Abstract.
To locate and image the compact emission regions in quasars, which are closely connected to the phenomenon of IntraDay Variability (IDV), space VLBI observations are of prime importance. Here we report on VSOP observations of two prominent IDV sources, the BL Lac objects S5 0716+714. To monitor their short term variability, these sources were observed with VSOP at 5 GHz in several polarisation sensitive experiments, separated in time by one day to six days, in autumn 2000. Contemporaneous flux density measurements with the Effelsberg 100m radio telescope were used to directly compare the single dish IDV with changes of the VLBI images. A clear IDV behaviour in total intensity and linear polarization was observed in 0716+714. Analysis of the VLBI data shows that the variations are located inside the VLBI core component of 0716+714. In good agreement with the single-dish measurements, the VLBI ground array images and the VSOP images, both show a decrease in the total flux density of $\sim 20$ mJy and a drop of $\sim 5$ mJy in the linear polarization of the VLBI core. No variability was found in the jet. These findings are supported by VLBA observations of five IDV sources, including 0716+714, in December 2000, that show a similar behaviour. From the variability timescales we estimate a source size of a few micro-arcseconds and brightness temperatures exceeding $10^{15}$ K. Independent of whether the interpretation of the IDV seen in the VLBI core is source intrinsic or extrinsic a lower limit of $T_B > 2 \times 10^{12}$ K is obtained by model fitting of the VLBI-core. Our results show that future VSOP2 observations should be accompanied by a single dish monitoring not only to discriminate between source-extrinsic (interstellar scintillation) and source-intrinsic effects but to allow also a proper calibration and interpretation of ultra-high resolution VSOP2 images.

1. Introduction
Since the discovery of intraday variability (IDV, i.e. flux density and polarization variations on time scales of less than 2 days) about 20 years ago (Witzel et al. 1986; Heeschen et al. 1987), it has been shown that IDV is a common phenomenon among extra-galactic compact flat-spectrum radio sources. It is detected in a large fraction of this class of objects (e.g. Quirrenbach et al. 1992; Kedziora-Chudczer et al. 2001; Lovell et al. 2003, see also D. Jauncey et al.; H. Bignall et al., these proceedings). The occurrence of IDV appears to be correlated with the compactness of the VLBI source structure on milliarcsecond scales: IDV is more common and more pronounced in objects dominated...
by a compact VLBI core than in sources that show a prominent VLBI jet. In parallel to the variability of the total flux density, variations in the linearly polarized flux density and the polarization angle have been observed in many sources (e.g., Quirrenbach et al. 1989; Kraus et al. 1999, 2003; Qian & Zhang 2004). The common explanation for the IDV phenomenon at cm-wavelength is nowadays interstellar scattering (e.g., Rickett et al. 1993; Rickett 2001b). On the other hand some effects remain that cannot be easily explained by interstellar scintillation and that are probably caused by relativistic jet physics (e.g., Qian et al. 1996, 2002; Qian & Zhang 2004). For example the correlated intra-day variability between radio and optical wavelengths, which is observed in sources like 0716+714 and 0954+658 (e.g. Wagner et al. 1990; Quirrenbach et al. 1991; Wagner et al. 1996) and the recent detection of IDV at millimetre wavelengths in 0716+714 (Krichbaum et al. 2002; Kraus et al. 2003; Agudo et al. 2006; Fuhrmann et al. 2008) suggests that at least part of the observed IDV has a source-intrinsic origin.

Independent of the physical cause of IDV, it is obvious that IDV sources must contain one or more ultra-compact emission regions. Using scintillation models, typical source sizes of a few ten micro-arcseconds have been derived (e.g., Rickett et al. 1993; Dennett-Thorpe & de Bruyn 2002; Bignall et al. 2003). In the case of source intrinsic variability and when using the light-travel-time argument, even smaller source sizes of a few micro-arcseconds are obtained. In this case it implies apparent brightness temperatures of up to $10^{18}$–$10^{19}$ K (in exceptional cases up to $10^{21}$ K), far in excess of the inverse Compton limit of $10^{12}$ K (Kellermann & Pauliny-Toth 1969). These high apparent brightness temperatures can be reduced e.g. by relativistic beaming with high Doppler-factors (e.g., Qian et al. 1991, 1996; Kellermann 2002).

The motivation of this VLBI monitoring, therefore, was to find how rapid structural variability on sub-mas-scales occurs and where the IDV component is located in the jet. An array of 12 antennas consisting of the 10 stations of NRAO’s VLBA, the 100 m radio telescope of the Max-Planck-Institut für Radioastronomie in Effelsberg (Germany), and the 8 m HALCA antenna of the VSOP was used to follow the short-term variability of 0716+714 and 0954+658 at 5 GHz in autumn 2000. During short gaps in the VLBI schedule the Effelsberg antenna was used to measure the light curve of a calibrator and our target sources. A detailed description of the experiment and data reduction can be found in Bach et al. (2006). Here we will concentrate on the results of 0716+714, the results of 0954+658 will be presented by Bernhart et al. (in prep.).

2. Results and Discussion

The ground array and the VSOP images of 0716+714 show a bright core and a jet oriented to the north (Fig. 1). The linear polarization images indicate that the jet magnetic field is perpendicular to the jet axis. Compared to the jet axis, the electric vector position angle in the core is misaligned by around 60°. This is explained either by opacity effects in the core region or by a curved jet. Here, jet curvature is supported by recent high resolution 3mm VLBI observations that show the inner jet structure ($r < 0.1$ mas) at a similar position angle as the EVPA in the core at 6 cm wavelength (Bach et al. 2006).
Simultaneous flux-density measurements with the 100 m Effelsberg telescope during the VSOP observations revealed variability in total intensity (∼ 5 %) and in linear polarization (up to ∼ 40 %) accompanied by a rotation of the polarization angle by up to 15 °. The analysis of the VLBI data shows that the intra-day variability in 0716+714 is associated with the VLBI-core region and not with the milli-arcsecond jet. Both the ground array and the VSOP maps show a similar decrease of the flux densities in total intensity and linear polarization of the core component, which is in good agreement with the variations seen with the Effelsberg radio-telescope (more details are given in Bach et al. 2006). These findings could be confirmed by VLBA observations of five IDV sources, including 0716+714, a few month later in December 2000, that show a similar behaviour (Impellizzeri et al. in perp.). In this, 0716+714 displays a behaviour that is similar to what was previously observed in the IDV sources 0917+624 and 0954+658, where components in or near the VLBI core region were also made responsible for the IDV (Gabuzda et al. 2000b). Over the time interval of our VSOP observations, no rapid variability in the jet was observed and we cannot confirm the variability outside the core and in the jet found by Gabuzda et al. (2000a).

The simultaneous variation of the polarization angle with the polarized intensity in the core suggests that the variations might be the result of the sum of the polarization of more than one compact sub-component on scales smaller than the beam size (multi-comp. model). Assuming a redshift of z = 0.3 (Wagner et al. 1996) and that these variations are intrinsic to the source, we derived brightness temperatures of ∼ 3 \times 10^{15} \text{K} to ∼ 10^{16} \text{K}. Doppler factors of > 20 are needed to bring these values down to the inverse-Compton limit. These numbers agree with the observed speeds in the jet if the angle to the line of sight is very small (θ < 2°), as already proposed by Bach et al. (2005). Because of the unknown redshift, the derived speeds and brightness temperatures represent only lower limits.

Figure 1. **Left:** Single dish polarization variability of 0716+41 on Oct. 4 and 5. **Middle and right:** VSOP contour maps of Stokes I of 0716+714 with polarization vectors superimposed (1 mas corresponds to 6.7 mJy/beam). Contours start at 1.8 mJy/beam increasing in steps of 2. A clear drop in polarized flux (shorter vectors) and a rotation by 10° is visible in the core region from Oct. 4 to 5.
However, interstellar scintillation effects could also explain the IDV seen in the VLBI core, if the core region consists of several compact and polarized sub-components, with sizes of a few ten micro-arcseconds. To explain the observed polarization variations, the sub-components must scintillate independently in a different manner, which means that they must have slightly different intrinsic sizes and intrinsic polarization (e.g. Rickett 2001b,a).

Independent of whether the interpretation of the IDV seen in the VLBI core is source intrinsic or extrinsic, the space-VLBI limit to the core size (<0.1 mas) gives a robust lower limit to the brightness temperature of $\geq 2 \times 10^{12}$ K and therewith exceeds the inverse-Compton limit. This implies a lower limit to the Doppler factor of about $\geq 4$ and, independent of the model we use to explain the variability, relativistic beaming must play a role.

The increased sensitivity, higher resolution, and frequency flexibility of VSOP-2 will provide a powerful tool to look even deeper into the core region and to distinguish which fraction of the IDV is due to source intrinsic variations and which is caused by the interstellar medium. Variability surveys like MASIV (Lovell et al. 2003) revealed that IDV is present in a huge number of sources and therefore it seems advisable that future VSOP2 experiments are accompanied by a simultaneous flux monitoring to allow a proper calibration of the data and to interpret possible structural changes on short time scales.

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