# Correlation of the Relative SiO Maser Distributions with the Stellar Light Curves

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We carried out VLBI observations of SiO $v = 2$ and $v = 3$ $J = 1 \rightarrow 0$ masers towards 12 long-period variables (LPVs) using four telescopes of the VLBI Exploration of Radio Astrometry (VERA) combined with the Nobeyama 45 m telescope. We found some correlation of the relative maser distributions with the stellar light curves. The location of the $v = 2$ masers coincide with the $v = 3$ masers region at pulsation phase $\phi = 0.0 - 0.2$.

**Keywords**: AGB stars, SiO masers.

## 1 Introduction

There are three models of the pumping mechanism of circumstellar SiO masers: (1) stellar radiation pumping; (2) collisional pumping; (3) $H_2O$–SiO line overlapping [1, 2, 3]. It has been difficult to distinguish the most plausible model from the previous observations of only the $v = 1$ and $v = 2$ maser lines in the $J = 1 \rightarrow 0$ transition. Here, we focus on the $v = 3$ maser line, which is expected to provide a new clue of the dominant maser pumping mechanism. According to the theoretical model of the third mechanism, the location of the $v = 2$ masers seem to coincide with the $v = 3$ masers region with respect to the central star when the line overlapping mechanism of the $v = 2$ masers is enhanced [3]. In fact, the results of Imai, et al. (2010) showed that, in W Hya, only the distance to the $v = 2$ masers from the central star visibly changed with time (by up to 4 mas) while those to the $v = 3$ masers hardly changed (with in 1 mas in two months) [4]. According to Gonidakis, et al. (2013), the positions of the $v = 1$ (likely as well as the $v = 2$) $J = 1 \rightarrow 0$

masers toward TX Cam move with the propagation of shock waves caused by pulsation of the central star [7]. In the case of W Hya, however, it was not clear whether the $v = 2$ masers came to coincide with the $v = 3$ masers region as a shock wave propagated. We expect that the $v = 3$ masers should be a unique prove to investigate the origin of the change in the $v = 2$ maser distribution with respect to that of the $v = 3$ masers and its dependence on stellar pulsation (light curve) phase.

## 2 Observations and results

We carried out VLBI observations of SiO $v = 2$ and $v = 3$ $J = 1 \rightarrow 0$ masers towards 12 LPVs (WX Psc, AP Lyn, U Ori, VY CMa, R Leo, RS Vir, W Hya, U Her, RU Her, V1111 Oph, V4120 Sgr, and T Cep) using four VERA 20 m telescopes and the 45 m telescope of Nobeyama Radio Observatory (NRO) on March 24–25 and May 21–22 in 2012. The target sources were selected from the $v = 3$ maser sources observed by Cho et al. (1996) [5]. The combination of the VERA and NRO telescopes covers baseline lengths from 400 km to 2300 km, which enabled to detect relatively extended maser emission compared with those detected with VERA only.

The $v = 3$ maser emission was detected towards five out of 12. We succeeded in superimposition of the $v = 2$ and the $v = 3$ maser maps towards

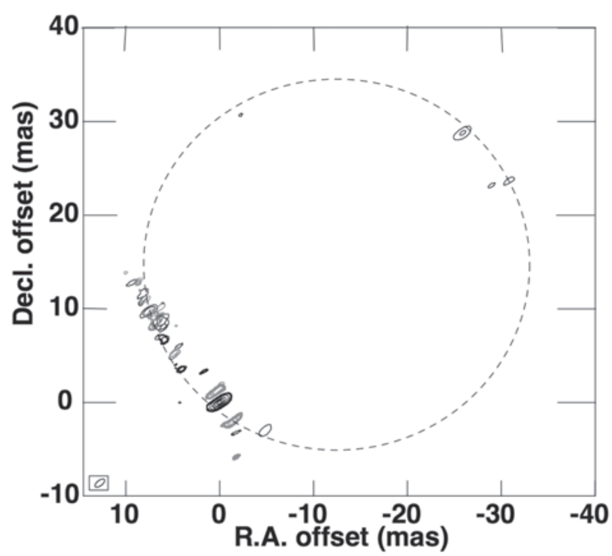


Fig. 1. Composite map of $v = 2$ (thick black contours) and $v = 3$ (thin grey contours) maser lines toward T Cep observed on May 20 ($\phi$ ~0.2). A dashed circle is drawn so as to fit to the $v = 2$ maser distribution

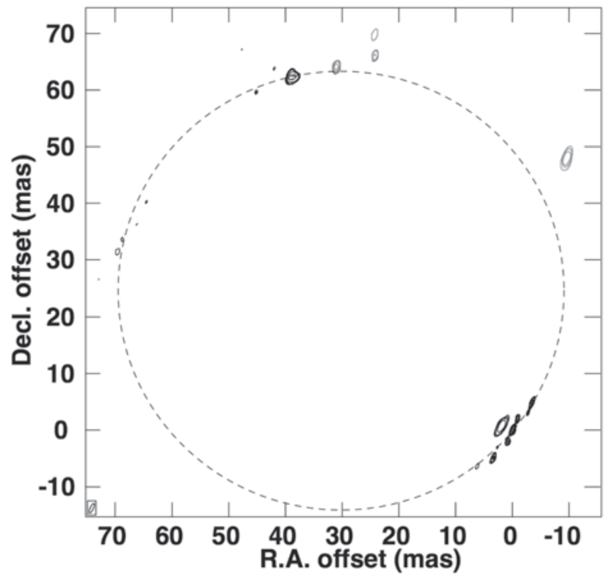


Fig. 2. Same as Fig. 1 but toward W Hya observed on May 20 ($\phi$ ~0.0)

T Cep, W Hya, WX Psc, and R Leo using the phase-referencing technique. In this technique, the visibility data in the velocity channel including the brightest $v = 2$ maser were used for fringe fitting and self-calibration, whose solutions were applied to the data of the remaining $v = 2$ and the $v = 3$ masers. Then, the $v = 3$ maser map was registered with respect to the position of the brightest $v = 2$ maser spot. Fig. 1 shows composite map in T Cep. The accuracy of the map registration was limited to $\sim 1$ mas because the fringe fitting solutions included the data of NRO, which had an antenna position error about a few decimeters. In the case of W Hya (Fig. 2), the uncertainty of the map registration is $\sim 50$ $\mu$as because the solutions does not include the data of NRO, but only the data of VERA.

## 3 Discussion

In T Cep (Fig. 1), it is clear that the $v = 2$ masers are well correlated with the $v = 3$ masers in the spatial distribution. In W Hya (Fig. 2), the distance to the $v = 2$ masers from the central star is the same as that to the brightest $v = 3$ maser spot. The locations of the $v = 2$ masers with respect to the $v = 3$ masers are consistent with that expected from the line-overlap theory. T Cep and W Hya were observed at light-curve phases of $\sim 0.2$ and $\sim 0.0$, respectively. In addition to our results, Imai, et al. (2010) showed that the $v = 2$ masers located in the same region of the $v = 3$ masers at phase $\sim 0.2$. From these observations, we predict that the line overlapping mechanism of the $v = 2$ is likely enhanced at $\phi = 0.0 - 0.2$, when the infrared emission from $H_2O$ molecule would increase. This phase is consistent with the mid-infrared maximum delayed from the visual maximum by phase $0.15 \pm 0.05$ [6].


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