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Towards Determination of the Outer Galactic Rotation Curve

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Abstract. To determine the outer Galactic rotation curve we observed the Galactic water maser source W3(OH) relative to an adjacent extragalactic continuum source ICRF0241+622, with phase reference VLBI. The observations were carried out using the VLBA at 22GHz. Preliminary results from the observations indicate that the detected proper motions of W3(OH) relative to the extragalactic source follow an elliptical orbit. The proper motions of masers due to Galactic rotation, Solar motion and intrinsic motion are nearly linear; therefore, this "orbit" is mainly due to annual parallax. We also observed other Galactic water maser sources with the VLA. We found useful sources for phase reference VLBI astrometry.

1. Introduction

Accurate determination of the rotation curve of our Galaxy on the outer side of the Solar circle is very important for estimating the dynamical mass and hence the total amount of dark gravitating matter within the Galaxy. In the outer Galaxy, however, the tangential point method cannot be applied because there are no such points along a line of sight. Therefore, the uncertainty of the outer Galactic rotation curve is fairly large compared to the inner rotation curve (e.g. Honma & Sofue 1997). We proposed to determine the distance of Galactic water maser sources using trigonometric parallax and tangential velocity, using an adjacent extragalactic source and phase reference VLBI astrometry observations. We have observed two pairs of sources with the VLBA and measured proper motions of water maser sources in the Galactic star forming regions IRAS21008+4700 and W3(OH) relative to the positions of adjacent extragalactic continuum sources. These measured proper motions were mostly consistent with their predicted motions (Hachisuka et al. 2000).

2. Feasibility of Phase Reference VLBI at 22 GHz

Results of observations of strong maser sources in the Galactic star forming region W3(OH) and an adjacent, fairly strong extragalactic continuum source, ICRF0241+622, clearly showed that the atmospheric phase fluctuations are well compensated, even though the two sources are separated by a finite angular distance of 2.17 degree. In fact, the large atmospheric phase fluctuations of several hundred degrees, observed in the fringe phases of the two sources were mostly compensated in the phase reference calibration with AIPS (Fig.1). After calibration, the residual error due to atmospheric fluctuations in the resultant difference of the fringe phases averaged for a switching cycle (40 second) was about 10 degrees. This 10 degrees phase error corresponds to a positional accuracy of about 30 micro-arcseconds for a projected baseline of 2000 km.

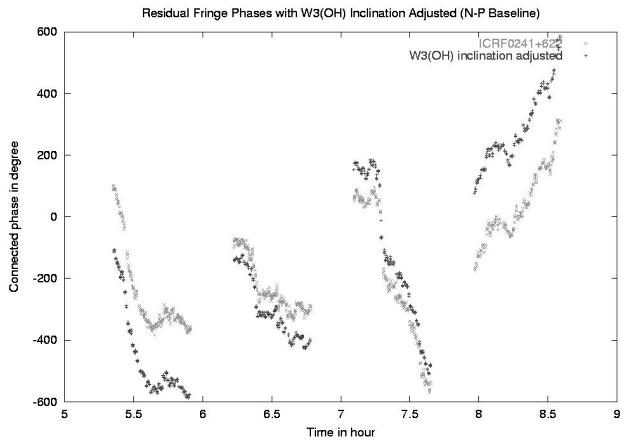

Fig. 1. Raw residual fringe phase of maser spot in W3(OH) and extragalactic ICRF0241+622 (North Liberty - Pie Town baseline). The systematic change in the fringe phase of the maser spot due to its offset in position from the phase center is subtracted by a linear fitting. The fringe phases of the two sources show large random variations in time by more than a radian within a few minutes due mostly to the atmospheric effect. However, their time behaviors are quite similar.

3. Observation and Data reduction

We have observed W3(OH) and ICRF0241+622 with the VLBA at seven epochs during the course of a year. These observation were done using phase reference VLBI with a switching cycle of 40 seconds. Here we report only the first five epochs. The other Galactic water maser source, IRAS21008+4700 was also observed with the VLBA using the same method.

⋆ On behalf of the VERA Project Team

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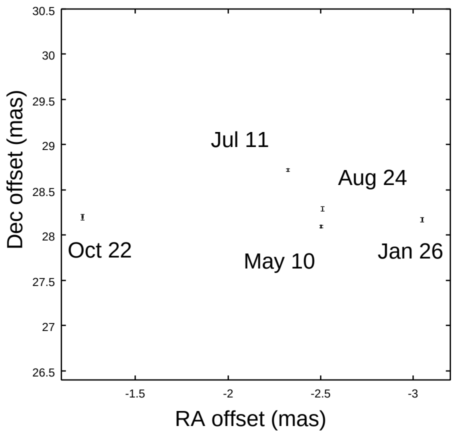

Fig. 2. Detected proper motion of maser spot in W3(OH) relative to an adjacent extragalactic continuum source, ICRF0241+622. These observations were carried out in 2001.

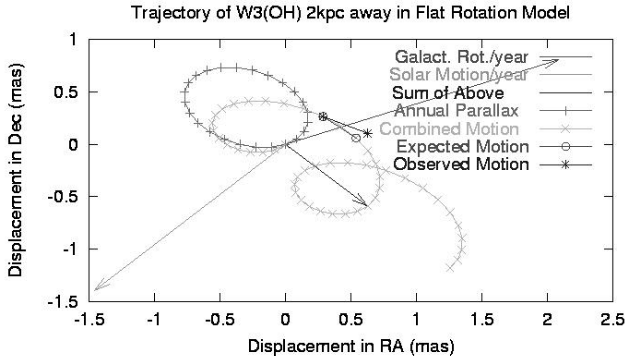

Fig. 3. Expected proper motion of W3(OH) relative to adjacent extragalactic source ICRF0241+622. The distance to W3(OH) of 2 kpc was assumed. Observed motion is the results of previous VLBA observation (Hachisuka et al. 2000).

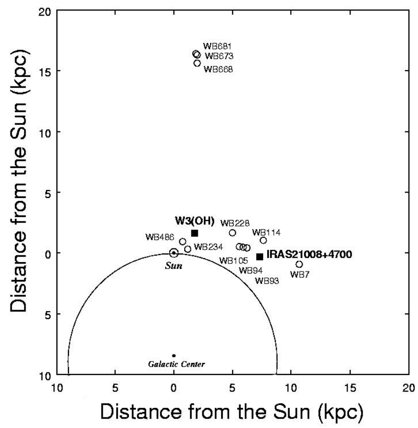

Fig. 4. Distribution of target Galactic water maser sources. Observed (filled squares) and candidate sources (open circles) with VLBA monitoring observation. The distance of candidate sources were estimated from radial velocity of CO emission (Wouterloot & Brand 1989).

The data reduction was done using phase reference procedures within AIPS. We calibrated only the extragalactic reference sources; these solutions were then applied to the target Galactic maser source.

4. Results

The preliminary results on the proper motion of water maser spots in W3(OH) shows that they follow an elliptical orbit (Fig.2). These maser spots have the same radial velocity, $V_{\rm LSR} = -49.0 km/s$. In general, proper motions of maser spots in a Galactic source relative to an extragalactic source are combined with Galactic rotation, peculiar motion deviating from Galactic rotation, intrinsic motion due to inner motion (e.g. outflow and accretion disk), Solar motion and annual parallax Except for annual paralax, these proper motion terms are nearly linear during a year. Therefore, we think this elliptical "orbit" is mainly due to annual parallax. If the distance to W3(OH) from the Sun is 2.3 kpc (Georgelin & Georgelin 1976), the predicted annual parallax is 0.43 mas (Fig.3). The parallactic ellipse of detected proper motion is roughly 0.5 mas. Therefore, we think that the W3(OH) is about 2 kpc away from the Sun.

5. VLA water maser survey

The H_2O maser is insufficient to determine the outer Galactic rotation curve limited sample. We selected Galactic water maser sources from the Arcetri Maser Catalog (J. Brand, et al. 1994) and other catalogues (Wouterloot, et al. 1993). We surveyed other Galactic water maser sources with VLA and found about 11 maser sources which seem to be useful for our aims (Fig.4).

6. Conclusions

We have observed the Galactic water maser source W3(OH) relative to adjacent extragalactic continuum source ICRF0241+622 with phase reference VLBI. We showed the feasibility of phase reference VLBI at 22 GHz from the behavior of residual fringe phases. A preliminary result from monitoring observation of W3(OH) shows the possibility of detecting annual parallax at about 2 kpc away from the Sun. We also surveyed other Galactic water maser sources with the VLA. In future, we will determine the outer Galactic rotation curve by these observations.

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