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Pumping Mechanisms for SiO Masers around VX Sgr

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Abstract. VX Sgr, a semi-regular variable, is a red giant star with intense SiO maser emission at 43 GHz. The pumping mechanism of the circumstellar SiO masers has been controversial for decades since its discovery. In order to pursue this long-standing problem further, we have carried out simultaneous VLBA observations of two 7 mm SiO masers at five epochs in about two years. We present relatively aligned $\upsilon = 1$ and $\upsilon = 2$, $J = 1$–0 SiO maser maps and discuss the dominant pumping mechanism, which may be epoch dependent or a combination of both mechanisms.

Key words. Stars: individual (VX Sgr) — techniques: interferometric.

1. Introduction

VX Sgr is a semi-regular variable with an optical pulsation period of about two years. The star exhibits intense SiO maser emission (Greenhill *et al.* 1995; Xi *et al.* 2006). The SiO maser pumping mechanism remains open with both radiative pumping and collisional pumping models plausible. SiO masers, arising closer to the surface of the star than OH, H_2O masers, are believed to be a powerful tool to study the extended stellar atmosphere. The radiative pumping models predict that SiO masers from $J = 1$–0 rotational transitions of different vibration states $\upsilon = 1$ and $\upsilon = 2$ cannot lie in the same zone. Interestingly, VLBI observations by Miyoshi *et al.* (1994) showed co-spatial distribution of two lines within 2 mas, and thus (inconclusively, because of its poor resolution of 7 mas) argued for the collisional pumping model; whereas Desmurs *et al.* (2000) showed systematically smaller radii for $\upsilon = 2$ masers in TX Cam by 2.6±0.5 mas (compared with resolution of 0.6×0.3 mas), which seems to support the radiative pumping scheme. In order to further investigate the pumping mechanism of SiO masers, we performed the multi-epoch high-resolution VLBA observations of both $\upsilon = 1$ and $\upsilon = 2$, $J = 1$–0 SiO masers to test the universality of any valid pumping models.

2. Observations

We performed simultaneous observations of two 7 mm SiO masers with the corresponding rest frequency of 43.122 and 42.820 GHz using the VLBA, towards VX

Sgr at five epochs in about two years. The observations were separated by approximately six months to cover the 2-yr pulsation cycle of VX Sgr. We used a special phase referencing technique (bandwidth synthesis) to achieve the relative position between the two transitions. With a delay accuracy of 1 nano-second, the phase could be linked between the two lines by tracking the group delay across all IFs without any 2π ambiguities, and later transferring the phase solutions from one IF to the other (rather than independent self-calibration of each IF). The technique enabled us to achieve the relative position with a sub-milliarcsecond accuracy. The post data reduction is done using AIPS.

3. Results and discussion

Figure 1 shows the relative position and total intensity, which is summed over all velocity channels with emission. The masers exhibit a ring structure with a radius of 14 mas around VX Sgr. At epochs I and II, υ=1 masers form a clear ring structure, but the $\upsilon = 2$ line has relatively few maser features, most of which reside in the Southern and Northern parts. From epoch III, more υ=2 masers appear, both υ=1 and υ=2 lines develop a ring structure. Interestingly, at epochs IV and V, many new stronger masers of both the lines appear, among which the main features reside in the inner shell and show almost the same shape and location in the two transitions.

For a long time, SiO maser pumping mechanism is controversial with both radiative pumping (Bujarrabal *et al.* 1996; Desmurs *et al.* 2000) and collisional pumping models (Lockett & Elitzur 1992; Doel *et al.* 1995). In the radiative schemes, the stellar radiation provide the energy and υ=1 and υ=2, J=1−0 masers are expected to be pumped under different physical conditions. The υ=2 maser spots tend to be a bit closer to the central star. In the collisional schemes, the masers energy comes from collision of the shock in the outflow with H_2 molecules. The model predicts that the masers in the two transitions should be coincident in space and velocity.

Based on the different predictions of two different models, the relative position is usually considered as a critical evidence to constrain the pumping mechanism. The first two epochs I and II show that the $\upsilon = 2$ maser spots are distributed in the Southern and Northern parts, while the υ=1 maser spots form a ring structure. The large difference in the distribution can be explained more easily by radiative pumping than by collisional pumping. Because in radiative schemes, the systematically different physical conditions are required to pump the masers. Therefore, compared to collision, radiation tends to pump the two types of masers distributed in different space. The detailed analysis of the relative positions in these two epochs is ongoing. In epoch III, both masers form a ring structure, but the $\upsilon = 2$ masers are closer to the central star than the $\upsilon = 1$ masers. In epoch IV, many new maser spots appear, among which the main/brightest spots from both υ=1 and υ=2 masers show almost the same shape and location. Epoch V keeps the characteristics of the epoch IV.

In all five epochs, the relative position of both masers changes. Perhaps the real pumping mechanism is epoch dependent or a combination of both mechanisms. Future multi-frequency and multi-epoch observations are still necessary in order to obtain more powerful evidence.

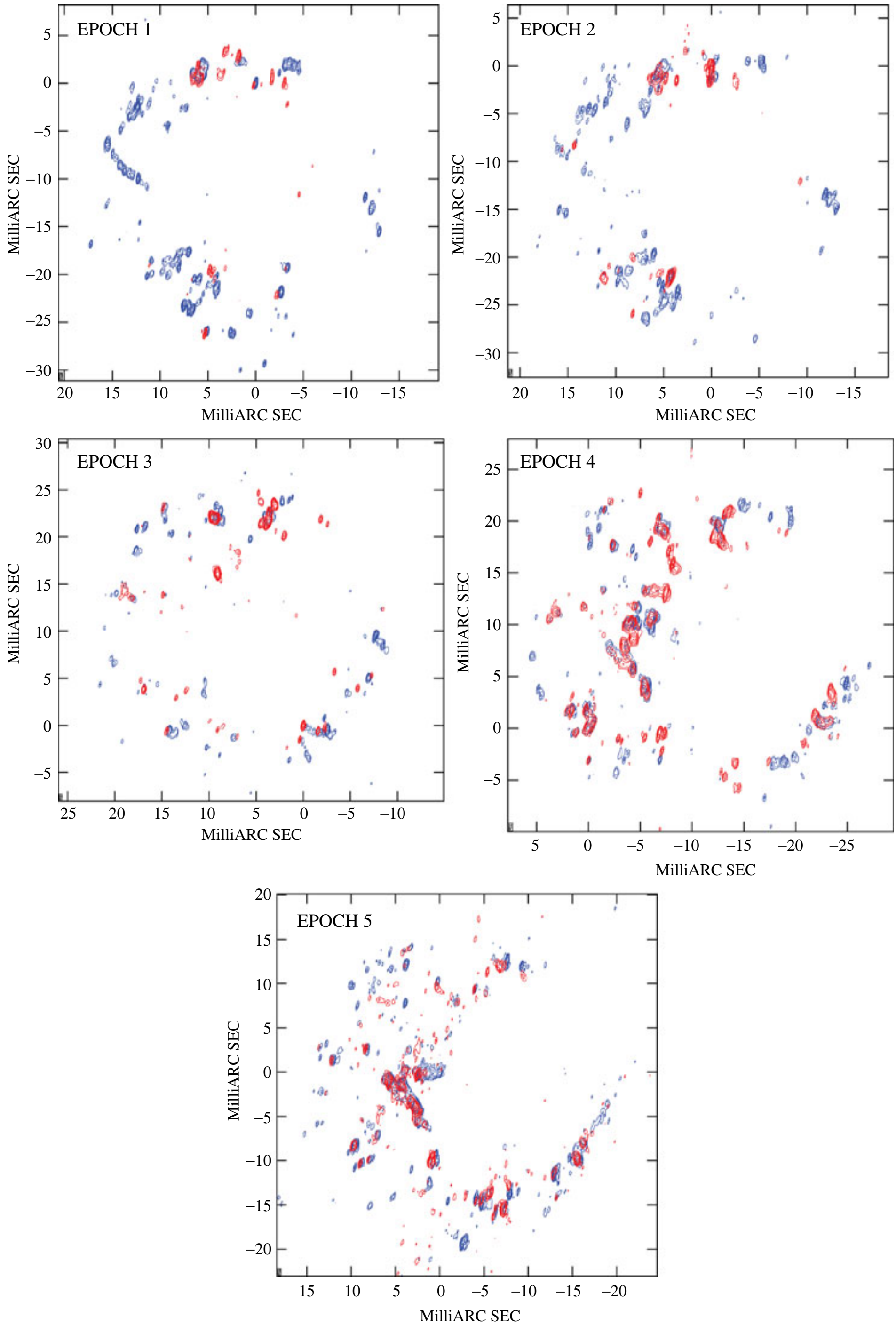

Figure 1. The relative position of υ=1 and υ=2 masers, which are represented by the blue and red contour, respectively. The vertical and horizontal axes represent declination and right ascension. Units: milli-arcsecond.

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