Astrophysical Phenomena Revealed by Space VLBI
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Observations of Intraday Variable Sources

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Abstract

Evidence is obtained for relatively rapid motion in an IDV source. We present first results from a VSOP monitoring of BL 2007+77, which reveals structural variability on a 3 week time scale.

1 Introduction

Since its discovery in the mid eighties (Witzel et al. 1986, Heeschen et al. 1987), Intraday Variability (IDV), which is common in about one third of compact flat spectrum radio sources, still poses the question of its physical origin. The variations in total intensity and polarization lead to apparent brightness temperatures of $T_B = 10^{15-21}$ K, largely exceeding the inverse Compton limit ($T_B = 10^{12}$ K). In order to avoid Doppler factors of $D > 100$, which would be required if bulk relativistic motion is the only cause for IDV, models invoking refractive interstellar scintillation (e.g. Rickett et al. 1995; Walker 1998; also Kedziora-Chudczer et al. and Jauncey et al. these proceedings), special shock-in-jet models (Qian et al. 1996a; Spada et al. 1999), and coherent emission mechanisms (Benford & Lesch 1998) are discussed.

In the last years it became clear that sources, which are intrinsically small, must show interstellar scattering effects (cf. Wagner & Witzel, 1995) and that the IDV phenomenon is probably a (frequency dependent) mixture of source intrinsic and propagation effects. However, even if refractive interstellar scintillation is adopted as the main cause of IDV in radio bands, the problem of the small source sizes, which lead to intrinsic brightness temperatures of $> 10^{14}$ K and Doppler factors of $D \geq 100$ remains[1], at least for the more rapid sources like e.g. PKS 0405−38 (Kedziora-Chudczer et al. 1997). Recently, it was suggested that this brightness temperature and Doppler factor could be a factor

[1] In this case T_B scales with D and not with D^3.

Table 1: The Experiments on 2007+77 at 5 GHz

Code	Date	Epoch	Stations	Polarization
V053F1	1998 Mar.10	1998.19	VLBA+Y+HALCA(1)	no
V053F3	1998 Apr. 1	1998.25	VLBA+Y, no HALCA	no
V053F4	1998 Apr. 5	1998.26	VLBA(8)+HALCA(3)	no
W044F1	1999 Sep. 5		VLBA+EB+HALCA	yes
W044F2	1999 Sep. 7		VLBA+EB+HALCA	yes
W044F3	1999 Oct. 2	1999.75	VLBA+EB+HALCA(3)	yes
W044F4	1999 Oct. 4		VLBA+EB+HALCA	yes

Note: HALCA(n) mean data from HALCA with n tracking stations. Y denotes for the VLA, EB for Effelsberg. A missing entry in the third column means not yet fully analyzed.

of 10 lower, if the distance of the scattering screen is reduced (to 25 pc in the case of J1819+38, Dennett-Thorpe & de Bruyn, 2000). However, interstellar scintillation cannot explain the correlated radio-optical IDV, observed in 0954+65 (Wagner et al. 1993) and 0716+71 (Wagner et al. 1996; Qian et al. 1996b).

Evidence for large Doppler factors also comes from the standard synchrotron theory. Homogeneous synchrotron sources with sizes θ of a few to a few ten micro-arcseconds cannot be in equipartition, unless the Doppler factors are larger than $D > 50$ for $\nu_m \leq 22$ GHz. Another argument comes from the magnetic field, which should not decrease below the field induced by the cosmic background radiation. The sources have to be Doppler boosted with $D > 12$ for $\theta < 10\,\mu$as, but with $D > 192$ for $\theta < 5\,\mu$as ! In the frame of incoherent synchrotron theory, this dilemma might be solved, if one either allows a violation of the brightness temperature limit (cf. Kellermann et al. these proceedings) or just higher jet velocities. The latter seem to be detected in at least some sources (e.g. Marscher et al. these proceedings; Kraus et al. 1999).

2 VSOP Observations of IDV Sources

Owing to their high brightness temperature and intrinsic compactness, IDV sources are promising targets for present and future space VLBI observations. The observations of IDV sources therefore got the status of a 'key project' for VSOP. So far, data were obtained for 1803+78

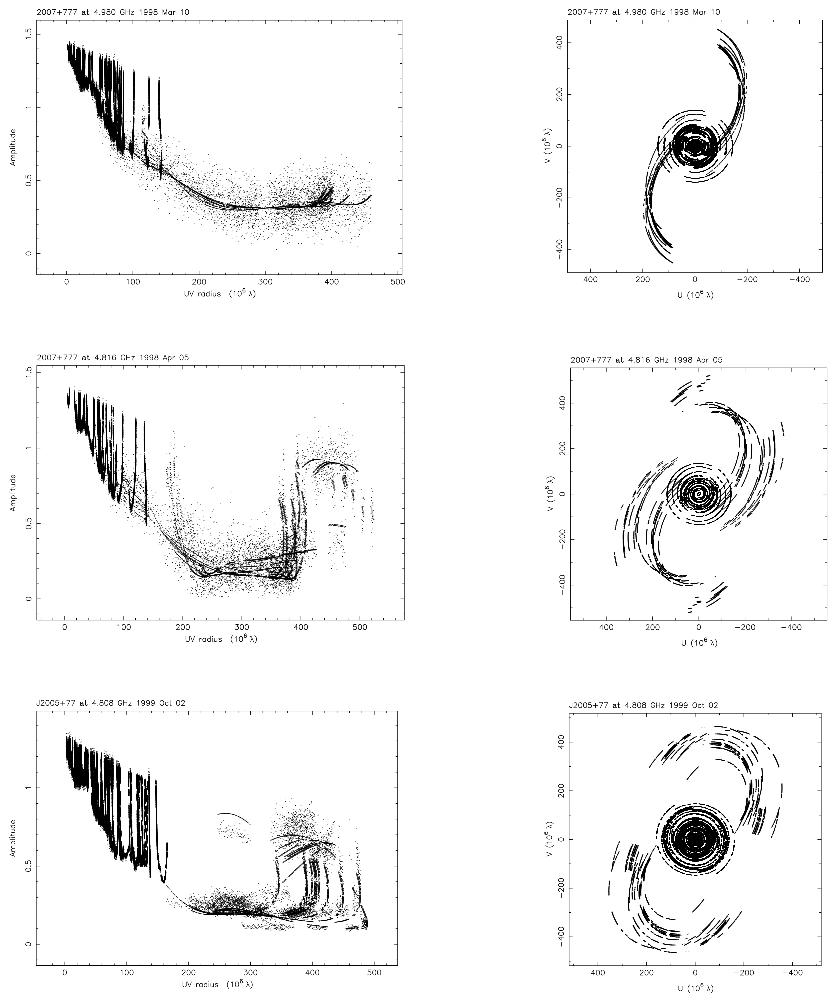

Figure 1: Visibility amplitudes (left) and (u, v)-coverages (right) for the experiments V053F1 (top), V053F4 (center) and W044F3 (bottom). Differences in the (u, v)-coverage could cause differences in the final images or model fits, which could be misinterpreted as structural variability. These uncertainties are reduced, if the data from the ground array are imaged/model fitted first. Although HALCA provides the higher angular resolution and therefore allows to determine positions within the source more accurately, the basic changes of the source structure already became obvious, when only the ground array data were analyzed.

(V053E) and 2007+77 (V053F & W044F). Here we report on VSOP observations of the BL Lac object 2007+77 ($z = 0.342$) during 1998–1999 at 5 GHz. This IDV sources is relatively slow and varies on time scales of a few days (Quirrenbach et al. 2000). The variability amplitudes increase with frequency and in the infrared/optical are by a factor of 5/10 larger than in the radio (Peng et al. 2000a). Table 1 summarizes the observational details. In addition to total intensity (3 epochs during AO1), the source was observed also in polarization and with a more uniform (u, v)-coverage in 1999 (4 epochs in AO2). From AO2, only W044F3 is analyzed so far. Whereas V053F covers timescales of 4, 21 & 26 days, the comparison of these data with W044F3 probes a time scale of 1.6 years. In Figure 1 we show the visibility amplitudes (left) and the (u, v)-coverages (right) for the 3 experiments with HALCA. We note that during March/April 1998 flux density measurements with the 100 m RT at Effelsberg revealed no significant flux density variations of 2007+77 on timescales of days. Between 1998.2 and 1999.8, however, the total flux density decreased by 30 %. During this period, the position angle of the total polarization vector increased from $-40°$ to $-10°$. A change probably corresponding to this, is seen in the ground array maps, which show an increase of the position angle of the axis in the central 1 mas region of the jet. This indicates that the direction of the magnetic field, or the inner jet itself, is slowly rotating towards north. In Figure 2 we show the polarization image obtained from W044F3. The comparison with the remaining 3 polarization observations from AO2 (see Table 1) will clarify, if and how the jet emission evolves in polarization.

The data set of 1998 allows to search for structural variations on timescales of 4 days to ~ 3 weeks. After fringe fitting and careful checks of the amplitude calibration, using two calibrators observed with the ground array, we imaged the sources in basically two ways, with and without HALCA baselines. The source structure was parameterized by circular Gaussian component fitted to the visibilities. Figure 3 shows the high angular resolution maps (beam: 0.4 mas) which include the HALCA baselines. The positions of the Gaussian components are superimposed. The brightest component at the map center ($r = 0$ mas) is used as a reference. We note that between the two maps on top (V053F1 and V053F4), the relative alignment of the 3 western components (the component at $r = 0$ mas, and the two components east and west from it, see Figure 4) has changed on a timescale of only 26 days. Further evidence for structural variability on such timescales comes from the

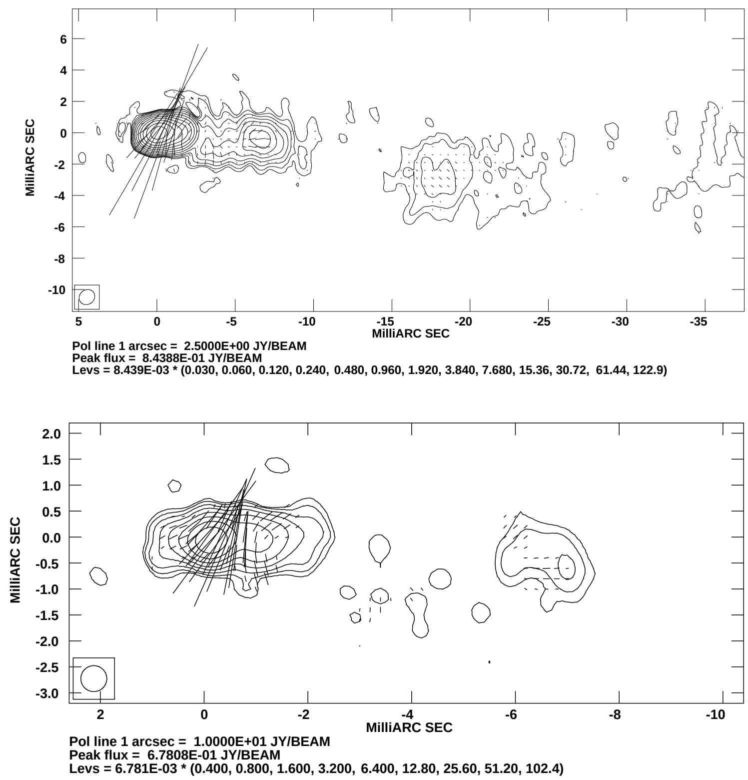

Figure 2: Polarization maps of 2007+77 obtained in 1999.75 at 5 GHz. Top: ground array only. Bottom: including baselines to HALCA.

comparison of the residual images (Figure 5).

In addition to the north-south 'displacement' of the core, the east-west separation of the 2 outer components has increased by 0.11 mas, which corresponds to an angular separation rate of 1.6 ± 0.6 mas/yr or an apparent velocity of $\beta_{app} = 40 \pm 15$ c (for $H_0 = 50$ km s^{-1} Mpc^{-1}, $q_0 = 0.05$). Between 1998 and 1999, a new component appeared near the brightest component (see Figure 3, bottom, and Figure 4). This ejection of a new component was accompanied by a small flux density outburst observed at 5 GHz (Peng et al. 2000b). Using either the beginning (1998.7) or the peak of the flare (1999.2) as time of ejection of this component, a velocity between 7 and 13 c is obtained, consistent with velocities measured earlier (Witzel et al. 1988).

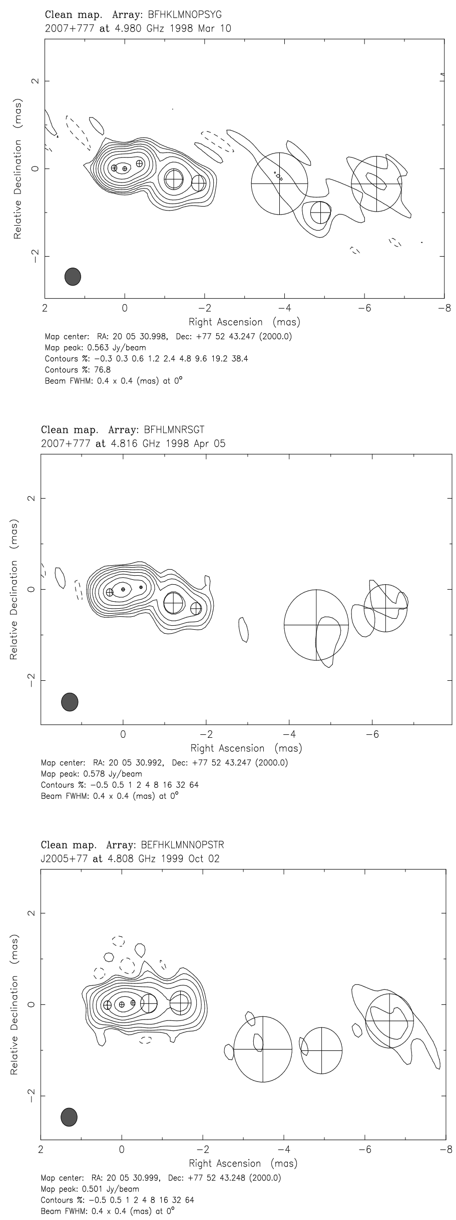

Figure 3: Maps of the Gaussian model fits. All maps are convolved with a circular beam of 0.4 mas size. The observing dates from top to bottom are March 10, 1998, April 5, 1998, and October 2, 1999.

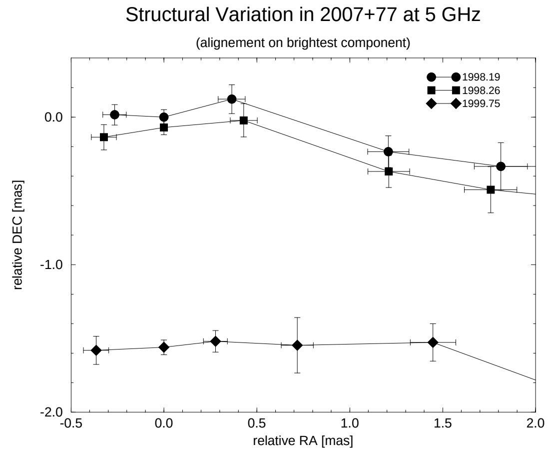

Figure 4: Positions of components in the inner jet region from the 3 VLBI observations. The vertical shifts in declination are proportional to the observing times. The relative alignment in right ascension is arbitrary, with the brightest component located at the map center at $r = 0$.

In Figure 6 we plot the brightness temperature along the jet axis, derived from the Gaussian model fits. For the brightest component ('the core'), which remained unresolved on ground-to-space baselines, the lower limit to the brightness temperature varied between $T_B \geq 7.7 \cdot 10^{12}$ K in 1998.19 and $T_B \geq 2.1 \cdot 10^{12}$ K in 1999.75. This clearly indicates time variable bulk relativistic motion with Doppler factors $D > 2.1$, respectively $D > 7.7$. An order of magnitude larger values of D would be obtained, if the brightness temperature limit is not 10^{12} K, but is lower, e.g. $\sim 10^{11}$ K as required from energy equipartition. We note that the component 0.3 mas east of 'the core' has a brightness temperature below 10^{12} K, either indicative of synchrotron self-absorption at the jet base (likely), or presence of a counter-jet (unlikely).

The determination of the jet velocity depends on the component registration at different epochs and on the assumption of the stationarity of the reference point. At present, it is difficult to determine the source kinematics unambiguously. Scenarios in which the assumption of the stationarity of the core component is dropped lead to a different component identifications and to velocities in the range of $4 \leq \beta_{app} \leq 21$. The higher velocity values are obtained, if the most eastern jet component is regarded as the 'self-absorbed' core.

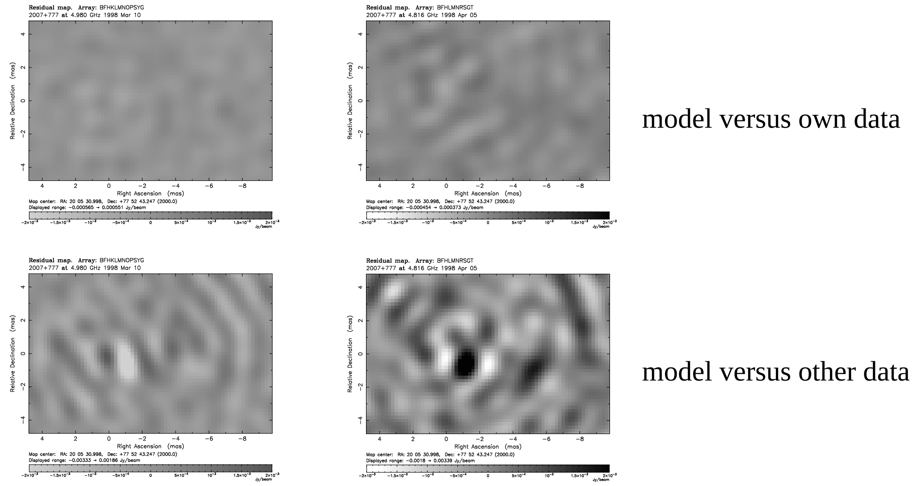

Figure 5: Comparison of the residual maps from epochs 1998.19 (V053F1, data set 1) and 1998.26 (V053F4, data set 3). The maps on top show the residuals between data and model set 1 (left) and data and model set 3 (right). Below the residuals are shown after data and model were exchanged. Plotted are data set 1 versus model set 3 (left) and data set 3 versus model set 1 (right). Structural variability between the two epochs show up as enhancements or depressions of the residual flux.

3 Summary

As a tentative result we conclude, that in 2007+77 structural variations on time scales of a few weeks, are detected. So far, no variations are detected on a timescale of a few days, which is consistent with the stationarity of the total flux during the observations. Variations appear in flux and position, position variations are along and transverse to the jet axis. The brightest component (core) is probably not stationary. The analysis of the other VSOP observations of 1999 (see Table 1) will resolve the remaining ambiguities for the component identification and will answer the question, if the velocities in 2007+77 are higher than previously thought. Of particular interest will be the search for changes of the orientation of the polarization vector on mas-scales. The rotation of the jet axis to the north, which was accompanied by a rotation of the polarization vector of the total flux, let us expect to detect polarization changes on mas-scale, also on short times scales.

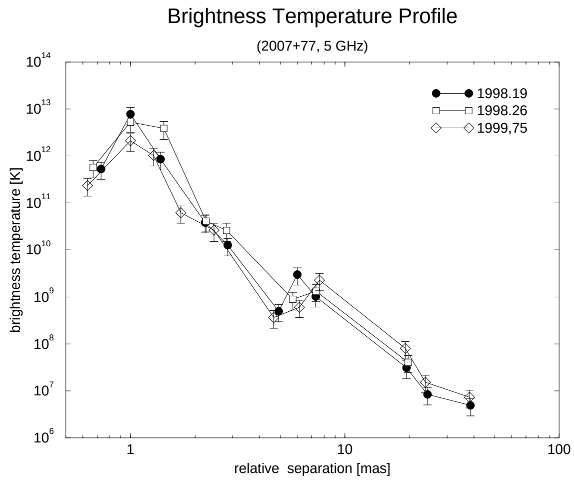

Figure 6: The brightness temperature profile along the jet axis. The individual values of the brightness temperatures of the components were calculated from the parameters of the Gaussian component model fits.

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