mm-VLBI: Jets in the Vicinity of Galaxy-Cores

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Abstract. Millimeter-VLBI provides an angular resolution of up to a few tens of microarcseconds and allows imaging of compact radio sources, self-absorbed at longer wavelengths, with unsurpassed angular resolution. At 43 GHz the participation of the VLBA and the 30 m-MRT at Pico Veleta (e.g. Krichbaum *et al.*, 1993 a&b), and at 86 GHz the addition of the 100 m-RT at Effelsberg and the 30 m-MRT (Schalinski *et al.*, 1993, and this volume) have improved the imaging capabilities of mm-VLBI observations.

Results: The increased sensitivity of mm-VLBI observations allows the investigation of fainter objects, previously not accessible. As one example we show in Fig.1 the first detection of the compact radio source Sgr A* in the Galactic Center with VLBI at 43 GHz in May 1992 (Krichbaum *et al.*, 1993d) and at 86 GHz in April 1993 (Krichbaum *et al.*, 1994). In both observations the size of Sgr A* appeared to be larger than its expected scattering size, indicative of intrinsic source structure showing up at mm-wavelengths. Future monitoring with mm-VLBI is necessary to search for (not unexpected) structural variability.

Monitoring of AGN with mm-VLBI reveals in all cases observed in sufficient detail jet curvatures of increasing amplitude towards the self-absorbed VLBI-cores (e.g. in 1803+784: Krichbaum, 1990, OJ 287: Krichbaum *et al.*, 1993c), and sub- or superluminal motion along 'quasi-helically' bent trajectories (e.g. 3C 84: Krichbaum *et al.*, 1993b; 3C 273: Krichbaum *et al.*, 1993c), which differ sometimes for adjacent jet components (e.g. 3C 345: Krichbaum & Witzel, 1992, Krichbaum *et al.*, 1992&1993a). In 3C 84, 3C 273 and 3C 345 the apparent velocity of jet components varies systematically along the jet axis, in 4C 39.25 (Alberdi *et al.*, 1993) a moving component decelerates and brightens, all of this suggesting differential Doppler boosting and motion along three-dimensionally curved trajectories. In 3C 345 the complex kinematics of C4 and C5 (Zensus, this volume) has been geometrically modeled by motion along a helical path on the surface of a conical jet (Qian *et al.*, 1992, Steffen *et al.*, 1993, and this volume; see also Camenzind, this volume). As a new example, the oscillations of the inner jet and its velocity variations $\beta_{app}(r)$ are shown for the BL Lac object 1803+784 in Fig. 2 (see the maps in: Krichbaum *et al.*, 1993b). The frequent occurence of 'quasi-sinusoidal' bends in the inner jets of very different classes of AGN (QSO's, BL Lac's, Seyfert's) suggests that this effect is common in a large fraction of AGN and that the underlying jet-physical process may be fundamental for the understanding of the creation of jets.

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References

Alberdi, A., Krichbaum, T.P., Marcaide, J.M., *et al.*, *A&A*, **271**, 93.
Krichbaum, T.P., 1990, in: *Parsec-scale radio jets*, ed. J. A. Zensus and T. J. Pearson (Cambridge University Press), p. 83.
Krichbaum, T.P., and Witzel, A., 1992, in: *Variability of Blazars*, ed. E. Valtaoja and M. Valtonen (Cambridge University Press), p. 205.
Krichbaum, T.P., Witzel, A., Graham, D.A., Zensus, J.A., 1992, in: *Physics of Active Galactic Nuclei*, ed. W.J. Duschl and S.J. Wagner (Springer, Heidelberg), p. 574.
Krichbaum, T.P., Witzel, A., Graham, D.A., *et al.*, 1993a, *A&A*, **275**, 375.
Krichbaum, T.P., Witzel, A., Graham, D.A., *et al.*, 1993b, in: *Sub Arcsecond Radio Astronomy*, ed. R.J. Davis and R.S. Booth, Cambridge University Press, p. 181.
Krichbaum, T.P., Witzel, A., Graham, D.A., 1993c, in: *Jets in Extragalactic Radio Sources*, ed. H.-J. Röser and K. Meisenheimer (Springer, Heidelberg), p. 71.

T. J.-L. Courvoisier and A. Blecha: Multi-Wavelength Continuum Emission of AGN, 187–188.

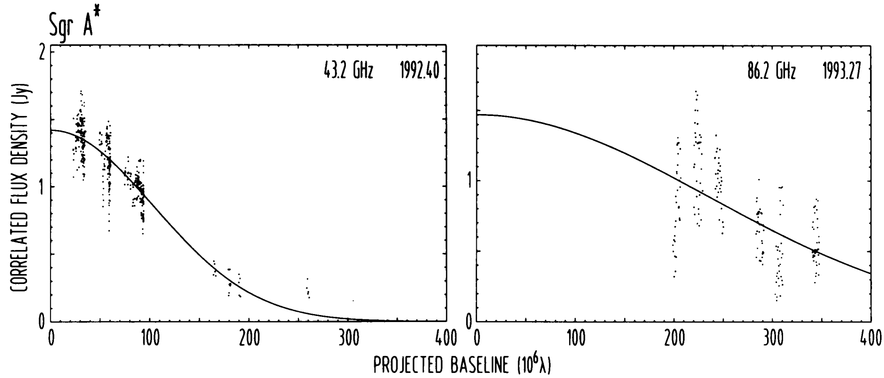

Fig. 1. Correlated flux density of Sgr A* plotted versus projected uv-distance (left: at 43 GHz, right: at 86 GHz). The solid line represents a circular Gaussian component fit to the data with flux density and size (FWHM) of $S_{43\,GHz} = (1.42 \pm 0.10)$ Jy, $\theta_{43\,GHz} = (0.75 \pm 0.08)$ mas, respectively $S_{86\,GHz} = (1.47 \pm 0.75)$ Jy, $\theta_{86\,GHz} = (0.33 \pm 0.14)$ mas. The corresponding brightness temperatures are $T_B(43\,GHz) = 1.7 \cdot 10^9$ K, and $T_B(86\,GHz) = 2.2 \cdot 10^9$ K. The scattering sizes extrapolated from VLBI observations at $\nu \leq 22$ GHz are $\theta^{scat}_{43\,Ghz} = 0.53 \pm 0.02$ mas and $\theta^{scat}_{86\,Ghz} = 0.13 \pm 0.01$ mas, both smaller than the source sizes given above (Krichbaum *et al.*, 1993d&1994). Note that at $r_0 = 8.5$ kpc an angle of 0.1 mas corresponds to $1.3 \cdot 10^{13}$ cm = 0.9 AU.

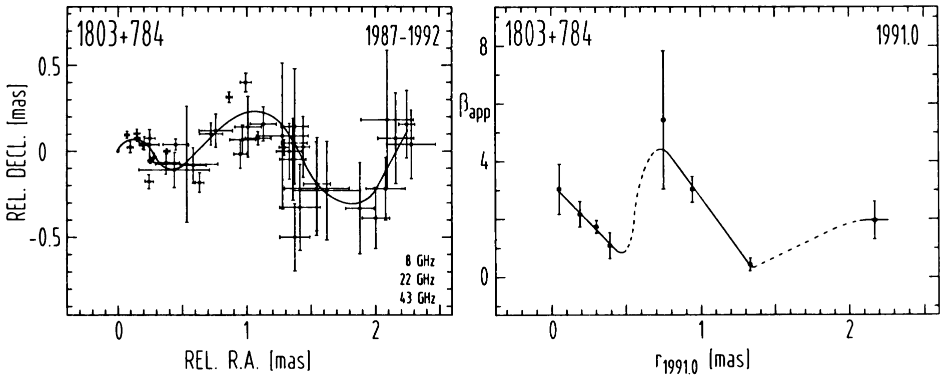

Fig. 2. Left: Relative positions of the VLBI components of the inner jet of 1803+784, obtained between 1987-1992 at 8, 22, and 43 GHz with respect to the stationary assumed VLBI-core. Data at 8 GHz are from Britzen et al., this volume. Right: Apparent velocity β_{app} ($z = 0.864$, $H_0 = 100$ km s^{-1} Mpc^{-1}, $q_0 = 0.5$) of the jet components plotted versus core-separation at epoch 1991.0. The oscillations of the 'mean jet-axis' and the systematic variations of $\beta_{app}(r)$ along the jet strongly indicate motion along a three-dimensionally bent path, e.g. a helically bent jet.

Krichbaum, T.P., Zensus, J.A., Witzel, A., *et al.*, 1993d, *A&A*, **274**, L37.
Krichbaum, T.P., Schalinski, C.J., Witzel, A., *et al.*, 1994, in: *The Nuclei of Normal Galaxies: Lessons from the Galactic Center*, ed. R. Genzel (Kluwer, Dordrecht), in press.
Qian, S.J., Witzel, A., Krichbaum, T.P., *et al.*, 1992, *Chin. Astron. Astrophys*, **16/2**, 137.
Schalinski, C.J., Greve, A., Grewing, M., *et al.*, 1993, in: *Sub Arcsecond Radio Astronomy*, ed. R.J. Davis and R.S. Booth, Cambridge University Press, p. 184.
Steffen, W., Krichbaum, T.P., Witzel, A., Zensus, J.A., in: *Sub Arcsecond Radio Astronomy*, ed. R.J. Davis and R.S. Booth, Cambridge University Press, p. 363.