Simultaneous observations of the two SiO maser transitions at 7 mm using the VLBA

By JIYUNE YI[1], R. BOOTH[1], J. CONWAY[1], P. DIAMOND[2] AND A. WINNBERG[1]

[1]Onsala Space Observatory, Onsala, Sweden

[2]University of Manchester, Jodrell Bank Observatory, Macclesfield, Cheshire SK11 9 DL

We have performed simultaneous VLBI observations of the SiO $v = 1$ and $v = 2$, $J = 1 - 0$ masers in the circumstellar envelopes of two mira variables, TX Cam and R Cas. A simultaneous observation of these two different lines is the only way to test if they are excited under the same physical conditions, but it challenges interferometry technique on both observation and calibration procedures to track the delay across the 300 MHz frequency gap between two lines. We report our successful results on these experiments with images of the 43 GHz $v = 1$ and $v = 2$ SiO maser lines.

1. Introduction

During their time on the asymptotic giant branch (AGB) stars begin to expel matter at a high rate but at a low velocity and they form a circumstellar envelope. Dust particles of silicate material solidify where the radiation temperature falls to about 1000 K, which is considered to be at a few stellar radii and SiO maser lines are believed to be formed deep in the envelope, below the dust condensation layer. Many circumstellar envelopes host OH, H_2O, and SiO masers and due to their high brightness temperatures, high resolution interferometric observations of these masers have been of great use in the study of the physical conditions in the envelopes of the late-type stars. Given their probable location inside the dust condensation radius, SiO masers are an unique probe of the inner part of circumsteallr envelopes. However, these extended atmospheres suffer from stellar pulsations and shocks which makes it difficult to understand the underlying physics of the pumping mechanism. We need a better understanding on the inversion schemes for the SiO masers and these observations were performed in the hope that we might gain further insights into this problem.

Observing the 7mm SiO masers in the $v = 1$ and $v = 2$, $J = 1 - 0$ transitions can be a useful tool to test pumping theories. The excitation temperature of the $v = 2$ line is double that of the $v = 1$ line, but their spectra are often very similar. To test the pumping mechanisms it is therefore of interest to determine the spatial distribution of the masers in each of the lines. We have conducted simultaneous observations of these two lines in Mira variables, TX Cam and R Cas using the VLBA. Here, we present our results based on images of TX Cam.

2. Observation

Simultaneous observations of two 43 GHz SiO maser lines in the $v = 1$ and $v = 2$, $J = 1 - 0$ toward TX Cam and R Cas were made using the Very Long Baseline Array (VLBA). Each source was observed for 4 hours in September 1998. The data were recorded in right circular polarization with a 8 MHz bandwidth ($\sim 56\ km\ s^{-1}$); line rest frquencies of 43.122027 GHz for $v = 1$ and 42.820542 GHz for $v = 2$ were adopted. In an attempt to track the delay across the 300 MHz between the two SiO lines and hence determine accurate relative positions in the two lines we centred 2 of our 8 bands at the $v = 2$ and $v = 1$ frequencies, respectively and distributed the other 6 bands evenly across the 300 MHz between $v = 2$ and $v = 1$ frequencies. The data were recorded in VLBA format and correlated in Socorro, New Mexico. Auto and cross-correlation spectra were produced with 256 spectral channels (31.25 kHz resolution). The synthesized beam was $\sim 0.6 \times 0.4$ mas for TX Cam and $\sim 0.5 \times 0.4$ mas for R Cas. Calibration and image processing will be described in more detail in a forthcoming paper.

3. Results and Discussions

In this paper we will only report on the results of TX Cam and include images from earlier observations. Maser features appear in the velocity ranges between 3.4 $km\ s^{-1}$ and 14.6 $km\ s^{-1}$ in the $v = 1$ line, and 3.1 $km\ s^{-1}$ and 15.3 $km\ s^{-1}$ in the $v = 2$ line respectively. The optical phase of TX Cam at this epoch was $\phi \sim 0.54$. Figure 1 shows images integrated over all velocity channels containing emission from two epochs of observations toward TX Cam. The ring structure presented in previous work by Booth et al.(unpublished) (shown in the upper images in Fig.1) is no longer apparent but much more disrupted shell structures appear with weakened total intensity in the lower images in Fig.1. Most of the features on the western side, which are blueshifted (assuming its stellar velocity of 9 $km\ s^{-1}$) and shown also by other observations (Diamond et al. 1994; Kemball & Diamond 1997), have disappeared in the later epoch but two blueshiftedmaser complexes appear persistently on the south-west side over both observations.

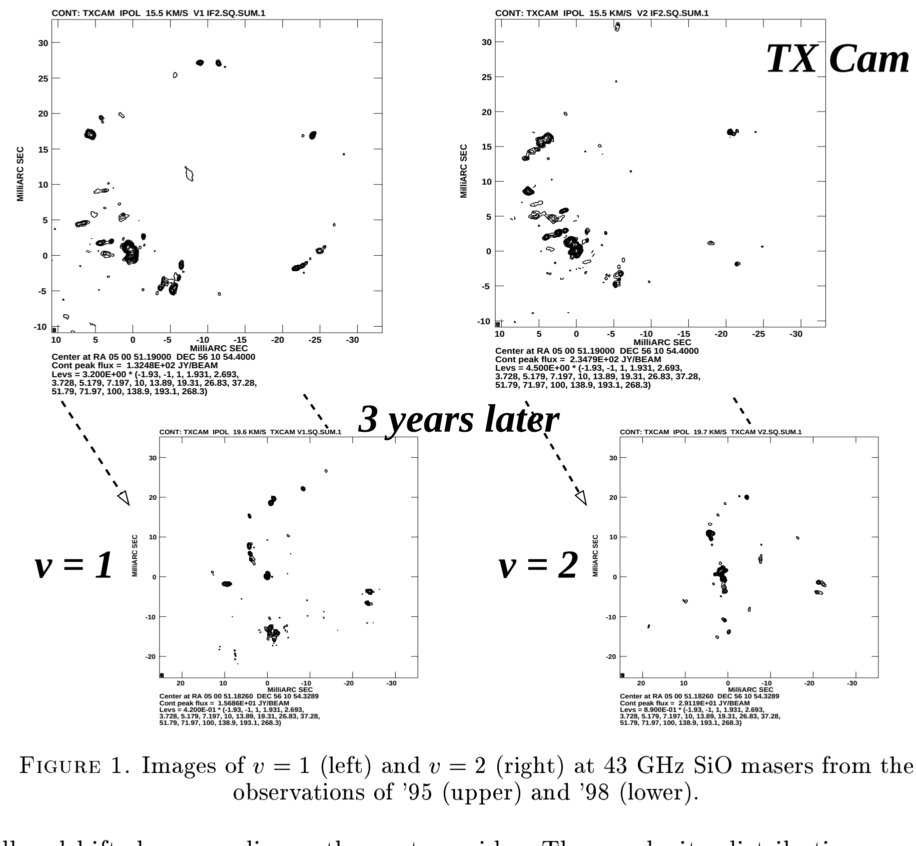

FIGURE 1. Images of $v = 1$ (left) and $v = 2$ (right) at 43 GHz SiO masers from the observations of '95 (upper) and '98 (lower).

All redshifted masers lie on the eastern side. These velocity distributions are consistent with the results of Diamond et al (1994) and with the hypothesis of tangential amplification of the masers.

Cho et al. (1996) have shown that the SiO $v = 1$ and $v = 2$ maser velocity patterns change as a function of stellar phase; sources with redshifted emission are dominant during the stellar phases from 0.3 to 0.8, while the sources with blueshifted emission are mostly seen during the phases from 0.0 to 0.2. Our two sets of observations toward TX Cam were made at its stellar phases of $\phi \sim 0.54$ and $\phi \sim 0.6$ for '98 and '95 observations, respectively and the maps in figure 1 show the majority of features are redshifted, which seems to be in agreement with the phase dependence on the velocities.

Considering now the relative ditributions of the $v = 1$ and $v = 2$ lines, our maps of '95 show that the diameter of $v = 2$ ring is smaller than the one of $v = 1$, and although the clear ring shape of the shell seems to be disrupted in the map of '98, the spacial distribution of maser features of $v = 1$ masers are, in general, displaced further from the star than the corresponding $v = 2$ features. Humphreys et al. (1996) predict from their simulated maps of $v = 1$ and $v = 2$ 43 GHz SiO masers that $v = 2$ masers lie a little inside (closer to the star) than the equivalent $v = 1$ masers. The separation will, they predict, vary as a function of stellar phase, as a shock transversing the maser zone encounters the $v = 2$ masers first, causing the $v = 2$ maser 'ring' to expand before the $v = 1$ ring. Humphreys et al. make the point that, although the two maser transitions can be pumped by the same sets of physical conditions, and therefore be spatially coincident in maps, the model results show that, consistently, the brightest $v = 2$, 43 GHz masers are pumped by conditions of higher density in the circumstellar envelope, closer to the star and therefore also in a denser stellar radiation field.

Overall our images of TX Cam over 43 months have shown that the ring structures of maser emissions can be greatly disrupted which is now understood as one of phase depedence features of SiO maser emission. A discussion of maser pumping from the comparison of spatial distributions between $v = 1$ and $v = 2$ 43 GHz masers at a single epoch would be over simplified. We will, in the next year or so perform multi-epoch VLBA observations to confirm the phase dependence features and constrain the inversion scheme with higher accuracy. In the forthcoming paper(s) we will be able to present multi-epoch images of both TX Cam and R Cas at different stellar phases and, we hope, ever-firmer constraints on pumping models.

REFERENCES

Cho, S.-H., Kaifu, N., & Ukita, N. 1996 *AJ* **111**, 1987.

Diamond, P. J., Kemball, A. J., Junor,W., Zensus, A., Benson J., & Dhawan V. 1994 *ApJ* **430**, L61.

Humphreys, E.M.L., Gray, M.D., Yates, J.A., Field, D., Bowen, G. & Diamond, P. J. 1996 *MNRAS* **282**, 1359.

Kemball, A. J., & Diamond, P. J. 1997 *ApJ* **481**, L111.