High Angular Resolution Monitoring of Prominent AGN at 86 GHz

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Introduction

Synchrotron-self absorption in the inner regions of AGN-jets at cm-wavelengths and a stronger source activity (variability of flux density and jet structure) at mm-wavelengths are two of the main motivations to study AGN with VLBI at mm-wavelengths. While VLBI imaging at 1 and 2 mm is not yet feasible (see Doeleman & Krichbaum, this conference), 3 mm-VLBI now provides high angular resolution images with a dynamic range better than 100:1 for the brightest sources. With the growing number of antennas participating in global CMVA (Coordinated Millimeter VLBI Array) experiments, more detailed studies of compact radio sources, which were imaged previously only with small arrays (3-5 stations), are possible. Here we present some new results from our ongoing 3 mm-VLBI monitoring of 3C 273 and 3C 454.3.

Results for 3C 273

We observed 3C 273 in January 1994 (4 stations), March 1995 (5 stations, including for the first, time Plateau de Bure), January 1996 (5 stations, including for the first, time Pie Town), and April 1997 (10 stations, including Sest). The maps of 1994 and 1995 show a south-west oriented core-jet structure of ~ 2 mas length, with at least two components receding at superluminal speeds from the core (Krichbaum et al. 1997 & 1998). VLBA observations of 3C 273 at 22 and 43 GHz by Marscher et al. in 1995.15 is sufficiently close to our observation in 1995.18 to allow a detailed comparison. In Figure 1 both maps are displayed. Dashed lines connect the location of individual jet components, obtained from Gaussian model fitting. The astoundingly good agreement of the component positions relative to the core in both maps demonstrates (i) the reliability of the 3 mm map, which results from a much smaller VLBI array than the 7 mm map, and (ii) allows an estimate of opacity effects and spectrum along the inner jet. The core and the component located at $r \sim 1.5$ mas exhibit inverted spectra ($\alpha_{43/86\text{GHz}} = 0.4 \ldots 0.7$, $S_\nu \propto \nu^{\alpha}$), whereas the spectra of the other components are steep ($\alpha_{43/86\text{GHz}} = -0.3 \ldots -1.0$, Figure 1, right panel). The relative offsets of the positions of the components at the two frequencies are small, typically $\leq 0.1$ mas. This is consistent with an optically thin jet with only small opacity position shifts in the individual components.

The new maps obtained in 1996 and 1997 are shown in Figure 2. The increased number of participating antennas has resulted in the improved uv-coverage and dynamic range of the images (dynamic range $\geq 300 : 1$). The 1996 map indicated, for the first time, the existence of faint jet emission beyond 2 mas core-separation. This emission is confirmed and better visible in the map of 1997, which shows faint emission even beyond the map area displayed here. The limited closure information for the short uv-spacings and remaining calibration uncertainties may cast some doubt on the reality of all details visible in the jet on mas-scales. However, we believe that the basic jet structure is represented correctly. To check this, we superimpose a nearly simultaneously observed 15 GHz map (from the 2 cm survey, Kellermann et al., 1998) on the 3 mm map in Figure 2 (right panel).

The emission at 15 and 86 GHz track each other well. For the inner 3–4 mas jet, the 86 GHz emission is located at the center of the jet seen in the 15 GHz map, indicating a central spine or

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1 A joint project of scientists at MPIfR, IRAM and Haystack
Figure 1. **Left:** 3C 273 at 43 GHz (top left) and 86 GHz (bottom left). Contour levels are -0.5, 0.5, 1, 2, 5, 10, 15, 30, 50, 70, and 90% of the peak flux density of 5.4 Jy/beam (top) and 4.7 Jy/beam (bottom). The restoring beam size for both maps is 0.4 x 0.4 mas, oriented at $\alpha = 0^\circ$. The data for the 43 GHz map were kindly provided by Alan Marscher. **Right:** Spectral index ($S_\nu \propto \nu^\alpha$) plotted versus core separation for the components marked by dashed lines on the left.

ridgeline with a smaller transverse width at higher frequencies (center brightening). At larger core separations, both the 15 and 86 GHz emission are displaced more to the south. At 86 GHz this bend is stronger than at 15 GHz. This suggests edge brightening, with an opacity shift such, that the 86 GHz emission is closer to the jet boundary than the emission at 15 GHz.

**Results for 3C454.3**

The OVV quasar 3C 454.3 was observed in 1996 and 1997, in the same experiments as 3C 273. Previous 3 mm maps showed an east-west oriented and slightly bent core-jet structure with two superluminally moving (~6 c) components embedded in a more diffuse underlying jet (Krichbaum et al., 1996 & 1997). Near the core, the apparent motion is slower than at larger core separations (10–22 c observed on a 2–7 mas scale), but follows the general velocity gradient (cf. Pauliny-Toth, 1998). The new 3 mm-maps are shown in Figure 3 (left panel). Whereas the map of 1996 (top) shows a relatively straight jet of 2–3 mas length, the map of 1997 (bottom) shows jet curvature to the south and then, beyond $r = 1.5 – 2.0$ mas, bending back towards north. We note that a sinusoidal jet path was suggested by Pauliny-Toth as a possible explanation of the observed velocity variations in the outer mas-jet. The change of jet orientation near 2 mas is also seen in a 15 GHz map, observed in 1997.19 (Kellermann et al., 1998). A superposition of this map with the 86 GHz map is shown in Figure 3 (right panel). It is seen that the overall positional agreement between the
jet at 15 and 86 GHz is not as good as for 3C 273 (see Figure 2). This may be due to different opacity effects in the two sources. We note that in 3C 454.3 the largest offsets between the two frequencies appear at a core separation of 2 – 3 mas. It is possible that opacity effects could cause frequency dependent offsets between the mean jet axis at 15 and 86 GHz. These offsets would depend on the viewing angle and could become more pronounced in regions of stronger jet curvature. The complexity of the source structure in 3C 454.3, the still limited uv-coverage (3C 454.3 was observed during one day, 3C 273 was observed on 3 consecutive days with redundancy), and remaining calibration uncertainties, however, require further observations in order to confirm this effect.

Conclusion

With up to 12 antennas participating in global CMVA experiments, maps with dynamic ranges of 300 to 500:1 can be made. For sources with long jets, like 3C 273 and 3C 454.3, the jet emission at relative large core separations is detectable, if short uv-spacings (100-1000 km) are available. Since at 3 mm the beam size is small (0.04 – 0.1 mas), relatively wide fields have to be mapped (> 50 – 100 beam sizes). For a better imaging of these complex structures in the future, a better uv-coverage on short and intermediate uv-spacings is needed. With regard to this, the participation of the ‘central’ antennas of the VLBA (PT, LA, FD, NL), and the short uv-spacings from the baseline Haystack–Quabbin and the European subarray (Metsahovi–Onsala–Effelsberg, Pico Veleta–Plateau de Bure)
Figure 3. **Left:** 3C 454.3 at 86 GHz observed in 1996.08 (top) and 1997.28 (bottom). Contour levels in both maps are -0.2, 0.2, 0.5, 1, 2, 5, 10, 15, 30, 50, 70, and 90% of the peak flux of 0.9 Jy/beam (top) and 1.2 Jy/beam (bottom). The restoring beam size is 0.25 x 0.1 mas, oriented at $\text{pa} = 0^\circ$. **Right:** The uv-coverage at 86 GHz for 1997.28 (top). Below the superposition of two nearly simultaneously observed maps at 15 GHz (contours) and at 86 GHz (grey scale) at epoch 1997.2. Contour levels are -0.1, 0.1, 0.3, 0.5, 1, 2, 5, 10, 15, 30, 50, 70, and 90% of the peak flux density of 3.9 Jy/beam at 15 GHz. Both maps are convolved with a beam of 1.1 x 0.5 mas size, oriented at $\text{pa} = 0^\circ$.

will be of particular importance. The addition of the phased interferometers (BIMA, OVRO, Plateau de Bure) within the next few years will help to improve the sensitivity of the whole array by at least a factor of 2–3. With an expected single-baseline detection sensitivity of $50-100$ mJy on baselines to and between the phased interferometers (present threshold: $>250$ mJy), the number of observable sources and the quality of images should increase dramatically.

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