Cosmic MASERs: From Protostars to Blackholes
IAU Symposium, Vol. 206, 2002
V. Migenes and M. J. Reid, eds

Highly polarized SiO $v = 0$ emission from late-type stars

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Abstract. We briefly report the results of polarimetric observations of SiO emission from late-type stars taken with a millimeter polarimeter installed at the Nobeyama 45m telescope. We found that the SiO $J = 2-1$ emission in the $v = 0$ state from R Cas contains a highly linearly polarized component, followed by the detection of highly linearly polarized emission of the same transition from VY CMa (Shinnaga et al. 1999). The high polarization degree is a strong evidence that the v=0 emission originates from maser action. We found out that, not only a peculiar supergiant star, but also a Mira variable star is associated with the SiO $v = 0$ maser.

1. Introduction

SiO maser had been first detected towards Ori A (OH) unexpectedly in 1973 (Snyder & Buhl 1974). Since then, maser emission in SiO rotational transitions in $v = 1$, 2, and 3 have been observed towards evolved, cool, long-period variable stars such as Mira-type stars and irregular sugergiants. Many survey studies of SiO masers have been carried out (e.g. Cho et al. 1996). Now more than a few hundred stars associated with SiO masers have been reported.

According to theoretical works (e.g., Goldreich, Keeley, & Kwan 1973; Deguchi, Watson, & Western 1986; Elitzur 1991; Watson 1994), polarimetric observations would be useful to test the theories for the pumping mechanisms. Regarding polarization properties of the SiO masers, many observational studies had been carried out (e.g., Troland et al. 1979; Kemball & Diamond 1997; Desmurs et al. 2000). In spite of all the observational and theoretical efforts, the pumping mechanism of the SiO masers is still a matter of debate.

https://doi.org/10.1017/S0074180900222535 Published online by Cambridge University Press

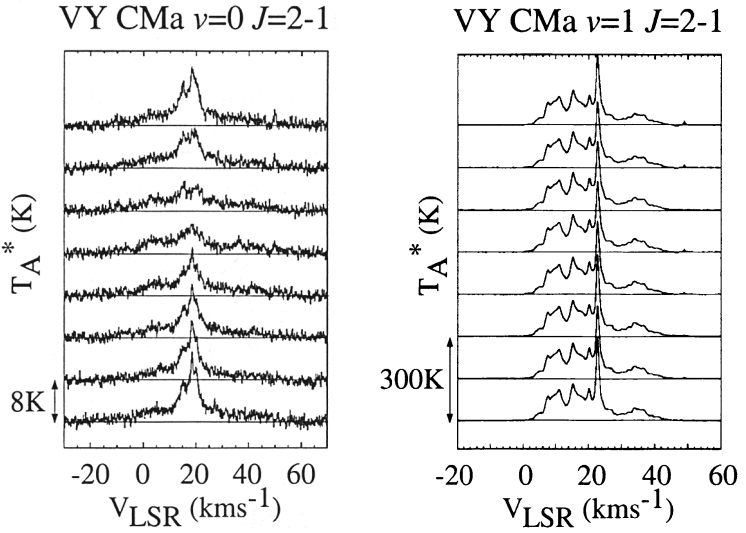

Figure 1. Spectra of SiO $J = 2 - 1$ lines towards VY CMa in the (a) $v = 0$ and (b) 1 states with different polarization angles. Data in (a) and (b) at each polarization angle had been acquired at the same time.

To infer the polarization properties further in detail, Tsuboi et al. carried out the monitoring observations of polarization survey of SiO masers towards strong SiO sources at 43 GHz using the Nobeyama 45 m telescope. Tsuboi et al. (1994) reported highly polarized $v = 0$ emission towards VY Canis Majoris (VY CMa) by observing SiO $J = 1 - 0$ transition. The high polarization degree is a strong evidence that the v=0 emission originates from maser action. To extend this study to higher-J transitions, we constructed a new polarimeter system which covers wide millimeter wavelength range at the Nobeyama 45-m telescope (Shinnaga et al. 1999). For the 86 GHz SiO masers, Shinnaga et al. (1999) clearly showed that SiO $J = 2 - 1$ transition in ground vibrational state of VY CMa is also highly linearly polarized (see figure 1a). VY CMa is known as a peculiar supergiant star in terms of the huge mass loss rate ($\sim 2 \times 10^{-4}$ $M_\odot$ yr^{-1}; Danchi et al. 1994) at a distance of 1.5 kpc (Lada & Reid 1978).

There is a remaining question whether SiO $v = 0$ maser is universal phenomena in late-type stars with SiO masers or a peculiar phenomenon for a peculiar supergiant star. To address this question, we made a survey observation of high signal-to-noise polarimetry of the SiO $J = 2 - 1$ transition in the $v = 0$, 1, and 2 state in some other stars.

2. Observations

The observations had been taken place in March 1998 and May 1999. The emission of the SiO $J = 2 - 1$ in the $v = 0$ and 1 states was simultaneously acquired at eight different position angles . The beam size of the 45-m telescope at 86 GHz was 18". We used an acousto-optical spectrometers (AOS) with a total band width of 40 MHz at a resolution of 37 kHz, corresponding to 0.13 km

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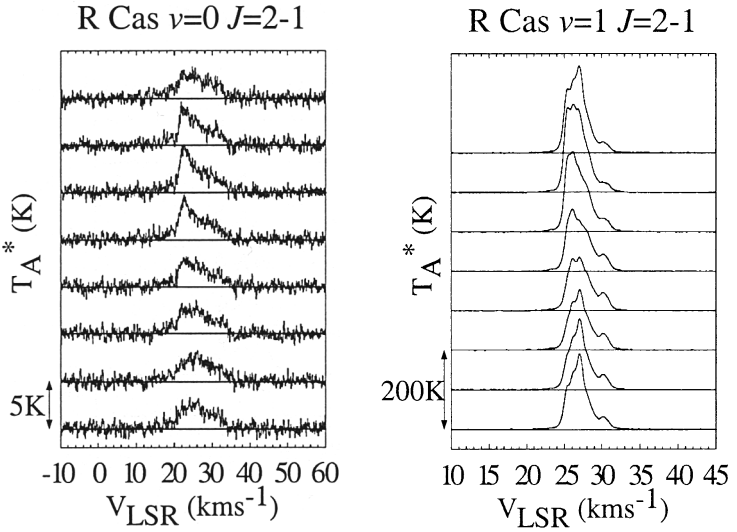

Figure 2. Spectra of SiO $J = 2 - 1$ towards R Cas in the (a) $v = 0$ and (b) 1 states with different polarization angles. Data in (a) and (b) at each polarization angle had been acquired at the same time.

s^{-1} in velocity. Pointing was corrected by observing the SiO sources themselves, at an accuracy of better than 5". The basic observational procedure is described in Shinnaga et al. (1999).

3. Results and Discussions

The spectra in Figure 1 (a) clearly shows two very narrow velocity components in the $v = 0$ state, as well as a weak broad emission feature. The peak intensity of the brightest narrow feature is $\sim$ 45 Jy. Our measurements show that the degree of linear polarization of the maser features is quite large (up to $\sim$ 50%). The weaker thermal emission is likely extended and traces a bipolar outflow in the circumstellar envelope. Since both v=0 and 1 transitions were observed simultaneously, they suffer the same experimental error. Therefore, the spectra prove that the observed polarizations for each transition are genuine.

Studying the highly linearly polarized emission in the SiO ground vibrational state, other examples have been investigated. As results of our survey observations, we found out that other stars have similar polarimetric characteristics as that of VY CMa. Here, we show the same spectra towards R Cassiopeiae (R Cas) in Figure 2. One prominent component in the ground state clearly shows the highly linearly polarized feature. The polarization degree of the $v = 0$ towards R Cas is up to $\sim$ 40 %, although the polarization degree of the $v = 1$ towards the star is only up to $\sim$ 25%. R Cas is a visual binary system formed by a Mira-type star with a faint companion at 28 – 30" from it (Proust et al. 1981) or a projected sky distance of $\sim$ 270 pc (Cahn & Elitzur 1979).

In conclusion, we found that the highly polarized ground state SiO maser is not an unique phenomenon for a particular star. Buhl et al. (1975) discussed

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the possibility of the $v = 0$ maser based on their survey work. Although they claimed that only the $v = 0$ emission towards VY CMa could be interpreted as a maser by judging from their profiles, our polarization measurements work proves that VY CMa is not only the case. The detail survey results will be described in another paper (Shinnaga, Tsuboi, & Kasuga 2001). To infer the pumping mechanism of the ground vibrational state SiO maser in detail, high resolution observations are needed.

Acknowledgments. This work was supported by Yamada Science Foundation and Foundation for Promotion of Astronomy. Authors thank the members of the 45 m telescope group for supporting the measurements and T. Ohno, A. Miyazaki, S. Imaizuki, & H. Kanno at Ibaraki University for their extensive help during the observations.

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