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43 GHz SiO Masers and Astrometry with VERA in the Galactic Center

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Abstract

We present Very Large Array (VLA) observations of 43 GHz SiO (J = 1–0, v = 2 and v = 1) maser emission in a sub-sample of late-type stars in the Inner Galaxy selected on their relatively strong (> 0.5 Jy) 86 GHz SiO masers, and located within 2.°5 of the galactic center. Furthermore we combine these results with a summary of previous surveys for 43 GHz SiO masers in the galactic center and comment on their use as calibrators for the Japanese "VLBI Exploration of Radio Astrometry" (VERA) network, which is intended to perform sub-milli-arcsecond astrometry in the Galaxy and the galactic center.

Key words: astrometry — Galaxy: center — masers — stars: late-type — surveys

1. Introduction

Although the most spectacular results are currently the measurement of near-infrared proper motions and individual stellar orbits around the black hole (Sgr A*) in a fraction of the central parsec of the galactic center (GC) (e.g. Schödel et al. 2002; Ghez et al. 2003; and references in them), circumstellar masers will probably be the most promising objects to probe the gravitational potential in the central *tens* of parsecs around the GC (Lindqvist et al. 1992a; Reid et al. 2003). The circumstellar shells in which maser emission originates are very prominent at radio and infrared wavelengths, and the masers instantaneously reveal the line-of-sight velocities accurately. Because the masers are readily found and the stars are rarely influenced by non-gravitational forces, the kinematics of stars with circumstellar masers within the inner tens of parsecs of the GC are ideal 'point-mass' probes to measure the gravitational field in the inner Galaxy, i.e., the region at the onset of the galactic bar. Many 1612 MHz OH, 22 GHz H_2O, and 43 and 86 GHz SiO masers have been found in the past (e.g. Lindqvist et al. 1991; Morita et al. 1992; Lindqvist et al. 1992b; Menten et al. 1997; Shiki et al. 1997; Izumiura et al. 1998; Sjouwerman et al. 1998b; Harju et al. 1998; Miyazaki et al. 2001; Deguchi et al. 2002; Imai et al. 2002; Sjouwerman et al. 2002 and references therein), but because of severe interstellar scattering in the galactic center (e.g. van Langevelde et al. 1992; Frail et al. 1994; Lazio et al. 1999), which scales as λ^2 (Lo et al. 1981), only the highest frequency (> 20 GHz) masers are useful for astrometry. In particular, the new four-station Japanese VERA array, which stands for "VLBI Exploration of Radio Astronomy", is intended to perform astrometry with 22 GHz H_2O and 43 GHz SiO masers in the Galaxy, i.e. *including* the GC (Honma et al. 2000b; Kawaguchi et al. 2000).

For radio sources where the calibrator and target cannot be observed simultaneously within the telescope beam (typically 1′ or less at 43 GHz), current practice of phase-referencing in Very Long Baseline Interferometry (VLBI) (or differential VLBI) ties the position of target sources to astrometric calibrator sources and extends the atmospheric coherence time. However, phase-referencing at high frequencies such as 22, 43, and 86 GHz, e.g. with the Very Long Baseline Array (VLBA) or the European VLBI Network (EVN), are highly hampered by the fast telescope switching cycles needed to compensate for the temporal tropospheric phase fluctuations. To obtain proper atmospheric phase calibration, sometimes cycles as short as 20 seconds on the target and 20 seconds on the phase-reference calibrator source (in which the calibrator needs to be detected with sufficient signal-to-noise) are needed, in particular at low elevation such as for the galactic center (e.g. Sjouwerman et al. 1998a; Reid et al. 2003). This results in reduced efficiency (< 50%) due to large telescope slewing overhead and large fraction of total observing time spent on atmospheric phase calibration.

VERA utilizes dual beams to simultaneously track tropospheric phase fluctuations at high observing frequencies between a strong, instantaneously detectable phase calibrator and a weak target source separated between ∼ 0.°3 and ∼ 2.°2 from the calibrator (Honma et al. 2000a; Kawaguchi et al. 2000; Honma et al. 2003). This technique of dual beams, which in principle allows to use observing frequencies that differ between the reference and the target beams (Asaki et al. 1998), removes the necessity of having an in-beam calibrator or moving the telescope between reference and target sources and the temporal interpolation of the visibility phases from the reference to the target source scans to extend the coherence time. It is implicitly assumed that most of the phase error is due to the interpolation between the times of detection of the target and of the phase-reference source, and that the atmosphere toward the target and phase-reference (spatial and spectral extrapolation) is similar. Most likely however, the observer will want to observe at similar frequencies and as much as possible through the same atmosphere to avoid phase errors propagating in an unknown fashion. This demands the availability of strong sources at the target observing frequency for phase calibration as close as possible to the target source. Normally, in the GC region one would use the ~ 1 Jy (at 43 GHz) source Sgr A* itself as calibrator (see e.g. Sjouwerman et al. 2002; Reid et al. 2003), but almost all the interesting target stellar masers — the ones that really probe the inner galactic gravitational potential — are distributed closer than VERA's minimum separation of $\sim 0.^\circ 3$ from Sgr A*. Using Sgr A* directly as calibrator in one of the dual beams of VERA is therefore impossible. No known and strong quasars are sufficiently nearby to be used by VERA for phase calibration and therefore some of the 43 GHz SiO masers located further out may be good calibrators. Note that this also excludes measuring the parallax of Sgr A* with respect to background quasars.

The purpose of this paper is twofold. First, we report on 43 GHz detections with the Very Large Array (VLA) of relatively strong 86 GHz masers in the GC (section 2) and summarize the current status of 43 GHz SiO masers in the GC (section 3). Second, we investigate their potential to serve as calibrators for VERA in the GC region (section 4) and a methodology to find the best 43 GHz SiO maser VERA calibrators (section 5). In principle the same can be done for H_2O masers in the GC, but because the H_2O masers are more variable and less predictable, and therefore have a low detection rate (15 to 25%) in circumstellar masers in the GC (e.g. Lindqvist et al. 1990; Levine 1995; Sjouwerman et al. 2002), here we restrict ourselves to the 43 GHz SiO masers.

In the following, we will use IRAS, LWHM, MHSOM, and SOD in combination with numbers to identify the sources in Deguchi et al. (2000); Lindqvist et al. (1992b); Messineo et al. (2002), and Shiki et al. (1997), respectively.

2. New 43 GHz Observations

To find more strong 43 GHz sources, in 1995 August we used the 43 GHz receiver installed at the Australia Telescope National Facility Parkes telescope to start extending the detections in Lindqvist et al. (1991) and Sjouwerman (1997) (Sjouwerman et al. 2002) by observing an additional 20 OH/IR stars from the list of Lindqvist et al. (1992b). Although the observing conditions were unfortunate, with a spectral resolution 250 kHz (1.7 km s^{-1}) in 3 hours of on-source time we were able to detect four sources in the ($v = 1$) line with an rms noise of typically 0.4 to 0.5 Jy. Unfortunately, due to the low sensitivity, the Parkes telescope turns out to be ineffective for the 43 GHz SiO maser searches in OH/IR stars.

However, many more candidate 43 GHz masers can be found outside the limited population of OH masing OH/IR stars (Izumiura et al. 1998). For example, K-band variables identified by Glass et al. (2001) were targeted by Imai et al. (2002), and Menten et al. (1997) and Izumiura et al. (1998) found 43 GHz SiO masers in blind VLA and Nobeyama surveys. Moreover, recently Messineo et al. (2002) reported on a survey for 86 GHz SiO masers in an infrared selected sample of late-type stars in the Inner Galaxy. Our group has chosen to focus on the 86 GHz SiO maser to obtain more stellar mass probes to investigate the structure of the Galaxy (Messineo et al. 2002). The 86 GHz masing stars in our sample have a lower mass-loss rate than the OH/IR stars. Our survey is therefore complementary to previous OH maser surveys, although we trace a slightly different population (e.g. Habing 1996; Messineo et al. 2003).

We have used the VLA to find 43 GHz ($J = 1$–0, $v = 2$ and $v = 1$) SiO maser calibrators for VERA by targeting a subsample of the brighter (> 0.5 Jy) stellar 86 GHz ($J = 2$–1, $v = 1$) SiO masers found by Messineo et al. (2002). To pilot the observations, we selected the 39 strongest 86 GHz masers of Messineo et al. (2002), all within $2.^\circ 5$ of Sgr A*. We will report elsewhere on our complete search in the less bright 86 GHz masers as they are not directly interesting as candidate calibrators for VERA. The bandwidth of the VLA at 43 GHz is so small that it is an inefficient survey instrument for SiO masers that have velocities in the range from -400 to $+400$ km s^{-1} (Messineo et al. 2002). However, because we have a-priori information on the stellar velocity from the 86 GHz maser detections, the VLA is with its large collecting area a very powerful instrument to detect the corresponding 43 GHz masers within a few minutes of observation. The only limitation is imposed by the rapid phase changes over the array, requiring a phase calibrator within about two degrees of the targeted source. Fortunately, Sgr A* itself, located at the highest apparent stellar density, happens to be a very good calibrator for the VLA observations (in contrast to the anticipated VERA observations).

The observations were carried out under very good weather conditions with the VLA in D-array on 2002 January 8. The observations were made in 'fast-switching' mode (i.e. rapid phase-referencing) at 3 second integrations, with three cycles of 70 seconds on the target interspersed with 30 seconds on the phase-reference Sgr A*, and observing the two ($J = 1$–0, $v = 2$ and $v = 1$) lines in dual polarization simultaneously. Using a spectral resolution of 195 kHz (1.4 km s^{-1}), this typically yielded 20 to 25 mJy noise per channel while still spectrally resolving the line. The data were reduced in AIPS in a standard way,[1] with the only real difference being the 3 second sample interval in the calibration ('CL' and 'TY' tables; the integration time during observations), and the calibration of the visibility phases before calibrating the amplitudes. The absolute amplitude calibration uses (a model of) 3C 286 (J1331+305), which is probably reliable to better than 20%. Pointing solutions during the observations and the complex spectral bandpass were obtained from J1733−130.

We observed 39, and detected 38 sources, mostly in both of the 43 GHz lines. The detections are summarized in table 1, where we only list the items currently of interest for candidate VERA calibrators (position and integrated flux). We will report elsewhere on the full survey in the less strong 86 GHz masers, including the 43 GHz detections of some non-targeted 86 GHz SiO masers. Typical integrated fluxes range from 0.5 to 8 Jy km s^{-1}. That the detection rate in the pilot is so high, probably has to do both with the selection of the stronger

[1] For high frequency, i.e. using Appendix D in the AIPS Cookbook.

Table 1. New Parkes and VLA 43 GHz SiO maser detections.

ID	Position* (J2000)		Integrated flux† ($v = 2$)	($v = 1$)	ID	Position* (J2000)		Integrated flux† ($v = 2$)	($v = 1$)
Parkes data, LWHM sources:					56	17 45 04.8	−29 05 48.	(< 0.48)	(< 0.51)
17	17 45 10.363	−29 18 12.24	‡	4.0	57	17 45 05.951	−28 57 48.03	6.57	8.33
101	17 45 11.468	−28 38 37.91	‡	0.8	59	17 45 13.465	−29 05 26.47	0.68	(< 0.14)
106	17 46 14.924	−28 44 16.60	‡	0.8	66	17 45 32.255	−28 33 42.77	1.16	1.15
108	17 46 33.143	−28 45 01.46	‡	0.8	70	17 45 42.315	−28 42 44.78	0.86	1.00
					72	17 46 05.898	−29 36 31.33	4.35	6.00
VLA data, MHSOM sources:					74	17 46 07.674	−28 12 39.32	1.51	3.21
11	17 39 37.284	−30 08 51.79	1.51	1.83	75	17 46 12.467	−28 07 04.99	6.05	6.13
18	17 42 04.358	−29 58 46.43	(< 0.15)	0.49	76	17 46 17.959	−28 57 15.39	1.84	3.19
24	17 43 09.783	−29 24 02.55	0.56	0.42	79	17 46 19.134	−28 31 57.05	1.88	2.76
25	17 43 23.465	−28 53 50.15	1.94	2.50	80	17 46 23.643	−29 06 19.31	3.83	4.06
26	17 43 25.246	−29 45 28.26	3.41	3.14	85	17 46 42.714	−28 35 43.60	2.18	1.62
27	17 43 32.729	−29 15 39.34	8.79	6.16	90	17 47 01.273	−28 04 59.67	3.26	3.54
29	17 43 34.798	−29 40 30.33	0.74	0.96	93	17 47 28.493	−27 50 58.48	1.93	1.94
30	17 43 35.110	−29 24 47.00	1.95	1.81	95	17 47 36.338	−28 23 28.36	0.80	0.68
31	17 43 39.778	−29 11 37.25	11.27	6.33	97	17 48 08.734	−28 18 35.53	0.70	1.19
32	17 43 41.773	−29 01 18.98	3.03	3.16	99	17 48 13.140	−28 19 41.35	1.69	1.94
34	17 43 49.964	−29 01 21.21	0.83	1.12	100	17 48 18.088	−28 07 38.80	4.15	5.71
44	17 44 19.905	−29 08 03.73	0.26	0.32	103	17 48 38.078	−26 59 52.34	1.62	0.63
46	17 44 30.495	−29 25 07.22	1.06	0.39	106	17 49 08.374	−27 33 29.31	2.71	3.24
49	17 44 54.931	−28 58 13.34	1.85	2.27	111	17 49 25.887	−28 00 45.36	2.88	2.72
52	17 44 58.881	−29 09 10.90	1.41	1.46	117	17 51 04.076	−27 18 50.50	1.20	3.36
55	17 45 01.333	−28 34 15.77	(< 0.16)	3.56	121	17 51 34.358	−27 27 17.14	0.84	1.17

* Parkes positions converted from Lindqvist et al. (1992b); VLA positions from this work (except MHSOM 56).
† Integrated flux in Jy km s^{-1}.
‡ Not observed.

86 GHz SiO masers, and the time interval of roughly a year (about the expected stellar pulsation period of 300–400 days) between the 86 and 43 GHz observations.

3. Previous 43 GHz Maser Surveys in the GC

As OH/IR stars frequently also harbor 22 GHz H_2O and/or 43 GHz SiO masers in their circumstellar shell (e.g. Habing 1996 and references therein), earlier surveys have tried to detect these higher frequency masers in OH/IR stars (see references in Sjouwerman et al. 2002). While the H_2O masers are highly variable, the 43 GHz (J = 1–0) SiO maser is more stable. Thus in particular the 43 GHz SiO maser can be used for astrometry, most notably in the galactic center region (Menten et al. 1997; Sjouwerman et al. 1998a; Sjouwerman et al. 2002; Reid et al. 2003). However, the number of 43 GHz masers in OH/IR stars in the galactic center is only a very small fraction of the known OH masers (Lindqvist et al. 1991; Sjouwerman et al. 2002), which has triggered searches for 43 GHz masers in other types of mid-infrared sources with colors typical for circumstellar envelopes, and in blind surveys in the galactic center [Menten et al. 1997; the Japanese groups as published in Shiki et al. (1997); Izumiura et al. (1998); Deguchi et al. (2000); Miyazaki et al. (2001); Deguchi et al. (2002); Imai et al. (2002)]. In particular, it is believed that the OH/IR stars are just the tip of the iceberg (Izumiura et al. 1998), and that the 43 GHz maser, or even the 86 GHz (J = 2–1) SiO maser, is readily observable in the much more numerous Mira, Long-Period and Semi-regular variables, and red supergiant stars (see section 5) (e.g. Habing 1996). The number of 43 GHz masers available for astrometric studies, kinematics, dynamics, and proper motions in the galactic center has been increasing — slowly, but steadily, and recently very rapidly (Deguchi et al. 2000; Imai et al. 2002; Sjouwerman et al. 2002 and references therein; this work). We have summarized the previous 43 GHz *systematic searches* in the GC in table 2, indicating the type of object targeted (if not a blind survey), the number of independent detections [i.e. a detection in the (v = 1) and (v = 2) transition is counted as one], and the maximum distance of the detections to Sgr A* (see also figure 1 and figure 2). Note that some surveys overlap in detections; we have not tried to account for this. Overlapping detections are of interest in order to asses the variability of the maser.

4. VERA Phase Calibration with 43 GHz Masers

The feasibility of obtaining and measure relative proper motions of maser sources in the central part of the Galaxy with VLBI techniques has been demonstrated (e.g. Reid et al. 1988a, 1988b; Reid 1993; Sjouwerman et al. 1998a; Reid et al. 2003). Although the sensitivity of VERA is less than the sensitivity of the VLBA, its dual beam calibration technique has recently successfully been demonstrated with two 22 GHz H_2O

Table 2. 43 GHz SiO maser surveys‡ in the GC with detections (with retrievable coordinates) within 3° of Sgr A*.

Authors and year	Target	Number†	$\Theta_{\mathrm{Sgr\,A^*}}$	
Deguchi et al. 2000	IRAS	86	$< 255'$	◇
Deguchi et al. 2002‖	blind	15	$< 4'$	
Imai et al. 2002	*K*-var	79	$< 17'$	•
Izumiura et al. 1998§	blind	14	$< 1'$	
Menten et al. 1997‖ ♯	blind	7	$< 1'$	
Miyazaki et al. 2001	blind	9	$< 15'$	□
Lindqvist et al. 1991**	OH/IR	14	$< 24'$	×
Shiki et al. 1997	blind	7	$< 62'$	△
Sjouwerman et al. 2002††	OH/IR	18	$< 15'$	+
this work / Parkes data	OH/IR	4	$< 23'$	⋆
this work / VLA pilot	86 GHz	38	$< 127'$	○

‡ Does not include our full survey.
† Number of independent 43 GHz SiO masers detected.
§ In single dish pointings, not plotted in figures 1 or 2.
‖ Crowding in central parsecs, not plotted in figures 1 or 2.
♯ Same as Menten and Reid (1998); Reid et al. (2003).
** Includes detections by Lindqvist et al. (1987).
†† Same as Sjouwerman (1997).

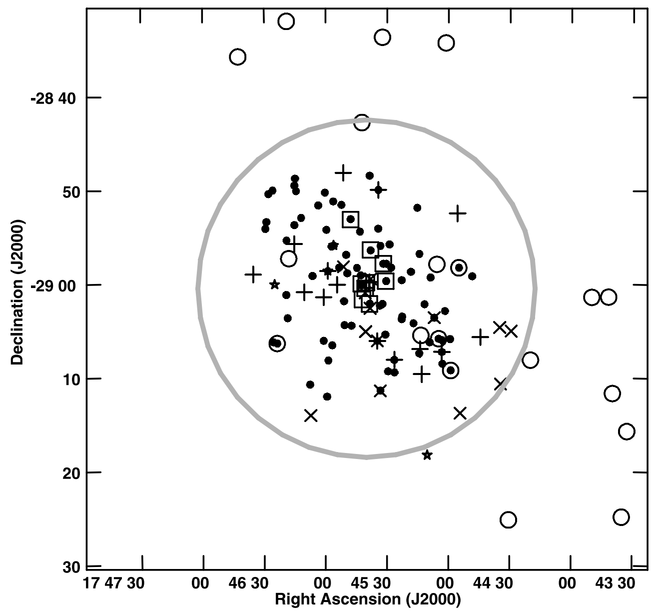

Fig. 1. The 43 GHz SiO masers within about 0°.5 of Sgr A* found previously and in this work. The density of sources around Sgr A* is convenient for an accurate determination of the gravitational potential in the inner few tens of parsec. However, the proximity of Sgr A* — to which one wants to measure relative positions — is unfortunate in order to use Sgr A* as the calibrator for these measurements with VERA. The symbols used are explained in table 2. A few detections are not shown because only a crude, single dish position is known (Izumiura et al. 1998), or plotting the positions in the inner (few) arcminutes defeats clarity due to crowding (Menten et al. 1997; Deguchi et al. 2002). The large gray circle represents a distance of 0°.3 to Sgr A*; potential VERA calibrators should be located *outside* the 0°.3 circle.

maser sources (Honma et al. 2003).

The sensitivity of the VERA network, with four 20 meter antennas, will in first instance not be sufficient to detect the majority of the circumstellar 43 GHz SiO masers in the galactic center. At 43 GHz, the line detection limit is around 1.9 Jy (0.25 Jy for continuum) which may degrade due to off-axis observing with up to about 25% (−1.2 dB) at 2° (Kobayashi et al. 2004; Kawaguchi et al. 2000). To convert the integrated fluxes to Jy km s^{-1}, the Nobeyama 43 GHz measurements toward IRAS sources were multiplied with the average conversion factor of 3.1 Jy K^{-1} (Deguchi et al. 2000), whereas the SOD integrated fluxes were calculated by multiplying the intensity with the velocity width (Shiki et al. 1997). Conservatively adopting that a source with an integrated flux of 4.0 Jy km s^{-1} is strong enough to be detectable on individual (off-axis) baselines with VERA (Kawaguchi et al. 2000), we identify 24 candidate 43 GHz calibrators for VERA in the GC region, where LWHM 17, IRAS 17404−2646, and IRAS 17487−3039 are border cases. Apart from having the highest integrated fluxes, these sources generally also have the higher peak fluxes. Eight other strong 43 GHz masers are either too close (MHSOM 57, and MHSOM 80), or too far away (IRAS 17328−2732, IRAS 17433−3222, IRAS 17530−2813, IRAS 17560−2816, IRAS 17563−2930, and IRAS 17566−2756) from Sgr A* to accommodate with VERA's dual beam.

The nine strongest masers selected have an integrated flux of at least 8 Jy km s^{-1} in at least one of the 43 GHz SiO lines. They are: MHSOM 27, MHSOM 31, IRAS 17404−2646, IRAS 17439−2712, IRAS 17464−2843, IRAS 17482−2824, SOD 1 (=MHSOM 88), SOD 2, and SOD 3. Because of their high integrated flux, especially IRAS 17482−2824 (V_{LSR} = 10 km s^{-1}, 84′ from Sgr A*) and the even closer source SOD 2 (V_{LSR} = −25 km s^{-1}, 36′ from Sgr A*), they probably are the best calibrators.

Kawaguchi et al. (2000) describe the effects of flux density and separation angle on the dual-beam calibration technique. When variability or the distance to Sgr A* are taken into account (section 5), a further 15 other sources are of interest. They are selected because they have an integrated flux of at least 4.0 Jy km s^{-1} in at least one of the 43 GHz SiO lines. Occasionally these masers may be stronger and located closer to Sgr A* than the nine mentioned above: LWHM 17, MHSOM 72, MHSOM 75, MHSOM 100, IRAS 17365−2916, IRAS 17413−3025, IRAS 17435−3003, IRAS 17437−2947, IRAS 17445−2744, IRAS 17464−2952, IRAS 17482−2848, IRAS 17487−3039, SOD 5, SOD 6, and SOD 7 (= MHSOM 99).

5. Discussion

With projected baseline lengths of up till about 2000 km, the VERA network will have a resolution of about one mas at a frequency of 43 GHz. This is exactly the proper resolution to observe circumstellar 43 GHz SiO masers in the galactic center (Sjouwerman et al. 1998a; Reid et al. 2003). The dual beam VERA will eliminate the need for fragile phase-referencing techniques and the advantage of using VERA over the VLBA, apart from the dual beam efficiency approach, is that VERA is dedicated to do full-time astrometry when it becomes fully operational in 2005. Meanwhile, VERA calibrators in the

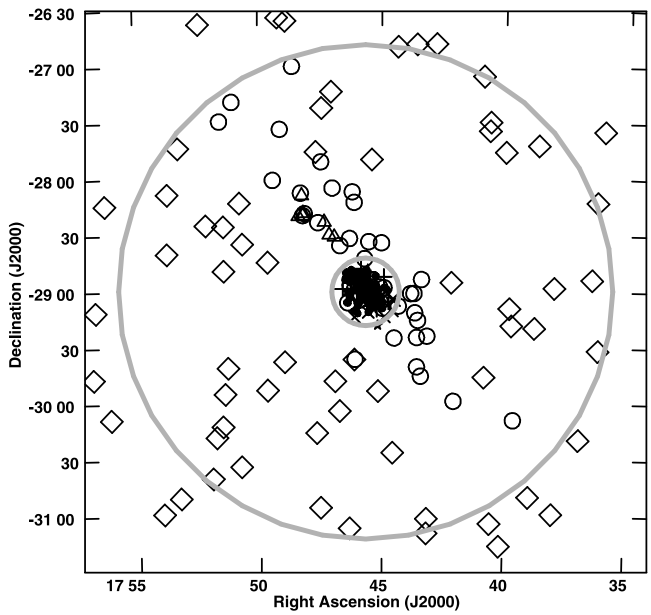

Fig. 2. The new 43 GHz SiO masers from the VLA within about $2\overset{\circ}{.}5$ of Sgr A* (table 1, circles) in addition to the SiO masers found previously [table 2, mostly Deguchi et al. (2000) and Shiki et al. (1997) — diamonds and triangles, respectively]. See also the blow-up of the clump of sources in the center and notes in figure 1. The two large gray circles represent a distance of $0\overset{\circ}{.}3$ and $2\overset{\circ}{.}2$ to Sgr A*; potential VERA calibrators should be located *between* the $0\overset{\circ}{.}3$ and the $2\overset{\circ}{.}2$ circles.

GC can be found by using Sgr A* as calibrator to investigate promising masers, which in turn can be used vice-versa to calibrate Sgr A* and the population of SiO masers in its direct vicinity (i.e. within $0\overset{\circ}{.}3$).

The IRAS and MHSOM sources were targeted searches in objects exhibiting infrared colors of circumstellar shells and envelopes. Together with the double OH-maser profile found in the LWHM sources, it is clear that all of these sources are of stellar origin: evolved, late-type (AGB) stars. With the exception of SOD 3, which has a $\sim 10\,\mathrm{km\,s^{-1}}$ broad line profile more typical for star forming regions in molecular clouds (Morita et al. 1992), and the possible exception of SOD 5 and SOD 6, which may be young stellar objects, the SOD sources found in a blind survey are also very likely to be evolved stars (Shiki et al. 1997; Deguchi et al. 1997).

In order for these stellar sources to be reliable calibrators for astrometric studies, two more issues need to be addressed in follow-up observations. First, the sources should have accurately known positions (fraction of an arcsecond) and simple structure detectable at VLBI baselines in order to be useful as calibrators for VLBI (i.e. VERA). Initial positions within an arcsecond (needed for the IRAS and SOD sources) can be obtained with the VLA, and the structure of the candidate calibrator successively can be simply derived by using VERA with Sgr A* in the calibrator beam to image the source, meanwhile also obtaining its mas-accurate VLBI position. Although the SiO masers are more stable than the H_2O masers, a second issue may be the SiO maser variability. It is essential to be sure to detect the calibrator during the VLBI observation. As the SiO masers in general are known to vary, one should select only those sources for calibration that are detectable at the time of observation. That this is an issue is shown by the fact that the candidate calibrator MHSOM 72 is also detected by Deguchi et al. (2000) in IRAS 17429−2935. However, the integrated (v = 2) and (v = 1) flux varies from 4.35 and 6.00 $\mathrm{Jy\,km\,s^{-1}}$ in this work (i.e. candidate calibrator) to about 0.64 and 1.25 $\mathrm{Jy\,km\,s^{-1}}$ in Deguchi et al. (2000) which is too weak for a VERA calibrator. The same may apply to SOD 7, a candidate selected by its $\sim 5.4\,\mathrm{Jy\,km\,s^{-1}}$ 43 GHz (v = 1) flux from the literature (Shiki et al. 1997), and MHSOM 99 which is too weak at 43 GHz ($< 2\,\mathrm{Jy\,km\,s^{-1}}$) to be considered as a candidate VERA calibrator. We therefore suggest to monitor the candidate calibrators for their maser flux variations over at least one pulsation period (typically 200 to 800 days; e.g. Habing 1996). This can be done before VERA will be fully operational.

6. Summary

The 43 GHz SiO masers can be used to measure stellar positions with VLBI, and thus proper motions over a time scale of years, e.g. with respect to the black hole Sgr A* (Sjouwerman et al. 1998a; Reid et al. 2003). In particular, the Japanese VERA array is intended for this purpose. However, the dual-beam VERA system is limited to a minimum separation between calibrator and target source of about $0\overset{\circ}{.}3$. The most spectacular science comes from the stellar proper motions very close to the black hole Sgr A*. Now that numerous 43 GHz SiO masing stars have been found close to Sgr A* (within $0\overset{\circ}{.}3$ to measure the proper motions of (figure 1), the 43 GHz SiO masers presented here may serve as calibrators for such a program to be carried out efficiently with VERA.

In order for such a program to be performed, the here suggested candidate 43 GHz SiO maser calibrators for VERA, 24 sources within $0\overset{\circ}{.}3$ and $2\overset{\circ}{.}2$ from Sgr A*, have to be observed for their accurate positions and be monitored for their flux variations.

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References

Asaki, Y., Shibata, K. M., Kawabe, R., Roh, D.-G., Saito, M., Morita, K.-I., & Sasao, T. 1998, Radio Sci., 33, 1297

Deguchi, S., Fujii, T., Izumiura, H., Kameya, O., Nakada, Y., Nakashima, J., Ootsubo, T., & Ukita, N. 2000, ApJS, 128, 571

Deguchi, S., Fujii, T., Miyoshi, M., & Nakashima, J. 2002, PASJ, 54, 61

Deguchi, S., Shiki, S., Matsumoto, S., Jiang, B. W., Nakada, Y., & Wood, P. R. 1997, PASJ, 49, 561

Frail, D. A., Diamond, P. J., Cordes, J. M., & van Langevelde, H. J. 1994, ApJ, 427, L43

Ghez, A. M., et al. 2003, ApJ, 586, L127

Glass, I. S., Matsumoto, S., Carter, B. S., & Sekiguchi, K. 2001, MNRAS, 321, 77

Habing, H. J. 1996, A&A Rev., 7, 97

Harju, J., Lehtinen, K., Booth, R. S., & Zinchenko, I. 1998, A&AS, 132, 211

Honma, M., et al. 2000a, PASJ, 52, 631

Honma, M., et al. 2003, PASJ, 55, L57

Honma, M., Kawaguchi, N., & Sasao, T. 2000b, in Proc. SPIE, 4015, Radio Telescopes, ed. H. R. Butcher, 624

Imai, H., et al. 2002, PASJ, 54, L19

Izumiura, H., Deguchi, S., & Fujii, T. 1998, ApJ, 494, L89

Kawaguchi, N., Sasao, T., & Manabe, S. 2000, in Proc. SPIE, 4015, Radio Telescopes, ed. H. R. Butcher, 544

Kobayashi, H., et al. 2004, in Proc. 10th anniversary of the VLBA, Future Directions in High-resolution Astronomy, ed. J. D. Romney, & M. J. Reid, ASP in print

Lazio, T. J. W., Anantharamaiah, K. R., Goss, W. M., Kassim, N. E., & Cordes, J. M. 1999, ApJ, 515, 196

Levine, D. A. 1995, PhD Thesis, University of California, Los Angeles

Lindqvist, M., Habing, H. J., & Winnberg, A. 1992a, A&A, 259, 118

Lindqvist, M., Ukita, N., Winnberg, A., & Johansson, L. E. B. 1991, A&A, 250, 431

Lindqvist, M., Winnberg, A., & Forster, J. R. 1990 A&A, 229, 165

Lindqvist, M., Winnberg, A., Habing, H. J., & Matthews, H. E. 1992b, A&AS, 92, 43 (LWHM)

Lindqvist, M., Winnberg, A., Ukita, N., & Johansson, L. E. B. 1987, A&A, 172, L3

Lo, K. Y., Cohen, M. H., Readhead, A. S. C., & Backer, D. C. 1981, ApJ, 249, 504

Menten, K. M., & Reid, M. J. 1998, ASP Conf. Ser., 144, 229

Menten, K. M., Reid, M. J., Eckart, A., & Genzel, R. 1997, ApJ, 475, L111

Messineo, M., Habing, H. J., Menten, K. M., Omont, A., & Sjouwerman, L. O. 2003, A&A in print

Messineo, M., Habing, H. J., Sjouwerman, L. O., Omont, A., & Menten, K. M. 2002, A&A, 393, 115 (MHSOM)

Miyazaki, A., Deguchi, S., Tsuboi, M., Kasuga, T., & Takano, S. 2001, PASJ, 53, 501; *Erratum:* PASJ, 53, 699

Morita, K., Hasegawa, T., Ukita, N., Okumura, S. K., & Ishiguro, M. 1992, PASJ, 44, 373

Reid, M. J. 1993, ARA&A, 31, 345

Reid, M. J., Menten, K. M., Genzel, R., Ott, T., Schödel, R., & Eckart, A. 2003, ApJ, 587, 208

Reid, M. J., Moran, J. M., & Gwinn, C. R. 1988a, IAU Symp., 129, 169

Reid, M. J., Schneps, M. H., Moran, J. M., Gwinn, C. R., Genzel, R., Downes, D., & Rönnäng, B. 1988b, ApJ, 330, 809

Schödel, R., et al. 2002, Nature, 419, 694

Shiki, S., Ohishi, M., & Deguchi, S. 1997, ApJ, 478, 206 (SOD)

Sjouwerman, L. O. 1997, Onsala PhD Thesis, Chalmers University of Technology, Gothenburg, Sweden

Sjouwerman, L. O., Lindqvist, M., van Langevelde, H. J., & Diamond, P. J. 2002, A&A, 391, 967

Sjouwerman, L. O., van Langevelde, H. J., & Diamond, P. J. 1998a, A&A, 339, 897

Sjouwerman, L. O., van Langevelde, H. J., Winnberg, A., & Habing, H. J. 1998b, A&AS, 128, 35

van Langevelde, H. J., Frail, D. A., Cordes, J. M., & Diamond, P. J. 1992, ApJ, 396, 686