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SiO maser emission from OH/IR stars close to the galactic centre

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Abstract. We have searched for 43 ($v = 1$ and $2, J = 1 \rightarrow 0$) and 86 GHz ($v = 1, J = 2 \rightarrow 1$) SiO maser emission simultaneously from a sample of 31 OH/IR stars close to the Galactic Centre using the Nobeyama 45 m telescope. 11 envelopes were detected in the 43 GHz ($v = 1$ and $2, J = 1 \rightarrow 0$) transitions and two solely in the $v = 2$ transition. Only upper limits were obtained at 86 GHz. We obtain luminosities in the intervals $(70 - 380) \times 10^{42}$ and $(80 - 370) \times 10^{42}$ photon s^{-1} for $v = 1$ and $v = 2$, respectively. We compare these luminosities with those of 7 OH/IR stars in the galactic disk. There is no significant difference between the luminosity distributions of the two stellar samples, given the small number of objects. However, we believe it is premature to draw any definite conclusions based on the data currently available. The luminosity of the $v = 2$ line is on the average ~ 1.5 times stronger than the luminosity of the $v = 1$ line. The upper limits of the 86 GHz ($v = 1, J = 2 \rightarrow 1$) data compared to the detected 43 GHz ($v = 1$ and $2, J = 1 \rightarrow 0$) lines suggest that the 86 GHz maser is weaker than the 43 GHz maser. The line widths and the line profiles are comparable to many of the simple structure spectra observed in ordinary Miras. Finally, the ratio of the SiO flux to the OH 1612 MHz flux is found to be small (~ 1) compared to the Miras ($\gtrsim 100$) which was also noted by Jewell et al. (1984) suggesting that the flux of the SiO maser is insensitive for the increase in mass loss rate.

Key words: Galaxy (the): center of–Stars: long period variables–Stars: OH/IR–Stars: circumstellar matter

1. Introduction

Maser action in the interstellar space is associated with massive star formation and with late stages of stellar evolution, two intensively studied phenomena. It has been shown to be a valuable probe of the kinematics and structure of high density regions. The SiO maser has been detected in several rotational transitions at different vibrational levels with corresponding energies of $\sim 0 - 5300$ K above the ground state. Detections of excited levels up to $v = 3$ have been made towards several late type stars (e.g. Jewell et al., 1987; Alcolea et al., 1989). From the results of VLBI experiments and from the detection of highly excited levels such as $v = 3$, the location of the SiO masers is believed to be within a few stellar radii from the star (e.g. Lane, 1982; Alcock and Ross, 1986; McIntosh et al., 1989; Jewell et al., 1987; Alcolea et al., 1989). In addition, the VLBI maps reveal a high degree of clumpiness of the detected emission ($\sim$ 50%). A detailed understanding of the SiO maser mechanism might provide important information on the not yet fully understood mass loss mechanism in the envelopes of evolved stars since it might originate close to the region where mass loss is initiated. However, despite considerable observational and theoretical efforts to understand the SiO maser phenomenon it remains largely unexplained. A summary of the SiO observations has recently been compiled (Engels and Heske, 1989). The pump mechanism of the SiO masers has been modelled using both collisional and radiative pumps (e.g. Elitzur, 1980; Bujarrabal and Nguyen-Q-Rieu, 1981; Langer and Watson, 1984). But neither of these models has been satisfactorily confirmed by observations. In particular the models have been unable to reproduce the observed high maser luminosity of the SiO maser ($\sim 10^{44-46}$ photon s^{-1}) as observed from some Miras and M-Supergiants using the assumption of a spherical, isotropic radiation. From the correlation between the SiO intensity and the 8 μm continuum Bujarrabal et al. (1987) suggest a radiative pump. However, Vardya et al. (1986) noticed an emission feature near 8 μm in the LRS spectra in several Miras which they suggested to be emission in the $v = 1 \rightarrow 0$ vibration-rotation band of SiO with possible contribution from $v = 2 \rightarrow 1$. These findings suggested Vardya et al. (1986) to support the collisional pump model by Elitzur (1980). Further constraints might be achieved by high resolution spectroscopy at 8 μm using the ISO.

The situation is even worse for the more evolved oxygen-rich Asymptotic Giant Branch stars, the so called OH/IR stars, having substantially higher mass loss rates ($\lesssim 10^{-4} M_\odot$ yr^{-1}). Only a small number of detections have been made and the time variation of the SiO maser in OH/IR stars is poorly known. In addition, the distances to most OH/IR stars are not accurately determined. However, there exist some OH/IR stars with distance errors $\lesssim 30\%$ (van Langevelde et al., 1990). Despite the small number of detections there are indications that the SiO maser phenomenon of OH/IR stars is different from that of ordinary Miras (Nyman et al., 1986). The most notable differences are the higher ratio of the 43 GHz $(v = 2, J = 1 \rightarrow 0)/(v = 1, J = 1 \rightarrow 0)$ line intensities and the weaker 86 GHz ($v = 1, J = 2 \rightarrow 1$) photon flux from OH/IR objects relative to ordinary Miras.

In this project we have started to study the SiO ($v = 1$ and $2, J = 1 \rightarrow 0$) and ($v = 1, J = 2 \rightarrow 1$) maser emission from a

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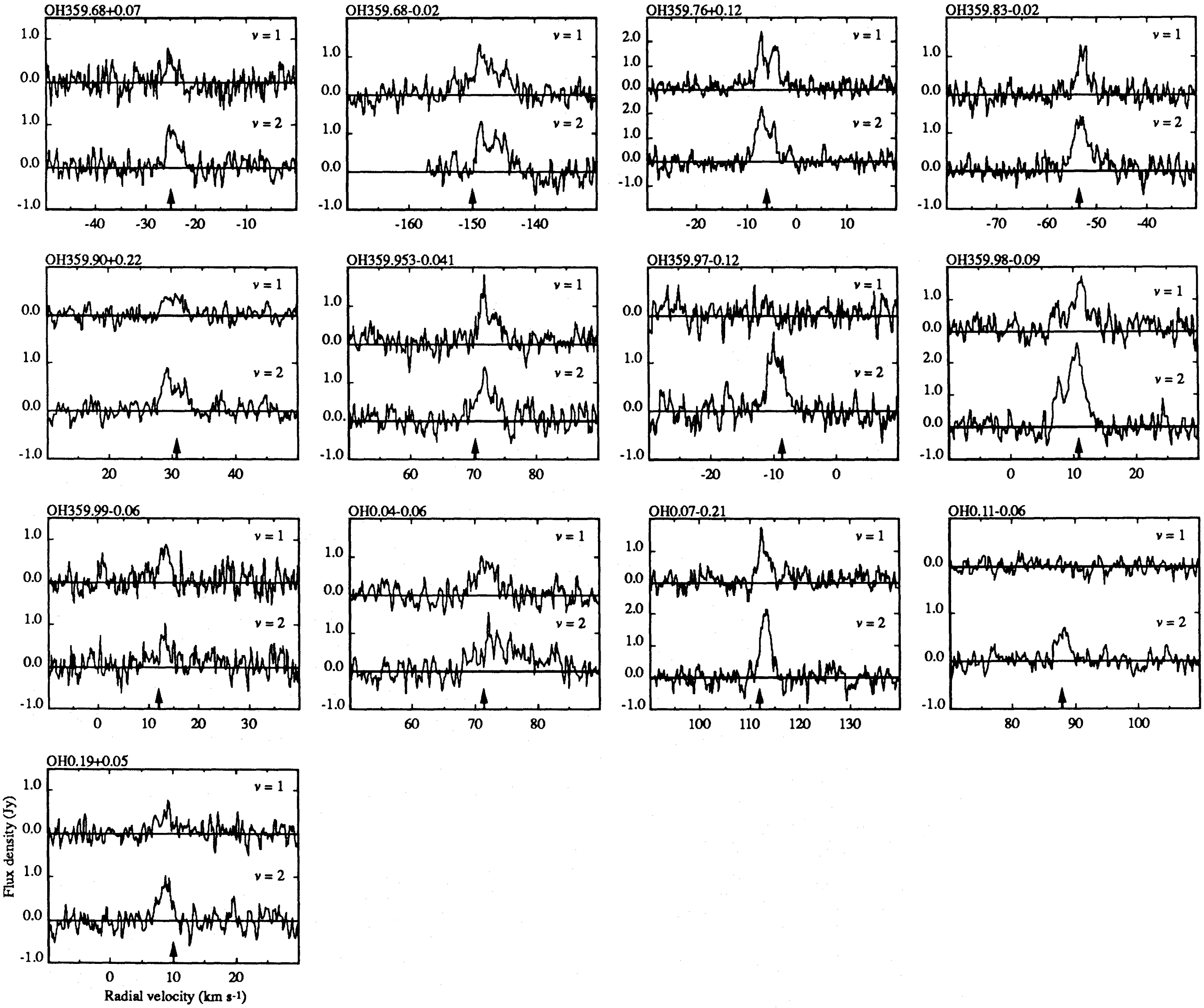

Fig. 1. SiO ($J = 1 \rightarrow 0$), $v = 1$ (upper) and $v = 2$ (lower) line profiles for the detected OH/IR stars. The intensity scale is in Jy. The vertical arrow indicates the radial velocity of the star estimated from the OH 1612 MHz line components

sample of OH/IR stars close to the Galactic Centre (GC) using the fact that they are all at about the same distance from us (Winnberg et al., 1985). A rough statistical calculation shows that at most one OH/IR star could be a foreground object. The same sample has been used for a preliminary SiO maser survey (Lindqvist et al., 1987) and a search for H_2O maser emission (Lindqvist et al., 1990a). Especially, the luminosity function would be feasible to study which could put constraints on the SiO pump mechanism. Moreover, we also compare the properties of the SiO maser towards OH/IR stars and Miras found in the disk of the Galaxy since there might be differences in the age and/or metallicity of the groups that could possibly be reflected in the SiO properties.

2. Observations

The simultaneous observations of the SiO maser emission ($v = 1$ and $2, J = 1 \rightarrow 0$) at 43 GHz and ($v = 1, J = 2 \rightarrow 1$) at 86 GHz were made using the Nobeyama 45 m telescope[1] between February 15-22 and May 25-26, 1988. Since the sample of OH/IR stars is confined to a small area of the sky ($\lesssim 0.5°$) and since we had knowledge of the radial velocity of the OH/IR stars we utilized a technique of switching between two different OH/IR stars in the on and off position. The frontend system consisted of a cooled SIS receiver at 43 GHz and a cooled Schottky receiver at 86 GHz. The system temperature was typically 250-350 K and 550-900 K at 43 and 86 GHz, respectively, depending on the weather. Calibration was achieved by the chopper wheel method.

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Table 1. Observational results

Source	Date	$S_I(J=1\rightarrow0)^a$		$L(J=1\rightarrow0)^b$		$S_I(J=2\rightarrow1)^a$	$L(J=2\rightarrow1)^b$
		$(v=1)$	$(v=2)$	$(v=1)$	$(v=2)$	$(v=1)$	$(v=1)$
OH359.68+0.07	Febr.-88	0.22	0.39	66	118	≤0.52	≤ 79
OH359.68−0.02	Febr.-88	0.83	0.80	251	243	≤0.48	≤ 73
OH359.75+0.14	Febr.-88	≤0.17	~0.18	≤ 51	~ 55	≤0.42	≤ 63
OH359.76+0.12	Febr.-88	1.26	1.17	380	355	≤0.43	≤ 65
OH359.78−0.12	Febr.-88	~0.17	≤0.12	~ 51	≤ 37	≤0.34	≤ 51
OH359.80−0.09	Febr.-88	~0.20	~0.33	~ 60	~100	≤0.36	≤ 54
OH359.81−0.07	Febr.-88	≤0.10	≤0.12	≤ 30	≤ 37	≤0.28	≤ 42
OH359.83−0.02	Febr.-88	0.54	0.98	162	299	≤0.43	≤ 65
OH359.83+0.15	Febr.-88	~0.15	~0.42	~ 45	~128	≤0.49	≤ 74
OH359.88−0.09	Febr.-88	≤0.14	≤0.12	≤ 42	≤ 37	≤0.33	≤ 50
OH359.90+0.22	Febr.-88	0.22	0.48	68	147	≤0.34	≤ 51
OH359.91−0.04	Febr.-88	≤0.14	≤0.12	≤ 42	≤ 37	≤0.38	≤ 57
OH359.93−0.06	May-88	≤0.24	≤0.26	≤ 73	≤ 79	≤1.59	≤240
OH359.94−0.08	May-88	≤0.15	≤0.15	≤ 45	≤ 46	≤0.62	≤ 94
OH359.94−0.05	Febr.-88	≤0.13	≤0.12	≤ 39	≤ 37	≤0.52	≤ 79
OH359.951−0.035	Febr.-88	≤0.11	~0.15	≤ 33	~ 46	≤0.52	≤ 79
OH359.953−0.041	Febr.-88	0.49	0.57	147	174	≤0.52	≤ 79
OH359.97−0.12	Febr.-88	≤0.17	0.60	≤ 51	181	≤0.48	≤ 73
OH359.98−0.09	Febr.-88	0.59	1.21	179	369	≤0.52	≤ 79
OH359.99−0.06	Febr.-88	0.40	0.39	122	120	≤0.52	≤ 79
OH0.00−0.14	May-88	≤0.24	≤0.26	≤ 73	≤ 79	≤1.59	≤240
OH0.04−0.06	May-88	0.50	0.82	150	251	≤0.67	≤101
OH0.06−0.02	May-88	≤0.15	≤0.15	≤ 45	≤ 46	≤0.62	≤ 94
OH0.07−0.21	Febr.-88	0.41	0.76	124	232	≤0.36	≤ 54
OH0.08+0.15	Febr.-88	≤0.11	≤0.11	≤ 33	≤ 33	≤0.52	≤ 79
OH0.08−0.12	May-88	≤0.16	≤0.17	≤ 48	≤ 52	≤0.96	≤145
OH0.11−0.06	Febr.-88	≤0.10	0.27	≤ 30	81	≤0.29	≤ 44
OH0.13+0.10	May-88	≤0.13	≤0.15	≤ 39	≤ 46	≤0.48	≤ 73
OH0.14+0.03	May-88	≤0.10	≤0.12	≤ 30	≤ 37	≤0.68	≤103
OH0.19+0.05	May-88	0.27	0.25	81	76	≤0.96	≤145
OH0.19+0.04	Febr.-88	≤0.17	≤0.18	≤ 51	≤ 55	≤0.52	≤ 79

[a] In units of 10^{-20} W m^{-2}. [b] In units of 10^{42} photon s^{-1}.

The telescope beamwidths are 40″ and 20″ and the aperture efficiencies 0.47 and 0.35 (3.7 Jy/K, 5.0 Jy/K), respectively, at 43 and 86 GHz. The pointing was checked regularly towards OH2.6−0.4 and the pointing accuracy was estimated to be 5″ rms in moderate wind conditions. Data were taken with acousto-optical spectrometers with 37 kHz resolution.

3. Results

We have observed 31 OH/IR stars found in the GC (Winnberg et al., 1985). 11 stars were detected in SiO ($J = 1 \rightarrow 0$) in both the $v = 1$ and $v = 2$ lines and two in the $v = 2$ line only (Table 1). The criterion used for a detection was that the SiO line should fall close to the average velocity of the two OH peaks at 1612 MHz, giving a detection rate of ~ 42% (13/31). Tentative detections were made in five envelopes. Only upper limits were obtained at 86 GHz ($v = 1, J = 2 \rightarrow 1$). The upper limits of the integrated intensities for the nondetections are obtained using the following formula from Nyman et al. (1986):

$$S_I \leq 3\sigma n^{1/2} \Delta v$$

were σ is the rms flux density, Δv the effective frequency resolution per channel, and n the number of channels. The latter quantity was given a value corresponding to a line width of 5 km s^{-1}, which is a typical upper value for the detected sources. The 3σ fluctuations in the spectra of the five tentative detections were typically 0.15×10^{-20} W m^{-2} using the same definition as above. The spectra obtained towards the 13 OH/IR stars are presented in Fig. 1. We also detected two new SiO masers while observing the pairs (OH359.94−0.05, OH359.98−0.09) and (OH0.04−0.06, OH0.14+0.03). The data indicate that they lie close to the first star in each pair. The radial velocities were ~ 84 and ~ −2 km s^{-1}, respectively. We did not have time to point up on these sources and consequently cannot give reliable intensities.

4. Discussion

4.1. The luminosity of the SiO maser

The OH/IR stars in the GC constitute an ideal sample to determine the luminosity of all kinds of radiation, such as IR continuum, OH, H_2O, and SiO maser lines, since they are all at about the same distance from us. The main purpose of this project is to determine the luminosity function of the SiO maser.

It is important to know how complete the OH survey is on which this SiO data set is based. Since the search for OH sources was based on observations using an aperture synthesis telescope the OH survey was limited mainly by the instrumental sensitivity (Winnberg et al., 1985; Lindqvist et al., 1991). This varied on the sky and can be approximated by a two-dimensional Gaussian with a half-power width of 27′ (the primary beam). The OH survey consisted of data taken in six such partly overlapping 'primary beams'. However, the 31 stars observed in the SiO lines were chosen from the field centred on Sgr A (Winnberg et al., 1985). Many of the stars within a few arcmin of Sgr A show large envelope expansion velocities, implying a slight bias. Another small observational bias was caused by the radial velocity coverage of the OH survey, –217 to +217 km s^{-1}. Some high-velocity OH/IR stars have been missed due to this.

A more serious problem than the bias of the OH survey is probably the time variability of the SiO masers. Thus, in order to obtain a luminosity function of SiO maser emission we would need to monitor a selection of SiO sources during a few years. The present data set of 13 detected SiO masers is far from sufficient to give a luminosity function. Lindqvist et al. (1991), however, present a much larger number of OH/IR stars in the GC (134) compared to Winnberg et al. (1985). This extended sample could be used for future SiO searches.

Thus, in the meantime we can only give some tendencies for the SiO maser luminosities from OH/IR stars. We have calculated the SiO luminosities using the following formula:

$$L = \frac{4\pi D^2}{h\nu_0} S_{\rm I}$$

assuming isotropic radiation. We have assumed a distance of D=8.5 kpc. $S_{\rm I}$ is the integrated flux density of the line (Table 1) and ν_0 is the rest frequency. Using this formula we obtain luminosities in the intervals $(70-380) \times 10^{42}$ and $(80-370) \times 10^{42}$ photon s^{-1} for $v = 1$ and $v = 2$, respectively. The detection limit of the luminosities is $\sim 40 \times 10^{42}$ photon s^{-1} in both transitions. The derived luminosities are presented in Fig. 2. The previous survey by Lindqvist et al. (1987) detected 3 OH/IR stars. The present survey is ~ 10 times more sensitive than that survey. We note that the maximum variation of the peak intensity between the detected OH/IR stars in 1986 and 1988 is ~ 5.

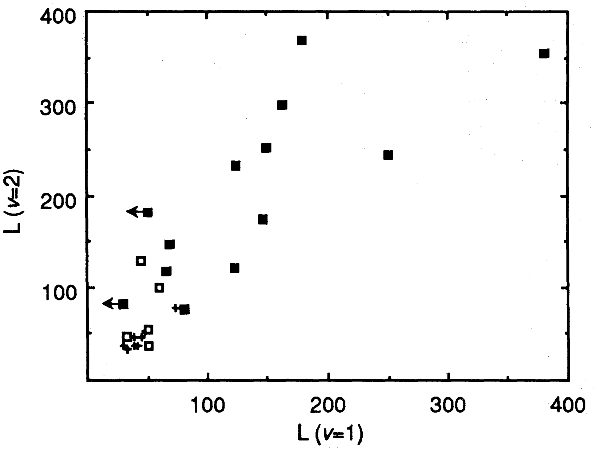

Fig. 2. The luminosity of the SiO ($v = 1, J = 1 \rightarrow 0$) versus that of the SiO ($v = 2, J = 1 \rightarrow 0$) transition in units of 10^{42} photon s^{-1}. Filled squares= detections, unfilled squares= tentative detections, crosses=upper limits

Table 2. A selection of OH/IR stars with well determined distances.

Source	$S_{\rm I}(J=1\rightarrow 0)^{\rm a}$ $(v=1)$	$(v=2)$	D (kpc)	$L(J=1\rightarrow 0)^{\rm b}$ $(v=1)$	$(v=2)$
OH21.5+0.5	0.9		7.9	235	
OH26.5+0.6	16.0		1.4	131	
	4.0			33	
	2.8	13.0		23	107
	1.9	12.0		16	99
OH28.7-0.6	0.7		1.4	6	
OH32.8-0.3	1.5		5.0	157	
OH39.7+1.5	2.8	8.2	1.5	26	78
	2.2			21	
		6.1			58
OH104.9+2.4	7.6		2.3	168	
	0.5			11	
		7.6			169
		5.0			111
OH127.8-0.0	8.4		2.9	296	
	8.2	16.0		289	567
	5.0	13.0		176	461
	0.8			28	

[a] In units of 10^{-20} W m^{-2}. [b] In units of 10^{42} photon s^{-1}.

For a thorough comparison of the luminosities between the OH/IR stars in the GC and in the galactic disk there is need for observations with similar sensitivity, corrected for the distance, for an increased sample of stars. The OH/IR stars in the GC differ in the sense of higher average expansion velocities than those in the galactic disk (Lindqvist et al., 1990b). As shown by Baud and Habing (1983) the expansion velocity is statistically related to the age of the star. It would therefore be interesting to compare the properties of the SiO maser for such samples. In order to make a crude comparison of the SiO luminosity of the OH/IR stars at the GC with the OH/IR stars in the galactic disk (Jewell et al., 1984, 1991; Nyman et al., 1986), we have selected the OH/IR stars the distances of which have been determined using the phaselag method with errors less than ~ 30% (van Langevelde et al., 1990). Seven OH/IR stars remained (Table 2). We have recalculated the luminosities using distances from van Langevelde et al. (1990). For OH/IR stars observed more than once, we use the arithmetic averages of the flux densities. The obtained luminosities span the intervals $(10-240) \times 10^{42}$ photon s^{-1} and $(70-510) \times 10^{42}$ photon s^{-1} for $v = 1$ and $v = 2$, respectively. Thus, on the basis of these limited samples we can not trace any difference between the GC and galactic disk OH/IR stars with respect to SiO luminosities.

4.2. *Velocities and line profiles*

Nyman et al. (1986) found that the SiO emission from OH/IR stars in the galactic disk was either totally blue or red shifted with respect to the stellar radial velocity, as estimated from the 1612 MHz OH maser. This is also the case for some of the OH/IR stars in the current sample (e.g. OH359.68–0.02, OH0.19+0.05; Fig. 1). However, in most cases there is close agreement with the stellar velocity. In addition, Jewell et al. (1991) found that the average SiO maser emission is close to the stellar velocity for a sample of both Miras and OH/IR stars. Thus, on the average the SiO maser is a good indicator of the stellar systemic velocity for both Miras and OH/IR stars. We have made a composite average for all detected stars. Before adding, each spectrum was

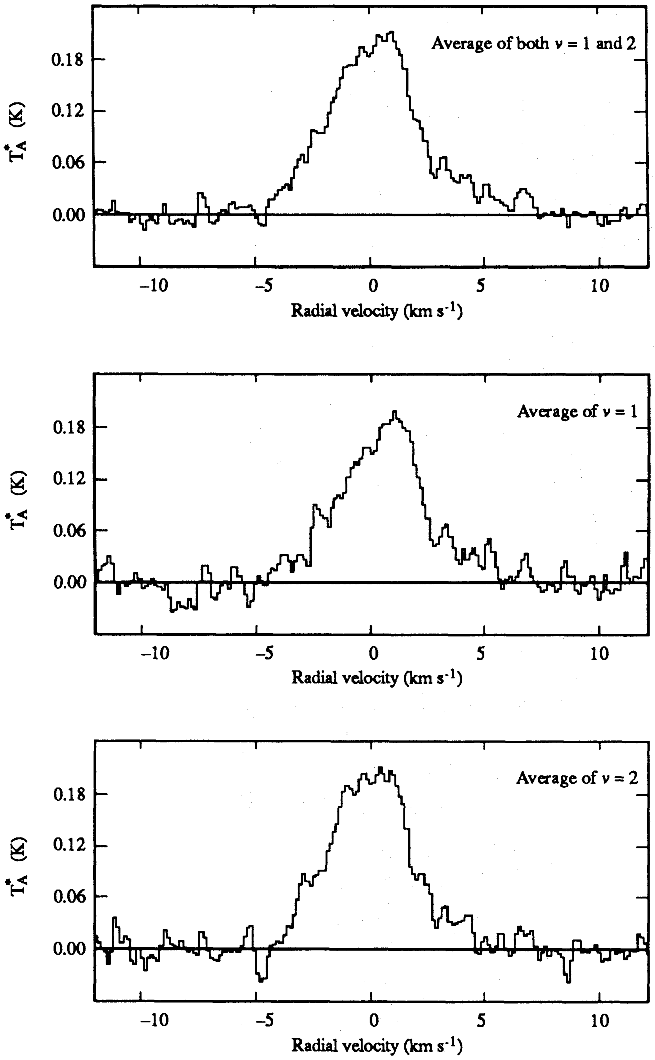

Fig. 3. Composite averages of all detections with the stellar radial velocity set to 0 km s^{-1}. The upper spectrum shows the average of both $v = 1$ and $v = 2$. The middle and lower spectra show $v = 1$ and 2, respectively. Each spectrum was given equal weight before averaging

given equal weight and the stellar velocity was set to 0 km s^{-1} (Fig. 3). The lower and the middle spectra are averages of the $v = 1$ and 2 lines while the upper spectrum is the average of both $v = 1$ and 2. The average profile of both transitions appears not as flat topped as the result of Nyman et al. (1986). There is an indication that the average line profile of the $v = 1$ is more peaked and perhaps slightly redshifted with respect to the stellar velocity compared to $v = 2$. However, since the distribution might be biased due to the small number of stars it is premature to conclude that there is any difference between the two transitions. The average equivalent width (profile area/peak intensity) is ~ 3 km s^{-1} compared to the value of ~ 4 km s^{-1} found in Miras (Martínez et al., 1988) whereas the OH/IR stars have significantly higher expansion velocities than the Miras, as estimated from the velocity extent of the OH emission (Baud and Habing, 1983). In addition, the OH/IR stars in the GC have in general higher expansion velocities than those in the galactic disk (Lindqvist et al., 1990b). The line profiles have generally one or two easily distinguishable components and there is good agreement between the velocity components in the various transitions. A certain rotational transition in different vibrational states is expected to be inverted at different distances from the star. This would lead to line profiles in contrast to our result. On the other hand one might expect similar line profiles from different rotational transitions within a vibrational state which is not the case in ordinary Miras (e.g. Lane, 1982). This might be explained by infrared line overlapping (Olofsson et al., 1985). Finally, the line widths and the line profiles are comparable to many of the simple structure spectra observed in ordinary Miras (e.g. Spencer et al., 1981; Lane,1982; Jewell et al., 1991). However, no OH/IR star has been found to have a complicated spectrum such as observed in e.g. W Hya, R Cas and IK Tau.

4.3. Intensity ratios

From the measurements of OH/IR stars in the galactic disk Nyman et al. (1986) found that $v = 2$ is stronger than $v = 1$ by a factor of ~ 4. This result differs from what is generally found in ordinary Miras. Spencer et al. (1981) and Lane (1982) found a value of ~ 0.7 for a sample of ordinary Miras. For the OH/IR stars in the GC we find that $v = 2$ is $\sim 1.5 \pm 0.2$ stronger than $v = 1$. Furthermore, two stars were only detected in the $v = 2$ line (OH359.97−0.12, OH0.11−0.06). Lindqvist et al. (1987) found a value of ~ 4 for OH359.97−0.12. Thus, we confirm the findings of Nyman et al. (1986) that $v = 2$ is generally stronger than the $v = 1$ line.

Lane (1982) found for ordinary Miras that the integrated flux in the $J = 2 \rightarrow 1$ line was stronger than the integrated flux in the $J = 1 \rightarrow 0$ line by a factor of ~ 2. For the upper limits at 86 GHz compared to the detections at 43 GHz we obtain an average value of $\lesssim 1.3$. A similar behaviour was also noted by Nyman et al. (1986). Le Bertre and Nyman (1990), on the other hand, concluded that the negative result by Nyman et al. (1986) was mainly a sensitivity effect. A larger data set with simultaneous observations of both the 43 and 86 GHz masers is needed in order to bring clarity about this ambiguity.

Finally, Jewell et al. (1984) noted that the ratio of the SiO flux to the OH 1612 MHz flux is small $(1 - 10)$ compared to the Miras ($\gtrsim 100$) suggesting that the flux of the SiO maser is insensitive to the drastic increase in the mass loss rate as the star evolves from a Mira to an OH/IR star. We find the same tendency for the present set of data for both $v = 1$ and $v = 2$ with an average of ~ 1 but we cannot give definitive flux ratios since the epochs of the SiO and OH observations differ. The estimated mass loss rates from the OH data for the detected sources is a few $\times 10^{-5}$ $M_\odot$ yr^{-1}.

5. Conclusions

The relatively high detection rate suggests that the SiO maser emission is a fairly common phenomenon also in the OH/IR stars close to the GC. We obtain luminosities in the intervals $(70 - 380) \times 10^{42}$ and $(80 - 370) \times 10^{42}$ photon s^{-1} for $v = 1$ and $v = 2$, respectively. We compare these luminosities with those of 7 OH/IR stars in the galactic disk. There is no significant difference between the luminosity distributions of the two stellar samples, given the small number of objects. However, we believe it is premature to draw any definite conclusions based on the data currently available. Our data indicate that the luminosity of the $v = 2$ transition is higher by a factor of ~ 1.5, on the average, relative to that of the $v = 1$ transition, thus similar to the OH/IR stars in the galactic disk but different to what has been found in ordinary Miras. The 86 GHz line is weaker than the 43 GHz line as observed by Nyman et al. (1986). The line widths and the line profiles are comparable to many of the simple structure spectra observed in ordinary Miras. Finally, the ratio of the SiO flux to the OH 1612 MHz flux is found to be small compared to the Miras which also was noted by Jewell et al. (1984) suggesting that the flux of the SiO maser is insensitive to the increase in mass loss rate.

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References

Alcock, C., Ross, R.R.:1986, ApJ, 310, 838

Alcolea, J., Bujarrabal, V., Gallego, J.D.:1989, A&A, 211, 187

Baud, B., Habing, H.J.:1983, A&A, 127, 73

Bujarrabal, V., Nguyen-Q-Rieu:1981, A&A, 102, 65

Bujarrabal, V., Planesas, P., del Romereo, A.:1987, A&A, 175, 164

Elitzur, M.:1980, ApJ, 240, 553

Engels, D., Heske, A.:1989, A&AS, 81, 323

Jewell, P.R., Batrla, W., Walmsley, C.M., Wilson, T.L.:1984, A&A, 130, L1

Jewell, P.R., Dickinson, D.F., Snyder, L.E., Clemens, D.P.: 1987, ApJ, 323, 749

Jewell, P.R., Snyder, L.E., Walmsley, C.M., Wilson, T.L., Gensheimer, P.D.: 1991, A&A, 242, 211

Lane, A.P.:1982, Ph. D. dissertation, Univ. of Massachusetts.

Langer, S.H., Watson, W.D.:1984, ApJ, 284, 751

Le Bertre, T., Nyman, L.-Å.:1990, A&A, 233, 477

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

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

Lindqvist, M., Winnberg, A., Habing, H.J.: 1990b, in *"From Miras to Planetary Nebulae: Which path for stellar evolution?"*, eds. M.O. Mennessier and A. Omont, Editions Frontières, Gif sur Yvette, p 259

Lindqvist, M., Winnberg, A., Habing, H.J., Matthews, H.E.:1991, A&AS in press

Martínez, A., Bujarrabal, B., Alcolea, J:1988, A&AS, 74, 273

McIntosh, G.C., Predmore, C.R., Moran, J.M., Greenhill, L.J., Rogers, A.E.E., Barvainis, R.:1989, ApJ, 337, 934

Nyman, L.-Å., Johansson, L.E.B., Booth, R.S.:1986, A&A, 160, 352

Olofsson, H., Rydbeck, O.E.H., Nyman, L.-Å.:1985, A&A, 150, 169

Spencer, J.H., Winnberg, A., Olnon, F.M., Schwartz, P.R., Matthews, H.E., Downes, D.:1981, AJ, 86, 392

van Langevelde, H.J., van der Heiden, R., van Schooneveld, C.:1990, A&A, 239, 193

Vardya, M.S., de Jong, T., Willems, F.J.:1986, ApJ, 304, L29

Winnberg, A., Baud, B., Matthews, H.E., Habing, H.J., Olnon, F.M.:1985, ApJ, 291, L45

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