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Astrometry of H_2O maser sources in nearby star-forming regions with VERA

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We present recent results of astrometic observations of H_2O maser sources in nearby molecular clouds with VERA. The main goal of our study is to measure the absolute proper motions and distances to nearby molecular clouds within 1 kpc from the Sun to reveal their 3-dimensional structures. So far, we have successfully measured the annual parallaxes of Orion KL in Orion, IRAS16293-2422 in Ophiuchus, NGC1333 SVS13 and L1448C in Perseus, and L1204G in Cepheus. Our results demonstrate the high capability of astrometry with VERA, which can provide most accurate distances to nearby molecular clouds. This will also enable us to reveal the overall structure of the local arm of our Galaxy as well as the Gould Belt.

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1. Introduction

In the last decade, phase-referenced VLBI astrometry of both high-mass and low-mass star-forming regions in nearby molecular clouds (<1 kpc) have been developed rapidly. Annual parallaxes have been successfully measured with VLBI Exploration of Radio Astrometry (VERA) and Very Long Baseline Array (VLBA). All of these works provide the most accurate distances toward the molecular clouds such as the Ophiuchus [10, 12], Taurus [12], Perseus [6, 8], Serpens [4], Orion [5, 11, 13, 16], and Cepheus [7, 14] regions as shown in Figure 1. These results are essential to refine physical and dynamical properties such as size, mass, and luminosity in star-forming regions.

Here we briefly review our results of annual parallax measurements with VERA of the H_2O maser sources associated with nearby star-forming regions as summarized in Table 1.

2. Observations

VERA observations of H_2O masers (22235.080 MHz) have been carried out since 2004. The baseline length of VERA ranges from 1000 to 2300 km. All of the observations were made in the dual-beam mode with which target maser sources and phase-reference sources were observed simultaneously. Calibration and imaging were performed using the NRAO Astronomical Image Processing System (AIPS). First, we adopted the results of dual-beam phase calibration measurements and the corrections for the a priori delay model applied in the correlation processing, although these by themselves are not accurate enough for precise astrometry. Amplitude and bandpass calibrations were made for each of a target and a reference source independently, while phase calibrations were made only for the reference source, of which solutions were applied to the target source. Further details are described in [9, 5], and references therein.

Table 1: Distances toward nearby star-forming regions observed with VERA

Source Name	Tracer	Parallax (mas)	Distance (pc)	Reference
L1448C	H_2O	4.31±0.33	232±18	[8]
NGC1333 SVS13	H_2O	4.25±0.32	235±18	[6]
Orion KL	H_2O	2.29±0.10	437±19	[5]
Orion KL	SiO	2.39±0.03	418±6	[11]
IRAS 16293-2422	H_2O	$5.6^{+1.5}_{-0.5}$	178^{+18}_{-37}	[10]
L1204G	H_2O	1.31±0.05	764±27	[7]

3. Results and Discussion

Figure 2 shows examples of the astrometric results from VERA, in which we carried out multi-epoch VLBI observations of a well known H_2O maser source Orion KL [5]. This is one of the first astrometric results obtained with VERA. One can easily find that the motion of the maser spot consists of a linear proper motion and sinusoidal modulation due to an annual parallax. The annual parallax of Orion KL is derived to be 2.29±0.10 mas, corresponding to the distance of 437±19 pc

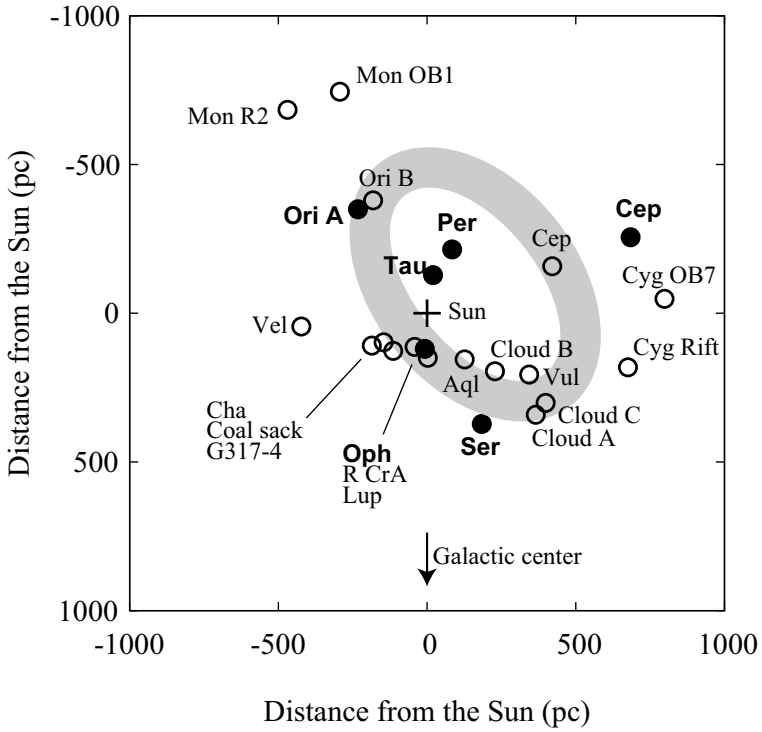

Figure 1: Distributions of nearby molecular clouds [3, 17]. Filled circles represent the positions of molecular clouds whose distances have been measured with VERA (Cepheus, Orion, Ophiuchus, and Perseus) and VLBA (Cepheus, Orion, Ophiuchus, Serpens, and Taurus). A grey ellipse indicates the Gould Belt [17].

from the Sun [5]. Subsequently, we carried out astrometry of the SiO masers associated with Orion KL (radio source I) and successfully determined the distance with higher accuracy, 418±6 [11]. All of these results are consistent with those obtained for other radio continuum sources in the Orion Nebula Cluster, 414±7 pc [13].

We also obtained the distances of NGC1333 SVS13 and L1448C in the Perseus Molecular Cloud, which are 235±18 pc [6] and 232±18 pc [8] from the Sun, respectively. These values are in good agreement with the photometric distance of NGC1333, 220 pc [2]. Because these two maser sources are highly time variable and their lifetimes are less than a half year, the uncertainties in the derived parallaxes are relatively large $\sim$ 10%. Thus, further monitoring observations would be helpful to improve the results. Note that we measured the absolute proper motions of the maser sources in NGC1333 SVS13 and L1448C which show similar velocity vectors with each other (Figure 3). In addition, the average proper motion of the radio continuum sources in NGC 1333 is consistent with those of the H_2O masers [1]. Although one cannot rule out the possibility of internal motions of masers (e.g. jets and outflow), they could represent systematic motion of the whole of the Perseus cloud complex.

Astrometric observations for the Ophiuchus (IRAS 16293-2422, [10]) and Cepheus (L1204G, [7]) regions have also been carried out with VERA. For the Ophiuchus region, we obtained the distance of 178^{+18}_{-37} pc for the H_2O maser source IRAS 16293-2422 [10] while those of other two radio continuum sources were reported to be $\sim$120 pc based on the VLBA observations with higher

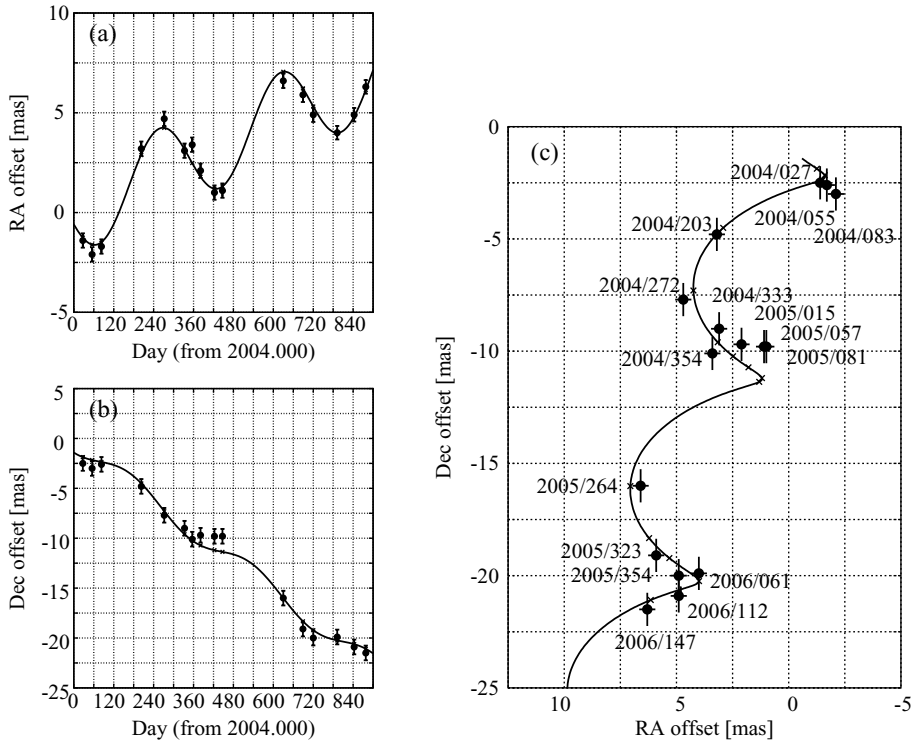

Figure 2: An example of the results of annual parallax measurements with VERA for Orion KL [5]. (a) Movement of the maser feature in right ascension as a function of time. (b) Same as (a) in declination. (c) Movement of the maser feature on the sky. Solid lines represent the best-fit model with the annual parallax and linear proper motion for the maser feature. Filled circles represent the observed positions of the maser feature with error bars indicating the standard deviations of the least-squares analysis (0.36 mas in right ascension and 0.74 mas in declination).

accuracy [12]. We need further astrometric observations of IRAS 16293-2422 in order to confirm whether there exist two molecular clouds at the different distances toward the Ophiuchus region. On the other hand, distance towards the Cepheus region obtained with VERA, 764±27 pc [7], is consistent with the VLBA result from the CH_3OH maser observations toward Cepheus A, 700±40 pc [14] within the mutual erros. Still, it is likely that the distance toward L1204G is slightly farther than Cepheus A.

In summary, VLBI astrometry with VERA is being used to investigate the 3-dimensional structures of the local molecular clouds by measuring the distances and kinematics of a number of sources. It will be a powerful tool to reveal the local structure of the Solar neighborhood including the local arm of our Galaxy and the Gould Belt.

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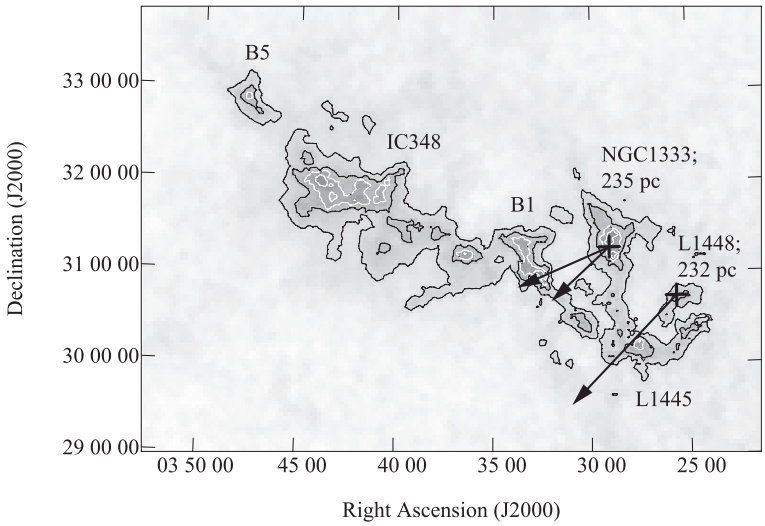

Figure 3: Absolute proper motions of the H_2O masers in L1448C and NGC1333 SVS13 [8]. The grey scale shows the visual extinction (AV) map derived from the 2MASS data [15]. Contour levels are AV =3, 5, 7, and 9 magnitude. Crosses and arrows represent the position of the maser sources and their absolute proper motion vectors, respectively.

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