FIRST DETECTION OF SGR A* WITH VLBI AT 7 MM AND 3 MM WAVELENGTH

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1. Introduction

An angular resolution of up to a few tens of a microarcsecond at present only can be achieved by mm-VLBI observations. Compact – inverted- or flat spectrum – radio sources self-absorbed at cm-wavelengths, become optically thin at mm-wavelengths, and the effects of refractive scattering decrease in the mm-band. Therefore mm-VLBI allows to directly image the innermost regions of compact radio sources with highest angular resolution (at $r_0 = 8.5$ kpc 100μas correspond to $1.3 \cdot 10^{13}$ cm $=$ 0.9 AU) and makes them accessible for more detailed investigations (e.g. Krichbaum & Witzel, 1992).
At 43 GHz the participation of the VLBA and Pico Veleta (e.g. Krichbaum *et al.*, 1993b & 1993c), and at 86 GHz the addition of the 100 m-RT and the 30 m-MRT (see Tab.1) has improved the imaging capabilities of mm-VLBI observations (Schalinski *et al.*, 1993). Here we report on the first detection of the compact radio source Sgr A* in the galactic center with VLBI at 43 and 86 GHz.

TABLE I
Antenna specifications at 86 GHz

Station	Location	Code	D [m]	T_{sys} [K]	η_A [%]	Gain [K/Jy]	Rec.
Effelsberg	Germany	B	60	200	13	0.13	CS
Pico Veleta	Spain	X	30	180	55	0.14	SIS

CS = Cooled Schottky-Diode mixer, SIS = Cooled SIS-tunnel-junction mixer.
For the 100m-telescope in Effelsberg the illuminated diameter is given.

2. VLBI Observations at $\lambda = 7$ mm

Sgr A* was observed on May 27&28, 1992 with global VLBI at 43 GHz for 2 x $\sim$ 4 hrs. The source was detected with signal-to-noise ratios of up to $SNR = 45$ on 6 VLBA-baselines (4 antennas). Details of the observations and the data analysis are described in Krichbaum *et al.*, 1993a. Figure 1 summarizes the basic result of this first 43 GHz VLBI detection of Sgr A*: based on the analysis of closure phases and visibility amplitudes some evidence for an elongation on milliarcsecond-scales $\sim 60°$ inclined versus the galactic plane was obtained, which recently was interpreted as evidence for a scaled down version of an AGN-type jet (Falcke *et al.*, 1993).

R. Genzel and A. I. Harris (eds.), The Nuclei of Normal Galaxies, 411–414.

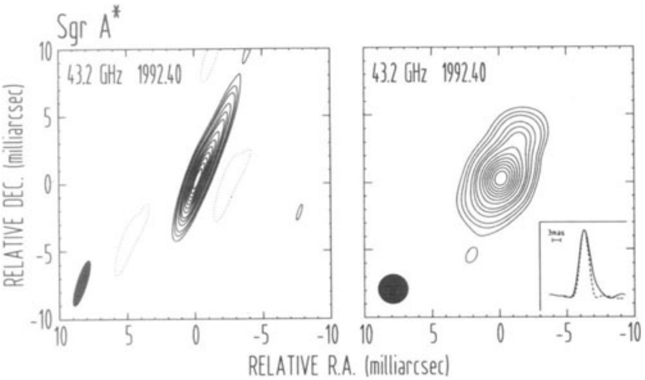

Fig. 1. *Left:* CLEAN-map of Sgr A* at 43 GHz, convolved with its canonical elliptical beam (3.6 x 0.7 mas, *P.A.* = $-18°$). Contour levels in both maps are -1.5, 1.5, 3, 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, and 90 % of the peak flux density of 0.81 Jy/beam. *Right:* Map convolved with a circular beam of 2.2 mas size, corresponding to the mean of the major and minor axis of the canonical beam. The insert shows cuts through the source structure along the elongation (solid line) and perpendicular to it (dashed line).

3. VLBI Observations at $\lambda = 3\,\mathrm{mm}$

In April 1993 we performed a global 3 mm-VLBI campaign, in which the antennas at Effelsberg (100 m), Pico Veleta (30 m), Onsala (20 m), Haystack (37 m) and Quabbin (15 m) participated. Based on a now considerably improved detection sensitivity, this observation led to first detections for ~ 20 new objects with total flux densities $S_{86\,GHz} \geq 2$ Jy.

Within this 86 GHz VLBI experiment Sgr A* was observed on April 8, 1993, on the baseline Effelsberg to Pico Veleta and detected with signal-to-noise ratios of up to 20 in 5 adjacent scans, each of 6.5 min duration (MK III, mode A, 112 MHz bandwidth). At mm-wavelengths changing weather conditions (and antenna pointing errors) can affect the amplitude calibration. We therefore checked our calibration using adjacent observations of NRAO 530 and 1749+096, which led to consistent station gain corrections. In Figure 2 the correlated flux density of Sgr A* at 43 and 86 GHz is plotted versus projected uv-distance.

The absolute flux density scale at 86 GHz was established with the 30 m-MRT, using the planets. With a flux density of NRAO 530 $S_{86GHz} = (6.4 \pm 0.6)$ Jy, we obtain for Sgr A $S_{86\,GHz} = (7.7 \pm 0.7)$ Jy (within 30" beam size). Correction for confusion by extended emission of Sgr A-West yields $S_{86\,GHz} = (2.1 \pm 1.3)$ Jy for Sgr A* (using $S = 5.6$ Jy contribution from free-free emission within 30" (Wright *et al.*, 1987)). Within the errors, this is consistent with the results shown in Fig.2 and with the spectrum of Sgr A* (P.G. Mezger, this volume).

4. Discussion

The above results demonstrate that mm-VLBI observations of the compact galactic center radio source are now possible. The data shown here were obtained using new (partly not finally calibrated) instruments and therefore still may be affected by unrecognized systematic calibration errors. At present anything beyond the detection of Sgr A*, is tentative and remains subject to further confirmation.

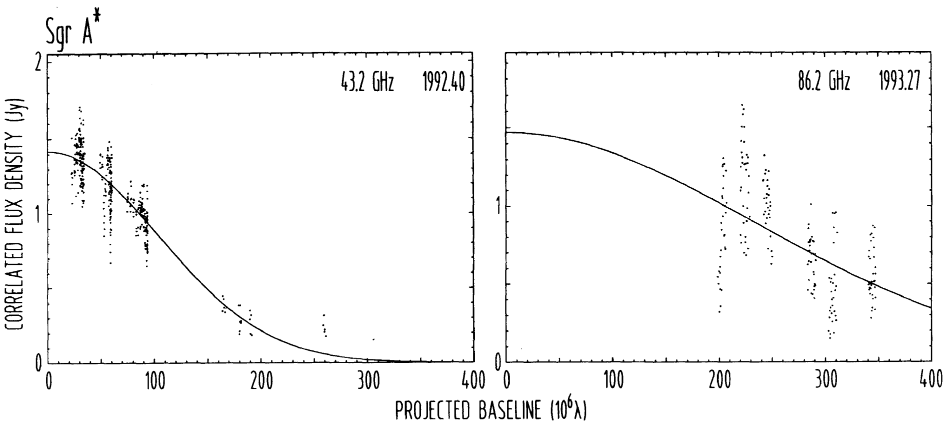

Fig. 2. Correlated flux density of Sgr A* plotted versus projected uv-distance (left: at 43 GHz, right: at 86 GHz). The solid line represents a circular Gaussian component fit to the data with flux density and size (FWHM) of $S_{43\,GHz} = (1.42 \pm 0.10)$ Jy, $\theta_{43\,GHz} = (0.75 \pm 0.08)$mas, respectively $S_{86\,GHz} = (1.47 \pm 0.75)$ Jy, $\theta_{86\,GHz} = (0.33 \pm 0.14)$mas. The corresponding brightness temperatures are $T_B(43GHz) = 1.7 \cdot 10^9$ K, and $T_B(86GHz) = 2.2 \cdot 10^9$ K. 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.

About 3 months after our 43 GHz observations, Backer et al. (this volume) confirmed the detection of Sgr A* with VLBI at 43 GHz in another experiment, in which Sgr A* basically appeared point-like. Since Sgr A* appears to have brightened by about 50% (from $S_{43\,GHz} = 1.4$ to 2.1 Jy) between both observations, differences in the source structure could be reconciled either by the still very limited dynamical range of the VLBI maps (faint features apparently disappear, if the peak flux density in the maps increases due to source brightening) or by structural variability of Sgr A* on mas-scales. Although the latter would not be unexpected[1], in particular with regard to the pronounced intrinsic flux density variations found recently at cm-wavelengths (Zhao *et al.*, 1991) and at mm-wavelength (Backer, this volume), future mm-VLBI monitoring will be necessary to clearly detect such variability.

Some hints for such structural variability already are obtained from inspection of 1.3 cm-VLBI data recently published. In 1983 the flux density and the mean Gaussian FWHM-size of Sgr A* was $S \simeq 1.2 - 1.5$ Jy and $\theta = 1.8 \pm 0.09$ mas. (Marcaide *et al.*, 1992 and references therein). However, in 1991 the source was slightly fainter ($S = 1.0$ Jy) and apparently broader ($\theta = 2.4 \pm 0.2$ mas) (Lo *et al.*, 1993). Thus both, 22 GHz and 43 GHz VLBI-data mutually indicate an inverse correlation of (apparent) source size with source brightness (if this would be source intrinsic, induced Compton scattering, expected for high brightness temperature sources surrounded by a dense plasma, provides an interesting explanation (Coppi *et al.*, 1993)).

In Figure 4 we plot source size versus wavelength. To reconcile for a possible ellipticity of the source structure seen at $\lambda = 1.3$ and 3.6 cm (Alberdi *et al.*, 1993, Lo *et al.*, 1993), we displayed the geometrical mean of the major and minor axis of the corresponding elliptical Gaussian. The observed frequency dependence of the source size generally is interpreted by angular broadening due to interstellar scattering (probably by the dense ionized ISM surrounding Sgr A*). At 7 mm and

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[1] The VLBI-cores of AGN usually have inverted radio spectra, exhibit high brightness temperatures and pronounced flux density variability, which generally is related to structural variability.

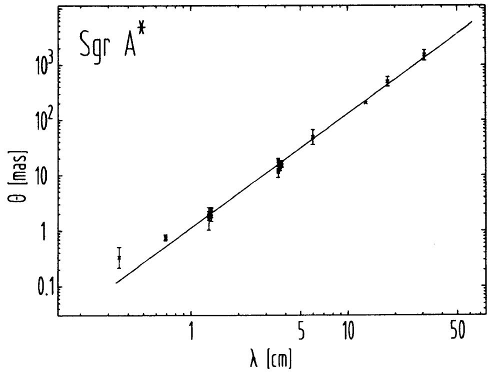

Fig. 3. **Geometrical mean size (*FWHM*) of Sgr A* plotted versus wavelength. Measurements at cm-wavelengths collected from the literature (1.3 cm $\leq \lambda \leq$ 31 cm) yield a slope of the line of 2.033 ± 0.015, consistent with expectations for a scatter broadened image (cm-data: Alberdi *et al.*, 1992 and references therein). The new measurements at λ = 7 mm and at λ = 3 mm show deviations from the simple λ^2-law, strongly indicative of internal source structure showing up at mm-wavelengths.**

3 mm the extrapolated scattering sizes from Fig.3 are $\theta^{scat}_{43\,GHz} = 0.53 \pm 0.02$ mas, and $\theta^{scat}_{86\,GHz} = 0.13 \pm 0.01$ mas, both considerably smaller than the measured sizes. Thus Sgr A* appears to be less affected by scatter-broadening effects of the ISM at mm-wavelengths. MM-VLBI therefore allows, for the first time, to image directly the underlying intrinsic source structure of Sgr A* with highest angular resolution.

Acknowledgements

We thank the staff of the participating observatories for their efforts. Special thanks for their help are due to S. Britzen, A.-M. Gontier, A. Greve, C. Naundorf, H. Steppe, R. Wegner, and W. Steffen. T.P.K. appreciates the support by the German BMFT-Verbundforschung.

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