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Imaging of quasars and active galactic nuclei. Fine-scale structure evolution

A. Chuprikov*
Astro Space Center of P. N. Lebedev Physical Institute of Russian Academy of Sciences, Profsoyuznaya 84 / 32, 117997, Moscow, Russia
E-mail: achupr@asc.rssi.ru

I. Guirin
Astro Space Center of P. N. Lebedev Physical Institute of Russian Academy of Sciences, Profsoyuznaya 84 / 32, 117997, Moscow, Russia
E-mail: igirin@asc.rssi.ru

We present partial results of four survey experiments carried out with the VLBA. All the observations were made between April and August 1999. There were at least two reasons for our interest in these data. Firstly, a number of the sources have already been included into the "Radioastron" scientific programme source list as well as into the VSOP scientific programme source list. The second reason is that these are dual-frequency observations as all the sources were observed at two frequency bands: S-band (2200 MHz) and X-band (8400 MHz), simultaneously. The influence of the Earth's troposphere as well as the influence of the ionosphere could be calibrated and compensated thanks to this frequency structure of observational data. The results of application of the new algorithm of such a compensation are demonstrated. Moreover, changes of some sources' fine structure during four months are shown.

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*Speaker.

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1. Introduction

In many cases, it is very important to compensate the visibility function phase errors caused by the Earth's troposphere and ionosphere. It is well known, that the influence of ionosphere is significant in the metre wavelength range. On the other hand, the troposphere can introduce serious corruption into visibility function phase in the millimetre range. Thus, in the centimetre wavelength range, it is reasonable to take into account both phase corrections. These phase corrections are especially important for long baselines; in particular, they are necessary for SVLBI data calibration.

There are many ways to solve the problem of such calibration. One of them are broadband observations. The Multi-Frequency Synthesis (MFS) method (Likhachev, 2004) could then be used to improve the (u,v)-plane coverage, and, hence, to improve the quality of reconstructed images. Alternatively, the broad band could be used to estimate both, ionospheric and tropospheric, phase errors and to remove them.

2. Observations

Four VLBA survey experiments were made in the period between April and August 1999. The codes and the dates of the experiments were:

- RDV14 (15 Apr 1999)
- RDV15 (10 May 1999)
- RDV16 (21 Jun 1999)
- RDV17 (02 Aug 1999)

Source lists of each survey included more than 80 sources. Many of them were observed during all four experiments. All the sources observed were bright and so fringe fitting could be made for each source during the data processing. The main property of these surveys is the dual-frequency structure of the data obtained with the VLBA correlator. Table 1 demonstrates this structure.

Table 1: Frequency structure of RDV14, RDV15, RDV16, and RDV17 data

	F_0[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

3. Data processing

The software project *Astro Space Locator* (ASL for Windows) (Chuprikov, 2002) has been used to process all the data. The data processing consists of the following stages:

- Amplitude calibration using GC and TY tables.
- Fringe fitting (the phase calibration).
- Averaging in time and frequency.
- Self-calibration.
- Imaging.

We have supplemented this scheme with a procedure of dual-frequency calibration of ionospheric delay as well as with a procedure of multi-band calibration of tropospheric delay. The procedure of dual-frequency calibration simply estimates the linear combination of S and X group delays:

$$\tau = \frac{f_X^2}{f_X^2 - f_S^2}\tau_X - \frac{f_S^2}{f_X^2 - f_S^2}\tau_S \tag{3.1}$$

and then compensates the ionospheric delay τ:

$$V_{kl}^{corr}(t, f) = V_{kl}(t, f)e^{j2\pi f \tau} \tag{3.2}$$

Such dual-frequency calibration can be carried out for processing of any data if there are at least two widely-separated frequency bands.

The procedure of multi-band calibration of tropospheric delay uses the multi-band delay (MBD) fitting procedure to determine the troposphere model errors as well as the clock model errors. A polynomial approximation is used for such fitting.

The main idea of our RDV14, RDV15, RDV16, and RDV17 sessions data processing was to compensate the ionospheric/tropospheric delays *before* self-calibration and *before* any imaging procedure. Then, the source image can be improved significantly.

Figure 1 demonstrates such improvement of a dirty map that has been obtained immediately after amplitude and phase calibration of the visibility function. Dirty maps of quasar J0017+8135 (0014+813) have been obtained for two cases. In the first case, the procedure of ionospheric/tropospheric delays compensation was ignored. In the second one, such a procedure was applied. It is clear that the signal-to-noise ratio is considerably better for the second case.

4. Some results

In some cases, we could observe changes of the fine structure of sources revealed thanks to application of calibration procedures described above. As an example, the evolution of the structure of J0017+8135 is shown in Figure 2. Obviously, the ejection of component into the jet occurred between 15 Apr 1999 and 10 May 1999. Later, between 21 Jun 1999 and 02 Aug 1999, this jet

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disappeared. In any case, this quasar shows a strong variability and monitoring of this object seems to be very interesting.

Another example of the structure evolution is shown in Figure 3 for the case of J1406+2827 (1404+286, OQ 208). This compact source is associated with the bright galaxy Mkn 668. Sometimes, OQ 208 is classified as a Seyfert 1 galaxy. Maps in Figure 3 present the compact structure of this source. Possibly, a re-distribution of intensity between components takes place.

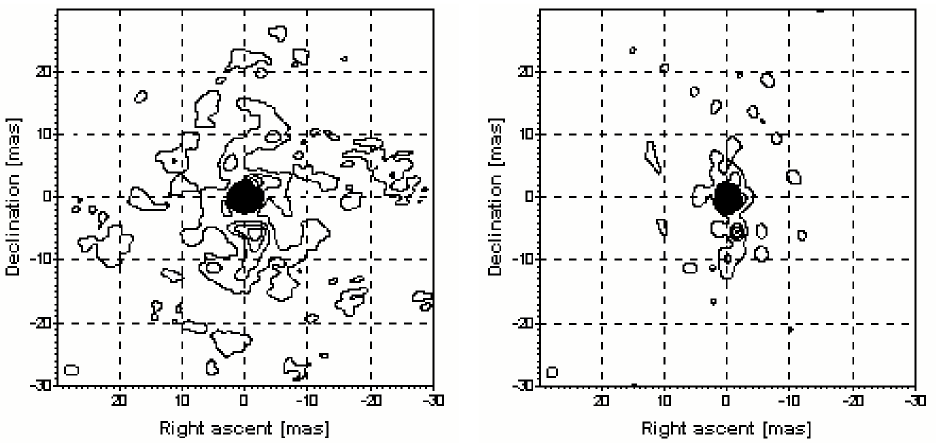

Figure 1: Dirty map of J0017+8135 without (left) and with (right) application of ionospheric/tropospheric delay compensation. RDV14, 15 Apr 1999.

5. Conclusions

We showed that using the procedure of dual-frequency calibration of ionospheric delay can essentially improve the dirty map of a source in the centimetre wavelength range. The procedure of fitting of multi-band delay (MBD) allows to calibrate and to remove the tropospheric delay for the same wavelength range. In particular, application of these two procedures to dual-frequency (S and X bands) data obtained with the VLBA during the observational sessions RDV14, RDV15, RDV16, and RDV17 allows to monitor some sources for variability of their milliarcsecond structure.

Acknowledgments

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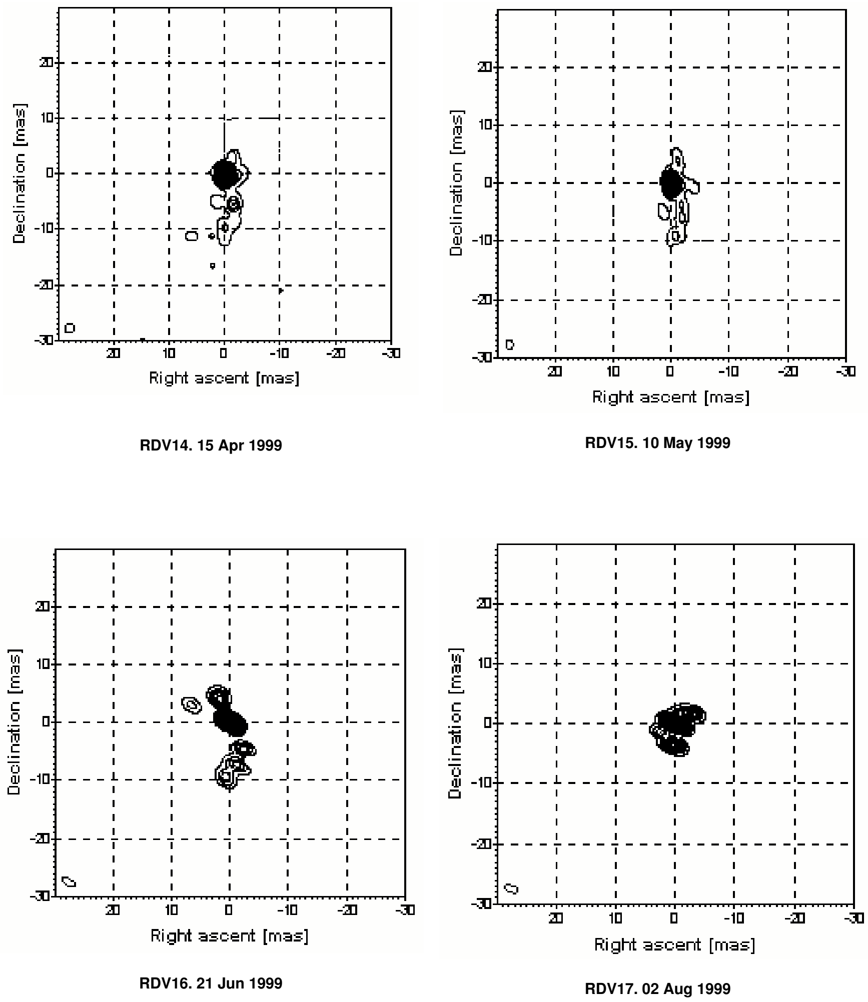

Figure 2: Evolution of the structure of J0017+8135 in the period between April and August 1999.

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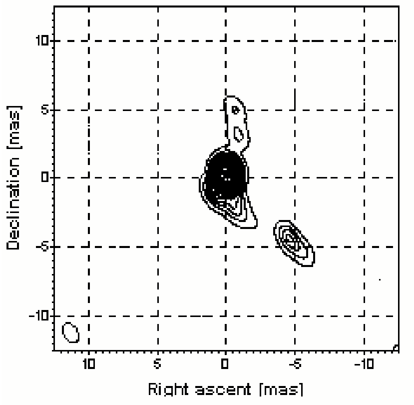
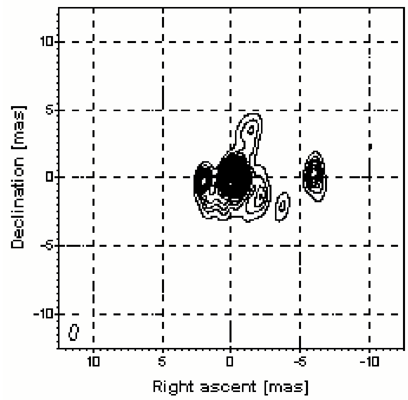
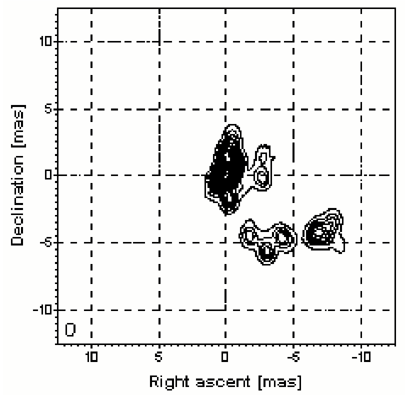


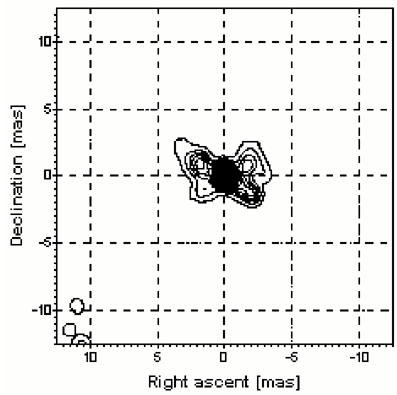
RDV14. 15 Apr 1999



RDV15. 10 May 1999



RDV16. 21 Jun 1999



RDV17. 02 Aug 1999

Figure 3: Evolution of the structure of J1406+2827 in the period between April and August 1999.