Detection of outer Galactic rotation though phase-referencing VLBI astrometry with water masers

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We measured proper motions of water masers in Galactic star forming region IRAS21008+4700 and W3(OH) relative to celestial position of an adjacent extragalactic continuum sources. The observations were carried out by VLBA at 22GHz in two epochs separated by a month in the phase-referencing mode with source switching cycle of 40 seconds.

We found that two maser features in IRAS21008+4700 detected with LSR velocities around -36km s^{-1} and -71km s^{-1} moved along the Galactic plane by about 0.46±0.05 mas and 0.36±0.07mas, respectively within the month. A simple flat rotation model of the Galaxy predicts a kinematic distance of IRAS21008+4700 of 7.3kpc, and a transversal velocity of 150km s^{-1} or 0.38mas/month. The proper motions can be explained as being mostly due to the Galactic rotation.

We also measured proper motions of water maser in W3(OH). Proper motions of the order of 0.5mas/month are clearly detected which apparently show compound effects of the Galactic rotation, solar motion and annual parallax.

These results seem to show a feasibility of the phase-referencing VLBI maser astrometry in the Galactic dynamics.

1. Introduction

Phase referencing VLBI observations allow us to estimate relative positions of two sources with submilliarcsecond accuracy (e.g. Lestrade (1999)). Multi-epoch experiments using phase referencing techniques are expected to allows us to investigate the three-dimensional structure and dynamics of the Milky Way Galaxy and reveal the distribution and total amount of dark matter. Especially, the outer Galactic rotation curve, one of the important parameters of Galactic dynamics, is crucial for estimating the dynamical mass and hence the total amount of the dark gravitating matter within the Galaxy. At present the outer Galactic rotation curve is not known accurately enough to determine the total mass of Galaxy since we are not able to use the tangent point method in the outer region of the Galaxy.

At the first step to determine the outer Galactic rotation curve, we carried out phase referencing VLBI observations between Galactic sources in outer region and extragalactic sources. We have selected two Galactic water maser sources in outer region. IRAS 21008+4700 is a star forming region where water masers were detected in single dish observations (Palumbo (1994)). W3(OH) is a famous star forming region and strong water masers emission has been detected. Alcolea(1992) detected the relative proper motions of water masers in W3(OH) which were part of bipolar outflow.

These sources are located in the Galactic plane since their galactic latitude are 0.41 degree and 1.07 degree, respectively. Their distances are estimated to be about 7.3kpc and 2.3kpc (Georgelin (1976))respectively.

TABLE 1. Observed sources

Target source	Reference source	Separation angle (degree)
IRAS21008+4700	ICRF2100+468	0.18
W3(OH)	ICRF0241+622	2.17

2. Observations

We have observed IRAS21008+4700 and W3(OH) as target sources. Extragalactic continuum sources, ICRF2100+468 and ICRF0241+622, were selected from the catalogue of International Celestial Reference Frame (Johnston (1995)) as reference sources. The separation angles between Galactic water maser sources and adjacent extragalactic sources are shown in Table 1.

We used all ten antennas of the VLBA. IRAS21008+4700 and ICRF2100+468 were observed on July 8 of 1998 for 5 hours and on August 7 of 1998 for 5 hours, W3(OH) and ICRF0241+622 were observed on November 17 of 1999 for 4 hours and December 16 of 1999 for 4 hours. We observed at 22.23GHz for center frequency with 1024 spectral channels, 2 BBC channels, 16MHz band width for each BBC with 2-bit sampling. A switching cycle is 40 seconds, on source time per cycle is typically 15 seconds for IRAS21008+4700 pair and 8 seconds for W3(OH) pair.

3. Data reduction

We have carried out a priori phase referencing calibration technique. We have used the Astronomical Image Processing System (AIPS) package for all data reductions. We have calibrated the amplitude for all sources. The clock offset calibrations have been made only for reference sources, then we have applied final calibrated solutions to the target sources respectively.

We have determined the positions of maser spots using JMFIT in the task of AIPS. We have determined the positions of maser spots by one dimensional Gaussian fitting since detected maser spots showed simple structure which is consistent with synthesized beam.

4. Results

4.1. *IRAS21008+4700*

We detected two maser features in both epochs. The LSR velocities of these maser features are around -36km s^{-1} and -71km s^{-1}, respectively. The proper motions of these maser features during a month are shown in Figure 1. It is clear that these maser features moved along Galactic plane.

4.2. *W3(OH)*

We detected about 40 maser features in both epochs. The proper motions of these maser features during a month are shown in Figure 2. The detected proper motions are mostly in west - south west direction with 0.1 mas/month to 0.7mas/month speed.

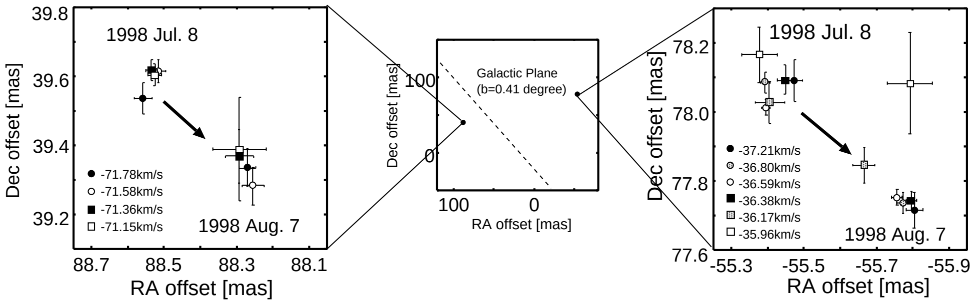

FIGURE 1. The proper motions of maser spots in IRAS21008+4700 relative to adjacent extragalactic source ICRF2100+468. Center panel shows the wide view of the location of two maser features in IRAS21008+4700. Dashed line is parallel to the Galactic plane ($b = +0.41°$). Right and left panels show the proper motions of each spot.

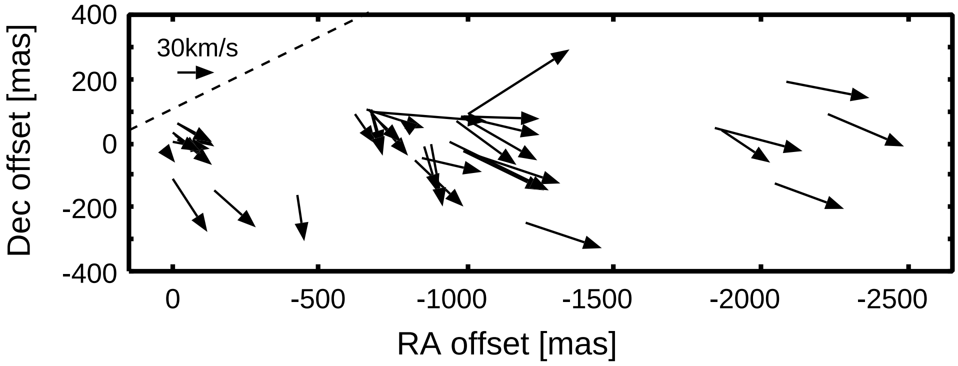

FIGURE 2. The transversal velocities of water maser features in W3(OH) relative to adjacent extragalactic source ICRF0241+622. A distance of 2.3kpc has been assumed. Dashed line is parallel to the Galactic plane ($b = +1.07°$).

5. Discussion

We did the following model calculations to check the above results. We assumed a simple flat Galactic rotation model and rotation speed near the Sun of 220 km/s. We also take into consideration the annual parallax and Solar motion. The results are shown in Figure 3.

The proper motions of IRAS21008+4700 were consistent with the predicted motion, especially the detected proper motions were due to mostly Galactic rotation. On the other hand, the average proper motions of W3(OH) maser features is roughly consistent with the combined effects of the annual parallax, Galactic rotation and Solar motion. We guess that the remaining inconsistency came from the intrinsic motion of W3(OH).

The detected proper motions are explained as the possibility of detection of outer Galactic rotation because of the detected proper motions did not contradict the predicted motions in the these comparisons.

6. Conclusion

We have observed Galactic water maser sources with adjacent extragalactic continuum sources by the phase-referencing mode during a month. We observed two Galactic water maser sources which are located at 7.3kpc and 2.3kpc from the Sun. The detected proper

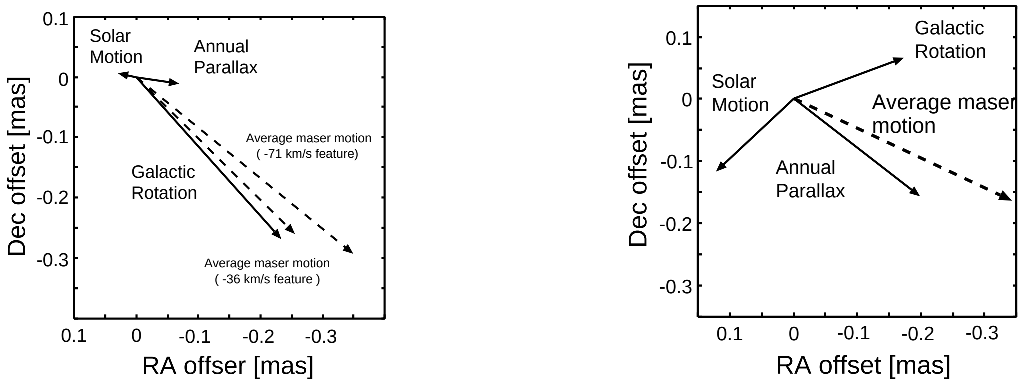

FIGURE 3. Comparison of our VLBA results with values predicted from flat rotation of Galaxy. Left panel shows the case of IRAS21008+4700. Dashed line are the detected proper motions for each feature. Right panel shows the case of W3(OH). Dashed line is the detected average proper motion.

motions of these sources are consistent with the predicted astrometric motion, the sum of annual parallax, solar motion and Galactic rotation. Moreover, the formal error of the Gaussian fits are as small as 0.4 mas to 0.01 mas which suggest that we can detect annual parallax from 2.5 kpc to 10 kpc within 10 percent accuracy. Therefore, we think that the results in these observations show the ability of phase-referencing VLBI to detect annual parallax and proper motion on kiloparsec scales.

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