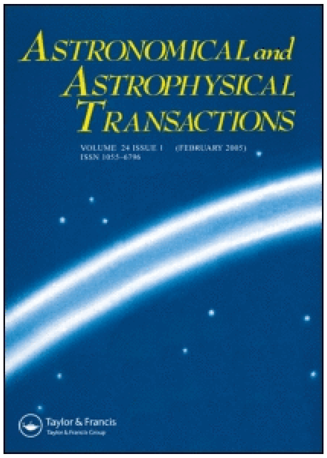

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The dual-frequency calibration of ionosphere influence in VLBA data processing

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The dual-frequency calibration of ionosphere influence in VLBA data processing

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Some results of processing data of Very Long Baseline Array (VLBA) experiments titled RDV14, RDV15, RDV16, and RDV17 are presented. Observations had been carried out on 15/04/1999, 10/05/1999, 21/06/1999, and 02/08/1999. The Flexible Image Transport System (FITS) files have been created with a VLBA correlator and then placed into archive. Later, these data have been kindly placed at my disposal by Dr. Leonid Petrov (Goddard Space Centre). The software project titled "Astro Space Locator" (ASL for Windows) has been used for post-correlation data processing.

Keywords: VLBA (Very Long Baseline Array); S/X Frequency Ranges; The Ionospheric Delay

1. Introduction

The ionized shell around the Earth is caused by the Sun's UV radiation. The electronic column density is peaked at the height of about 350 km above the ground and spreads by several tens of kilometres around this altitude. The Total Electronic Content (TEC) density variation has timescale of several hours and induces a delay of about 1 nanosecond at 8.4 GHz frequency. The same ionospheric delay is 13 times larger at 2.3 GHz frequency due to the phenomenon of dispersion. There are several strategies to calibrate and to compensate for this ionospheric delay. One of them is the technique of Dual Frequency Observations (see [1] for details). In other words, the ionospheric delay can be calibrated out with simultaneous observations in two widely separated frequency bands. Usually, these are:

- S Band (2.3 GHz)
- X Band (8.4 GHz)

A linear combination of two group delays in these bands yields straightforwardly the ionosphere-free delay (see equation (1)) that could be easily compensated at any baseline $(k - l)$ with multiplication of the visibility value by the corresponding exponential function

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(see equation (2)):

$$\tau = \frac{f_X^2}{f_X^2 - f_S^2} \cdot \tau_X - \frac{f_S^2}{f_X^2 - f_S^2} \cdot \tau_S \tag{1}$$

where

- $f_X \equiv 8.4 \cdot 10^9\, Hz,\ f_S \equiv 2.3 \cdot 10^9\, Hz$. These are frequencies of the X and S bands correspondingly
- τ_X andτ_S are the measured values of group delay for X and S bands

$$V_{kl}^{corr}(t, f) = V_{kl}(t, f) \cdot Exp(-j \cdot 2 \cdot \pi \cdot f \cdot \tau) \tag{2}$$

where

- $V_{kl}(t, f)$ is the initial visibility function value at time t and frequency f
- τ is the delay calculated using equation (1)
- $V_{kl}^{corr}(t, f)$is the corrected visibility function at time t and frequency f

We have used another method for ionospheric delay compensation. This delay value is proportional to $1/f^2$ (see equation (1)). Hence the phase error inserted into the visibility function by the ionosphere is proportional to $1/f$. Thus, we could write some non-linear equation for the visibility phase and solve it. Such a solution is given below.

2. Data processing

The processing of data has been carried out with the software "Astro Space Locator" (ASL for Windows). See [2] for a description of this software.

Table 1 shows a structure of initial dual frequency data of RDV14, RDV15, RDV16, and RDV17 VLBA experiments. Four of eight IFs contain data of the S-range, and four other IFs contain data of the X-range.

As mentioned above, the ionosphere phase error is proportional to $1/f$. Thus, we could write the following equation for current frequency band and current time interval:

$$\Phi_k(t, f) = 2 \cdot \pi \cdot \tau_k(t, f) \cdot (f - f_0) + Q_k(t) \cdot \frac{1}{f} \tag{3}$$

where

- $\Phi_k(t, f)$ is the visibility function phase for the kth antenna with respect to the reference antenna
- $\tau_k(t, f)$ is the delay of the kth antenna with respect to the same reference antenna

Table 1. Frequency structure of the data.

	F0 (MHz)	Bandwidth (MHz)	Number of channels
IF1	2221.22	8	16
IF2	2241.22	8	16
IF3	2331.22	8	16
IF4	2361.22	8	16
IF5	8406.22	8	16
IF6	8476.22	8	16
IF7	8791.22	8	16
IF8	8896.22	8	16

- $Q_k(t)$ is a coefficient of proportionality of ionosphere phase error to $1/f$. It is important that $Q_k(t)$ is the antenna based parameter and it depends on the TEC value that is variable in time
- f is the frequency in Hz
- f_0 is the lowest frequency of the current frequency band in Hz.

The well-known technique entitled Global Fringe Fitting (see [3] for details) has been used for this data processing. According to this method, the antenna based parameters (Φ_k, τ_k, Q_k) are used instead of the baseline parameters. If bandwidth and time interval values are small enough, then $\tau_k(t, f)$ and $Q_k(t)$ do not depend on time and frequency and hence

$$\Phi_k(t, f) = 2 \cdot \pi \cdot \tau_k \cdot (f - f_0) + Q_k \cdot \frac{1}{f} \tag{4}$$

The visibility phase of the reference antenna is declared to be equal to zero for every time and every frequency. In other words,

$$\tau_{Ref} = 0; \quad Q_{Ref} = 0 \tag{5}$$

For any other antenna, we have to estimate two values, τ_k and Q_k, for every frequency band and every time interval. Then, we could compensate the non-linearity of equation (4) and estimate a more accurate value of antenna delay with respect to the reference antenna. Such problems can be easily solved with the least squares method. Fortunately, equation (4) is linear with respect to values τ_k and Q_k. In this case, the least squares method allows one to find the most accurate and stable solution.

3. Some results

Radio images of four sources have been reconstructed for two cases:

- the ordinary procedure of calibration of phase and amplitude of visibility function has been used

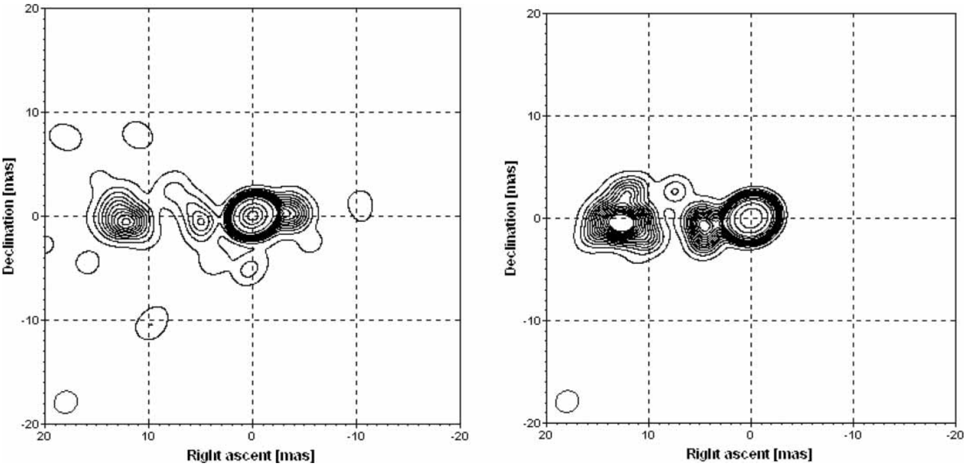

Figure 1. RDV14. ASL images of source J0217 + 7349 without dual-frequency calibration (left) and with dual-frequency calibration (right).

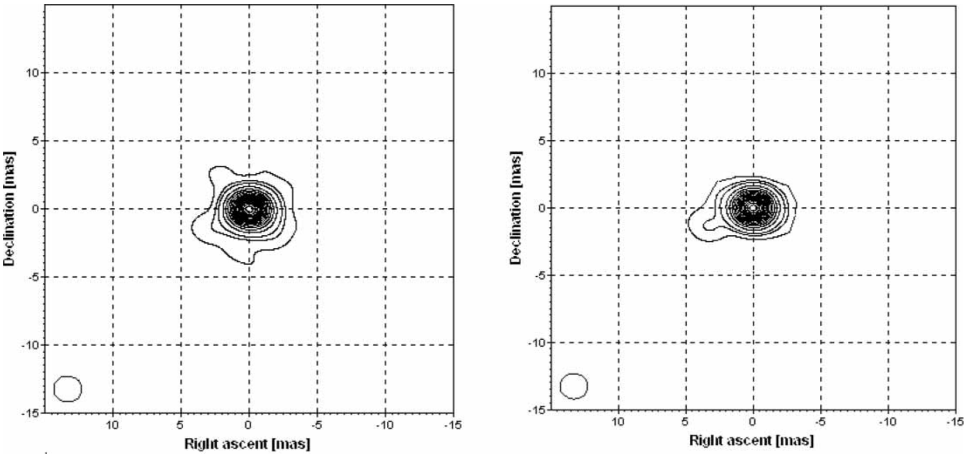

Figure 2. RDV15. ASL images of source J0555 + 3948 (DA193) without dual-frequency calibration (left) and with dual-frequency calibration (right).

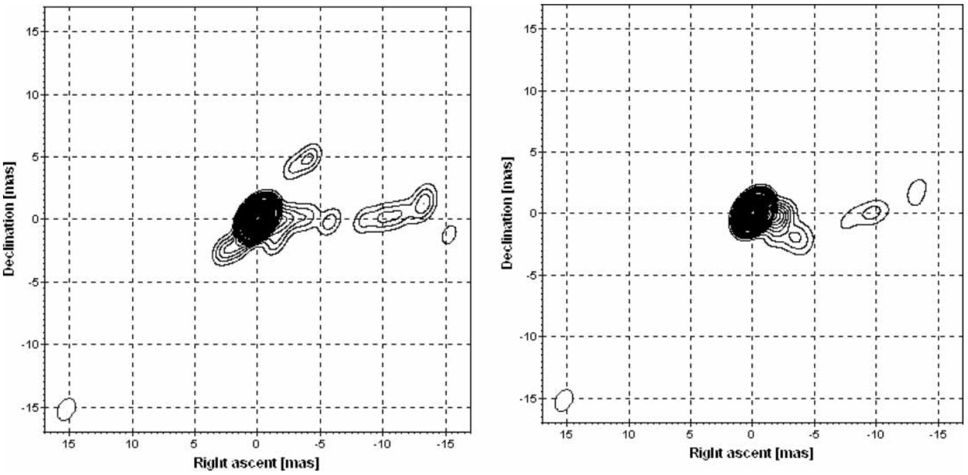

Figure 3. RDV16. ASL images of source J1800 + 7828 without dual-frequency calibration (left) and with dual-frequency calibration (right).

- the phase of the visibility function has been calibrated with additional usage of the procedure of dual-frequency calibration of ionosphere influence.

The results are shown in figures 1–4. In all cases, application of the procedure of dual-frequency calibration allows an increase of the signal-to-noise ratio. Thus we can obtain the fine structure of the source even for centimetre wavelength ranges.

4. Conclusions

My experience demonstrates that

- The usage of dual-frequency calibration of VLBA data can essentially improve the source image quality even if it is a strong source.

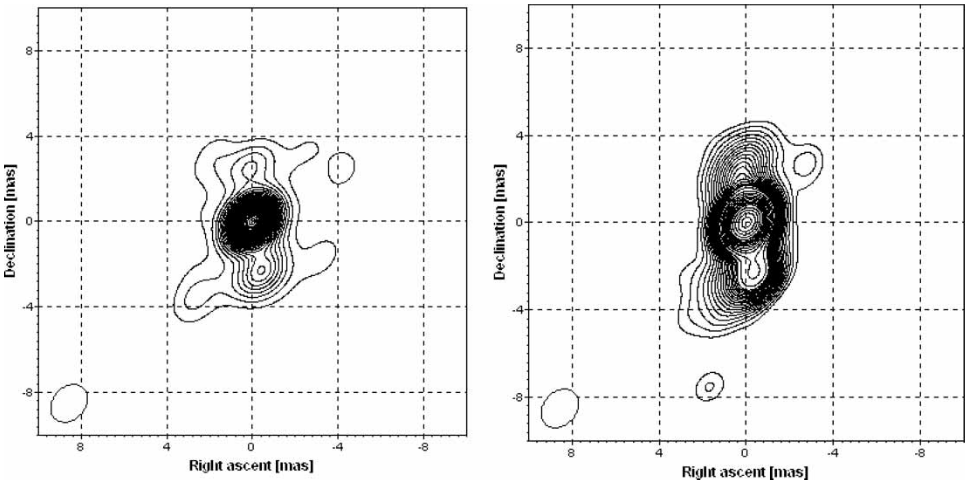

Figure 4. RDV17. ASL images of source J2202 + 4216 (BL LAC) without dual-frequency calibration (left) and with dual-frequency calibration (right).

- If the procedure has not been performed for any data, the final source image can be shifted from the phase centre, and, additionally, the image may have false components in this case.
- The procedure of dual-frequency calibration of VLBI data is absolutely necessary to reveal the fine radio structure of the source.

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