contribution adds an error lower than the expected thermal noise (like the VLBA-telescopes with instrumental polarizations below 2%) .

For the European telescopes, where the instrumental polarization ranges (at 6cm) from 2 to 22% with an average value of 9%, the D^2 contribution results in an additive phase error of 0.4 degree. The expected phase noise for a standard calibrator is around 0.04 degrees, which is one order of magnitude lower.

2.1. Definitions

As stated in Cotton (1989), in practice it is impossible to built perfect feeds that only respond to a given polarization. The instrumental polarization, also called polarization impurity or feed ellipticity, may be seen as the sensitivity of a feed to the other sense of polarization.

If v_L is the output of a left circularly polarized feed tracking a point source, one expresses the contamination by the right circular mode with a complex quantity D_L (Roberts et al. 1991,1994) as:

$$v_L = G_L(E_L e^{j\phi} + D_L E_R e^{-j\phi}) \quad (1)$$

where $D_L = de^{j\psi}$ with d of a few percent
E_L and E_R are the left and right circularly polarized components of the electromagnetic wave
$G_L = g_l e^{j\eta_L}$ is the antenna gain
ϕ is the parallactic angle, i.e. the angle between the local vertical on the feed and the direction to the north at the position of the source. It is constant for equatorially mounted antennas and for alt-azimuth mounts varies as:

$$\tan\ \phi = \frac{\cos\ b\ \sin\ H}{\sin\ b\ \cos\ \delta - \cos\ b\ \sin\ \delta\ \cos\ H} \quad (2)$$

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where δ is the source declination and H is the hour angle of the antenna having latitude b.

Assuming the circular polarization of the source to be negligible, the response of ai two element interferometer "i,k" will be:

$$v_{L_i}v^*_{L_k} = G_{L_i}G^*_{L_k}I\ e^{j(\phi_i-\phi_k)}[1 + D_{L_i}D^*_{L_k}e^{-2j(\phi_i-\phi_k)} + +D^*_{L_k}M^*e^{2j\phi_k} + D_{L_i}Me^{-2j\phi_i}] \quad (3)$$

where $I = 0.5(E_{R_i}E_{R_k} + E_{L_i}E_{L_k})$ and M is the visibility that corresponds to the fractional linear polarization.

Due to the low amplitude of the D and M terms we can rewrite the equation as:

$$v_{L_i}v^*_{L_k} = G_{L_i}G^*_{L_k}e^{j(\phi_i-\phi_k)}I[(1 + D_{L_i}D^*_{L_k}e^{-2j(\phi_i-\phi_k)}) (1 + D^*_{L_k}M^*e^{2j\phi_k})(1 + D_{L_i}Me^{-2j\phi_i})] \quad (4)$$

In other words: the instrumental polarization contributes in three terms to the parallel hand (v_Lv_L as in the equations above or v_Rv_R) data; the term containing D_iD_k is purely instrumental while the two terms containing $D\ M$ are related to the polarization of the observed source. Here our aim is to see how large the instrumental contribution alone may be. Therefore we will assume in the following that M is negligible in comparison with D (i.e. source polarization lower than 0.3%).

Rewriting the factor in D_iD_k (Massi et al. 1991) as:

$$1 + D_{L_i}D^*_{L_k}e^{-2j(\phi_i-\phi_k)} = (1 + d_id_kcos\gamma_{ik})e^{jd_id_ksin\gamma_{ik}} \quad (5)$$

with

$$\gamma_{ik} = (\psi_i - \psi_k) - 2(\phi_i - \phi_k) \quad (6)$$

(where d and ψ are the D term amplitude and phase) equation (4) reduces to:

$$v_{L_i}v^*_{L_k} = G_{L_i}G^*_{L_k}e^{j(\phi_i-\phi_k)}I(1 + d_id_kcos\gamma_{ik})e^{jd_id_ksin\gamma_{ik}} \quad (7)$$

2.2. *Closure phase: the Phase of the Bispectrum*

If at least three telescopes "i","k" and "m" are available the quantity called the bispectrum can be computed as the product of the three interferometric outputs:

$$S_{ikm} = (v_{L_i}v^*_{L_k})(v_{L_k}v^*_{L_m})(v_{L_i}v^*_{L_m})^* \quad (8)$$

The phase of the bispectrum is called the "closure phase" (Rogers et al.1974), which theoretically should differ from zero only due to noise contributions if a point source is observed.

In our case the closure phase is:

$$\theta_{ikm} = (\eta_i - \eta_k + \phi_i - \phi_k + d_id_k\sin\gamma_{ik}) + \quad (9)$$

where all "antenna" terms η and ϕ cancel each other and the remaining contribution is the instrumental polarization:

$$\theta_{ikm} = d_id_k\sin\gamma_{ik} + d_kd_m\sin\gamma_{km} - d_id_m\sin\gamma_{im} \quad (10)$$

In order to see at which level the instrumental polarization influences the data, in the next section we will compare the observed closure phase for the source DA193 with that computed by equation (10). The perfect agreement shown there will prove that the instrumental polarization is responsible for the large observed values of closure phase.

3. Estimate of the D terms

In order to determine the D terms in amplitude (d) and phase (ψ), a polarization VLBI observation has been made. In fact the cross hand correlation (assuming negligible source polarization) is:

$$\frac{v_{L_i}v_{R^*_k}}{v_{L_i}v_{L^*_k}} = \frac{G^*_{R_k}}{G^*_{L_k}}\frac{(D^*_{R_k} + D_{L_i}e^{-2j(\phi_i-\phi_k)})}{(1 + D_{L_i}D^*_{L_k}e^{-2j(\phi_i-\phi_k)})} \quad (11)$$

which becomes, expanded into a Taylor series:

$$\frac{G^*_{R_k}}{G^*_{L_k}}(D^*_{R_k} + D_{L_i}e^{-2j(\phi_i-\phi_k)})(1 - D_{L_i}D^*_{L_k}e^{-2j(\phi_i-\phi_k)}...) \quad (12)$$

Neglecting cubic and higher order terms, we get:

$$v_{L_i}v_{R^*_k} = \frac{G^*_{R_k}}{G^*_{L_k}}(D^*_{R_k} + D_{L_i}e^{-2j(\phi_i-\phi_k)}) \quad (13)$$

The source DA193 has been observed at 6 cm on 30 May 1995 for 12 hours by the 9 telescopes of: Effelsberg, Jodrell MK2, Medicina, Noto, Onsala, Shanghai, Simeiz, Urumqi and Westerbork. The data were correlated at the MPIfR (Bonn). No fringes were detected for the baselines with Urumqi. No data were recorded on tapes from Shanghai. The test was therefore performed on the remaining 7 telescopes.

The D terms were determined using both AIPS (Cotton 1993) and the software of the Brandeis group (Roberts et al.,1994). AIPS gives an estimate of D in each of the seven frequency channels, that is as a function of frequency. Table 1 gives average values for each telescope in amplitude and phase (column 1 and 3). In the table the average value for the Noto phase is not given, having large variations within the passband (discussed in detail in Paper IV, in preparation). In column 2 and 4 the values obtained with the Brandeis software are given. One may notice how large the D terms are for the European telescopes: Medicina and Onsala reaching values of 15% and 21%.

4. Comparison between Observations and Model

As stated in Sect. 2.2, in absence of errors, the closure phase of a point source should differ from zero only due to noise contributions. In Figure 1 the closure phase is given for the parallel-hand data (LL) of three triangles. The data are not noise-limited, on the contrary a regular trend is there evident, which proves that a systematic error still affects the data. This effect has not been noticed before because the closure phase of a point like source was never up to now monitored with a proper scale,

Table 1. Amplitude and phase of the D-Terms of the left hand circularly polarized feeds at 5 GHz

Telescope	d_{AIPS}	$d_{BRANDEIS}$	ψ_{AIPS}	$\psi_{BRANDEIS}$
Crimea	3.4	3.3	$74°$	$65°$
Effelsberg	8.9	9.5	$-73°$	$-76°$
Jodrell	2.0	2.7	$45°$	$60°$
Medicina	15.6	15.0	$84°$	$101°$
Noto	2.9	1.1	?	$4.4°$
Onsala	21.6	19.6	$-149°$	$-149°$
Westerbork	12.8	11.2	$-110°$	$-113°$

for such long period and at such time resolution as in our ”ad hoc” observation.

The contribution of the instrumental polarization to the closure phase, computed by using equation (10) and the D terms derived with the Brandeis software, is also plotted in Fig.1. As one can see equation 10 reproduces completely the observed trend. The agreement between data (closure phase) and equation 10 (contribution of the instrumental polarization to the closure phase) proves that the systematic errors present up to now in European VLBI data is in fact due to the high instrumental polarization of some of the telescopes.

The effects of its removal in terms of improvement of the dynamic range will be shown in the next paper (Paper IV). Preliminary tests show an improvement in dynamic range from 5000 to 9000. A work is in progress to optimize the D terms delivered by AIPS by fitting equation 10 to the closure phase of a point like source.

5. Conclusion

In this paper we have shown that:

1) the total intensity data acquired with the European VLBI telescopes are affected by a systematic error.

2)The physical origin of this error can be traced in the instrumental polarization

3)The effect of the instrumental polarization on the data can be modeled and therefore removed

4)the existing VLBI software must be changed to apply this correction.

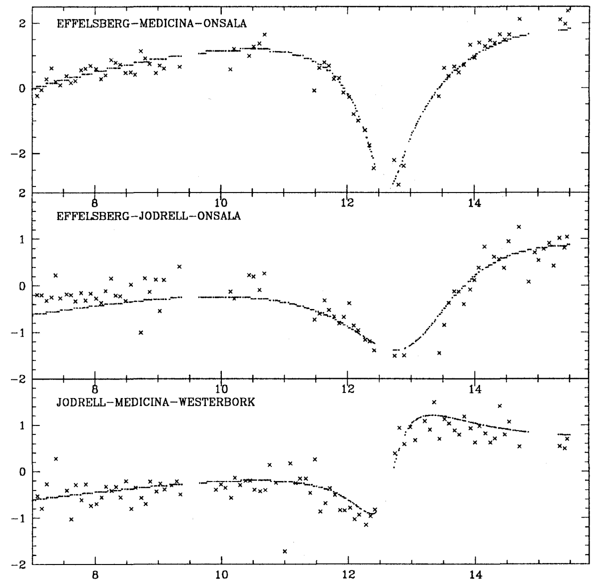

Fig. 1. Observed closure phase (x) and model of instrumental polarization contribution as computed with equation 10

Acknowledgements. Walter Alef was of invaluable help in all the steps of this work and Guidetta Torricelli made useful comments and suggestions. Dave Graham , Richard Porcas , Richard Schilizzi, Jürgen Neidhöfer, Sheperd Doeleman, Malcom Wamsley, Ambretta Falchi, Leslie Hunt, Klaus Reif and Claudio Codella were involved in many useful discussions. We acknowledge support for this research by the EU contract CHCGECT920011.

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