Cosmic Masers - from OH to H_0
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Distance and Size of the Red Hypergiant NML Cyg

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Abstract. We present astrometric results of phase-referencing VLBI observations of 22 GHz H_2O maser and 43 GHz SiO maser emission towards the red hypergiant NML Cyg using VLBA. We obtained an annual parallax of 0.62 ± 0.04 mas, corresponding to a distance of $1.61^{+0.13}_{-0.11}$ kpc. With a VLA observation in its largest (A) configuration at 43 GHz, we barely resolve the radio photosphere of NML Cyg, and find a uniform-disk diameter of 44 ± 16 mas.

Keywords. astrometry — masers — instrumentation: interferometric — stars: distance — stars: individual (NML Cyg) — supergiants

1. Introduction

NML Cyg has been assumed to be at the same distance as the Cyg OB2 association (Morris & Jura 1983). The luminosity of NML Cyg derived using the previous estimated distance of 1.74 ± 0.2 kpc by Massey & Thompson (1991) places it near the empirical upper luminosity boundary on the H-R diagram (Schuster *et al.* 2006). However, a luminosity estimate of a star is dependent on the square of its distance. Thus, a trustworthy distance is crucial to derive a reliable luminosity of NML Cyg. In addition to the distance, another fundamental stellar parameter is the size. NML Cyg's high mass-loss rate results in a dense circumstellar envelope, thus the star is hardly observable at visual wavelengths due to high extinction, while it is extremely luminous in the infrared. Blöcker *et al.* (2001) obtained a central star luminosity by integrating the spectral energy distribution from 2 to 50 μm, and derived a stellar diameter of 16.2 mas assuming $T_{\rm eff}$ = 2500 K. However, a direct detection of the star would be superior to indirect methods. Radio continuum emission from the evolved star's photosphere can be imaged by VLA using SiO masers as a phase reference (Reid & Menten 2007; Zhang *et al.* 2012), this allows us to directly determine the size of NML Cyg's radio photosphere.

2. Parallax of NML Cyg

We conducted VLBI phase-referencing observations of circumstellar 22 GHz H_2O and 43 GHz SiO masers toward NML Cyg and several extragalactic radio sources with the VLBA at five epochs in one year. We identified about 20 H_2O maser features with a $V_{\rm LSR}$ range of $-25.4 - 6$ km s^{-1}, while the SiO masers were very weak during our observation and only detectable at the last epoch. Using the positions of 18 H_2O maser spots relative to three background sources J2044+4005, J2046+4106 and J2049+4118 within 2° of

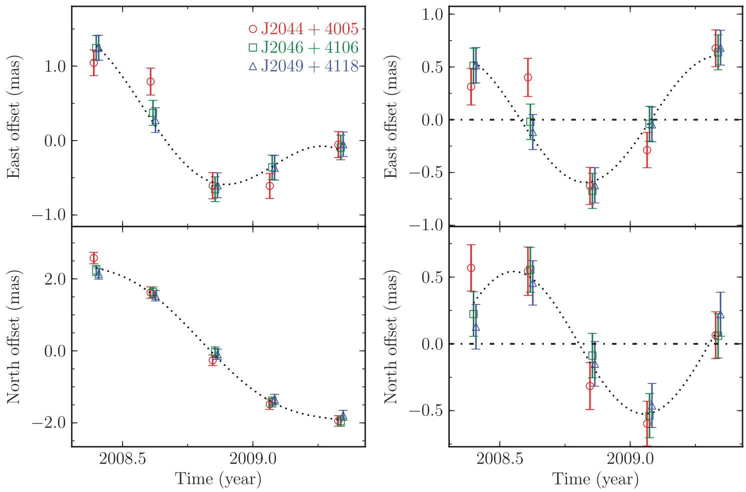

Figure 1. Parallax and proper motion data (*markers*) and best-fitting models (*dotted lines*) for the maser spot at the $V_{\rm LSR}$ of 6.48 km s^{-1}. Plotted are positions of the maser spot relative to the extragalactic radio sources J2044+4005 (*circles*), J2046+4106 (*squares*) and J2049+4118 (*triangles*). *Left panel*: Eastward (*solid lines*) and northward (*dotted lines*) offsets and best-fitting models versus time. Data of the eastward (*upper panel*) and northward (*bottom panel*) positions are offset horizontally for clarity. *Right panel*: Same as the *left panel*, except the best-fitting proper motion has been removed, displaying only the parallax signature.

NML Cyg, we determined a trigonometric parallax of 0.62 ± 0.04 mas, corresponding to a distance of $1.61^{+0.13}_{-0.11}$ kpc. Fig. 1 shows the parallax fit of one of the maser spots as an example.

3. Radio Photosphere of NML Cyg

We detected weak continuum emission at 43 GHz from the radio photosphere of NML Cyg using a calibration scheme in which circumstellar masers provide a phase reference for the continuum data with VLA. Taking into consideration possible biases introduced by the deconvolution process of images at low SNR, we fitted a round disk model to the *uv*-data directly and obtained a diameter of 44 ± 16 mas, which is comparable with two times that derived from the Stefan-Boltzmann law with a revised luminosity according to our distance and $T_{\rm eff} = 2500$ K.

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A memorable before dinner speech by Phil Diamond.

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