Radio Interferometry: Theory, Techniques and Applications, IAU Coll. 131, ASP Conference Series, Vol. 19, 1991, T.J. Cornwell and R.A. Perley (eds.)

ASTROMETRY OF SiO MASERS

First detections of circumstellar SiO maser emission at $\lambda = 7$ mm using three European VLBI stations

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INTRODUCTION

The positions of circumstellar molecular masers relative to each other, to the central star, and to the compact extragalactic sources are of astrophysical and astrometrical interest. The SiO masers at $\lambda = 7$ mm are especially interesting as the maser spots are located very close to the photosphere of the star. For astrometry we would like to see a proper distribution of the maser spots and several epochs of observations in order to estimate the position of the central star and eventual motions of the spots.

The optical position of this star can be determined with ground-based astrometric facilities, and many of the stars showing SiO emission are in the *Hipparcos* catalogue. A link between the Optical and Radio Reference Frames is achieved in a second step relating the maser spot positions to the Extragalactic Reference Frame (EGRF) established with VLBI (Baudry *et al.* , 1984).

EARLIER OBSERVATIONS OF SiO MASERS WITH VLBI

VLBI observations of SiO maser sources were performed in the past. The star-forming region *Orion A* was resolved with a three element interferometer in the U.S. with baseline lengths in the range 228-845 km (Moran *et al.* , 1977) but detected later with the 75 km baseline Haystack-FCRAO (Genzel *et al.* , 1979). The Mira variable *RCas* and the supergiant *VXSgr* were also detected using this interferometer (Moran *et al.* , 1979). The sizes of the spots were estimated to be $0''.007$. Results from further observations using the same baseline have been presented by Lane *et al.* (1980) and McIntosh *et al.* (1988). These experiments suggested that baseline lengths of about 100 km were the most suitable for VLBI observations of SiO masers in the circumstellar envelopes of late-type stars. This conclusion discouraged further observations as such baselines are not easily available at $\lambda = 7$ mm.

CURRENT OBSERVATIONS

Here we present the first detection of circumstellar SiO maser emission from the $v = 1$, $J = 1 \rightarrow 0$ transition at 43122.027 MHz ($\lambda \sim 7$ mm) using a three--station VLBI interferometer in Europe (see TABLE I). It consisted of the Onsala–Effelsberg baseline (832 km), the Effelsberg–Yebes baseline (1352 km), and the Onsala–Yebes (2154 km) baseline. This is the first VLBI observation including Yebes (for details about the Yebes setup see Colomer *et al.* , 1990). It is important to note that these baselines are much longer than the 100 km suggested to be optimum.

TABLE I Observational setup and characteristics

Station	Code	D (m)	T_{sys}	Q(Jy/K)	$\eta_A(\%)$	Receiver	Pol.
Onsala	T	20	420	18	48	SIS	LCP
Effelsberg	B	60[a]	450	3.6	27	Schottky	Linear
Yebes	Y	14	350	90	17	Schottky	LCP

[a] Illuminated diameter of the Effelsberg 100m-telescope.

The experiment was performed on June 25^{th}- 26^{th}, 1990. The observations were intended to produce first detections on a preliminary list of sources selected because of their optical brightness, their strong SiO maser emission (≥ 50 Jy) and their large distance from us (≥ 400 pc) [see TABLE II]. In order to produce as strong fringes as possible, the observations were scheduled to use minimal projected baseline lengths. The data were recorded on the Mark II VLBI system with the emission line centered in the middle of the 2 MHz (13.9 km/s at 43 GHz) filter band. The data were correlated at the Mark II correlator of the MPIfR in Bonn.

Out of the 19 observed sources, we detected 10 with the Onsala–Effelsberg baseline, 4 with the Effelsberg–Yebes, and 1 with the Onsala–Yebes as indicated in TABLE II. For these detections the projected baseline lengths were in the range 331-1739 km. Preliminary results from a first inspection of the data show that most of the sources observed are intrinsically an order of magnitude smaller than expected (as an example, the estimated size of μCep is 0.7 milliarcseconds). For some of the sources the data indicate that individual maser spots are spatially separated. Further analysis of this small set of data will provide valuable information regarding spot sizes and relative positions (Colomer *et al.* , 1990). In order to relate these positions to the EGRF we also need to observe nearby extragalactic objects. In this first test only three of them were observed (see TABLE III), mainly to prove that the equipment was functioning and also to obtain calibration information.

TABLE II List of observed SiO sources

Source name	α(1950.0)	δ(1950.0)	R (pc)	S_{peak}[a] (Jy)	v_{peak}[a] (km/s)	VLBI[b] detection
Y Cas	00 00 47	55 24 10	750	63	-17	NoF
S Per	02 19 15.1	58 21 34	2250	36	-40.0	NoF
IK Tau	03 50 43.7	11 15 31.8	400	270	33.6	BT
TX CaM	04 56 41.3	56 06 32.7	1100	225	4	BT,BY
OriIRc2[c]	05 32 47.0	-05 24 23.9	500	900	-7.9,16.7	BT,BY,TY
V Cam	05 55 57.7	74 30 23	930	153	6.5	NoF
VY CMa	07 20 54.6	-25 40 12.2	1500	2880	22.3	BT,BY
R Cnc	08 13 48.5	11 52 52.6	340	38	13.5	BT
R LMi	09 42 34.8	34 44 33.8	350	100	-2	NoF
R Leo	09 44 52.2	11 39 40.2	240	380	-1.0	BT
RU Her	16 08 08	25 12 00	500	18	-13.5	NoF
U Her	16 23 34.9	19 00 18	390	117	-16.1	NoF
VX Sgr	18 05 02.9	-22 13 55.6	1500	240	7.8	BT
GY Aql	19 47 25	-07 44 30	600	140	33	NoF
RR Aql	19 55 00.5	-02 01 16.8	380	130	30	BT
NML Cyg	20 44 33.8	39 55 57	500	9	4	NoF
μ Cep	21 41 58.6	58 33 02.6	800	630	26	BT,BY
R Peg	23 04 08.3	10 16 22	411	18	19.2	NoF
R Cas	23 55 52.0	51 06 37.8	270	90	24	BT

[a] Flux and velocity of the strongest observed features
[b] NoF = No detected fringes. BT, BY, and TY mean detected fringes on the corresponding baseline
[c] Orion A (near IRC2) has been detected at both velocities with the three baselines

TABLE III List of Extragalactic Sources

name	α(1950.0)	δ(1950.0)	S (Jy)[a]	VLBI
3C84	03 16 29.563	41 19 51.843	34.9	BT
3C345	16 41 17.614	39 54 10.858	5.4	NoF
3C454.3	22 51 29.522	15 52 54.239	7.7	BT

[a] Total flux at 43 GHz corresponds to epoch 1988.49 for 3C84 and 3C345, and epoch 1987.44 for 3C454.3 (Krichbaum and Witzel, 1990).

https://doi.org/10.1017/S0252921100013592 Published online by Cambridge University Press

FUTURE OBSERVATIONS

The observations were intended to yield first detections. Each source was therefore observed no longer than 30-60 minutes. In order to produce *maps* we need a much better u-v coverage. This is the goal of the next experiment scheduled for early 1991.

Once this is done, two more steps are required for astrometry, i.e. to relate the positions of the maser spots to nearby extragalactic objects and to estimate the position of the central star. The latter step, however, depends very much on the distribution of the maser spots over the photosphere of the star and calls for multi-epoch observations. These procedures will help linking the Optical and Radio Reference Frames, provided that enough stars are measured.

Further VLBI observations and results combined with single-dish monitoring will also be of astrophysical interest. Measured intrinsic sizes and spatial dynamics (position and velocity) of the SiO maser spots probe the physical conditions within the atmospheres of the stars.

The ongoing development of low-noise *HEMT* amplifiers at high frequencies will hopefully improve the sensitivity by as much as a factor of 4 and make this ambitious programme feasible. The introduction of more VLBI stations (e.g. the IRAM 30-m telescope on Pico Veleta, Spain, the Metsähovi 15-m telescope in Finland or the new MERLIN station in Cambridge, U.K) will also enhance the sensitivity and through the construction of closure triangles allow detections on the less sensitive baselines.

ACKNOWLEDGEMENTS

We thank the French *CNRS* for the loan of the hydrogen maser to the Centro Astronómico de Yebes. One of us (FC) is supported by a FPI grant of the Spanish *Ministerio de Educacion y Ciencia.*

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