A Giant Step: from Milli- to Micro-arcsecond Astrometry
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Astrometry of red supergiant VY Canis Majoris with VERA

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Abstract. We present observational results on the red supergiant VY Canis Majoris with VERA. We have observed 22 GHz H_2O masers and 43 GHz SiO masers (v=1 and 2 J=1-0) around VY CMa for 13 months. We succesfully detected a parallax of 0.87 ± 0.08 mas, corresponding to the distance of $1.15\ ^{+0.10}_{-0.09}$ kpc using H_2O masers. As the result of phase-referencing analyses, we have measured absolute positions for both H_2O masers and SiO masers. The H_2O maser features show rapid expansion off the central star.

Keywords. astrometry, masers, stars: distances, supergiants, stars: individual (VY CMa)

1. Introduction

VY CMa is one of the most luminous red supergiants in our galaxy. Its luminosity is 4.3×10^5 $L_\odot$ (Humphreys, Helton & Jones 2007) and distance is estimated to be 1.5 kpc (Lada & Reid 1978). VY CMa is ejecting large amount of gas and dust at a high mass loss rate of 4×10^{-4} $M_\odot$ yr^{-1} (Danchi *et al.* 1994). H_2O and SiO masers are commonly found in circumstellar envelopes (CSE) of supergiants. They are important tools to study structures and kinematics of the CSE, the mass-loss process and evolution of massive stars.

2. Parallax measurements of VY CMa

We have observed H_2O masers around the red supergiant VY CMa at 10 epochs with VERA for 13 months. The source J0725-2640, whose angular distanc from VY CMa is 1.059 deg, was observed as a positional reference source. Using a bright H_2O maser spot at the LSR velocity of 0.55 km s^{-1}, we succesfully detected a trigonometric parallax of 0.87 ± 0.08 mas, corresponding to the distance of $1.15\ ^{+0.10}_{-0.09}$ kpc. Figure 1 shows the results of our positional measurements for this H_2O maser spot. The astrometric accuracy in right ascension is better than that in declination. A possible reason for this disparity could be uncertainty in the atmospheric zenith delay.

3. H_2O masers and SiO masers around VY CMa

SiO masers are detected in a spherical shell at 2–4 R_* from the central star (Diamond *et al.* 1994) but the H_2O masers are distributed over a wider region than SiO masers. The resulting phase-referencing analysis indicates that the absolute positions for both H_2O masers and SiO masers are measured with an accuracy better than 1 mas. Figure 2

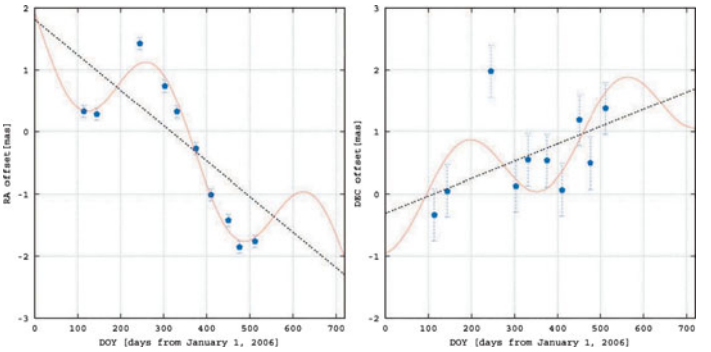

Figure 1. Results of position measurements for H_2O maser spot at the LSR velocity of 0.55 km s^{-1} in VY CMa. *Left panel*: The motion of the maser spot in RA as a function of time over 13 months. *Right panel*: The same as left panel but for Dec. Solid lines represent the best fit model for annual parallax and proper motion of a maser spot. Dotted lines represent proper motion (-2.09 mas yr^{-1} in RA and 1.02 mas yr^{-1} in Dec) and points represent the observed positions of a maser spot with error bars indicating the standard deviation from least-squares analysis (0.10 mas in RA and 0.42 mas in Dec).

shows the distribution of H_2O and SiO maser features. From the position of SiO maser ring, we can estimate the position of stellar component. The H_2O maser features move away from the central star with the velocity of 5–30 km s^{-1}. The diameter of SiO maser feature is about 40 mas, corresponding to 46 AU at the distance of 1.15 kpc. If the SiO masers are formed at 2 stellar radii, then the radius of VY CMa should be about 1200 $R_\odot$.

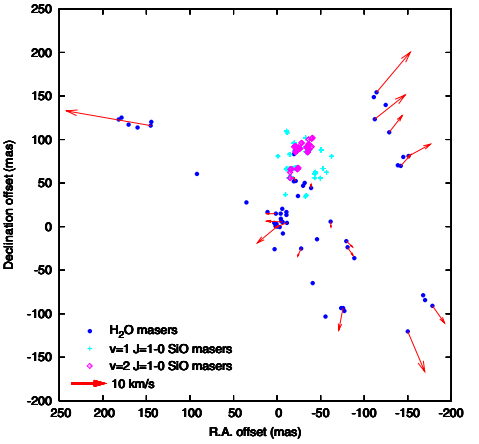

Figure 2. Direct Comparison of absolute positions between H_2O masers and SiO masers are possible with phase-referencing analyses. Closed circle, cross and open diamond represent H_2O masers, v=1 and v=2 J=1-0 SiO masers, respectively. Arrows represent the proper motion of H_2O masers from which the mean motion has been subtracted.

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