Cosmic Masers - from OH to H_0
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The bar effect in the galactic gas motions traced by 6.7 GHz methanol maser sources with VERA

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Abstract. To establish the existence of the galactic bar, ten methanol maser sources around the starting points of the spiral arms were observed with VERA (VLBI Exploration of radio astrometry) using the phase-referencing technique at 6.7 GHz band. For six out of ten sources, absolute proper motions were obtained with better than 3σ accuracy. Using VLBI 3-D data of eight sources, including our five sources, we compared the observed data with three galactic models and found that the model including the bar effect is better to explain the 3-D data, than a flat circular rotation model. A non-flat circular rotation model is also consistent with the VLBI data. Based on a dynamical model with a bar, we estimate an inclination angle of the bar around 35°, which is consistent with previous studies.

Keywords. masers, Galaxy: kinematics and dynamics, radio lines: ISM

1. Introduction

VLBI astrometry is one a powerful approach to obtain 3-D gas kinematics. For such astrometric observation, 6.7 GHz methanol maser sources have some advantages as the galactic gas tracer (e.g., large source numbers, long lifetime, and small internal proper motions), excepting the larger angular resolution than H_2O/SiO maser sources. Methanol has the special advantage for galactic bar studies, in that most of the sources concentrate around the molecular ring on the position-velocity map (Pestalozzi *et al.* 2005).

In May 2009, new 6.7 GHz receivers were installed in the VERA stations, and we confirmed a capability of 6.7 GHz astrometric observation with VERA (Matsumoto *et al.* 2011). It shows that parallax measurements using 6.7 GHz methanol maser are currently reached at 2 kpc with VERA. Thus, for far sources around the galactic bar, we need to present proper motions on the sky plane in units of mas yr^{-1}, instead of km s^{-1} because the parallax could not be detected.

2. Observations and Result

In Nov. 2009, we started astrometric observations of ten methanol maser sources with VERA. The frequency of the maser line is 6.668518 GHz ($CH_3OH\,5_1 \rightarrow 6_0A^+$). The ten maser sources were selected from Pestalozzi et al. (2005) with following criteria: (1) the galactic longitude of 40° or less, (2) declination larger than −37°, (3) the kinematic distance from the galactic center is less than 5 kpc, (4) the flux is brighter than 15 Jy or more in Pestalozzi et al. (2005) and detected with VERA, (5) existence of detectable

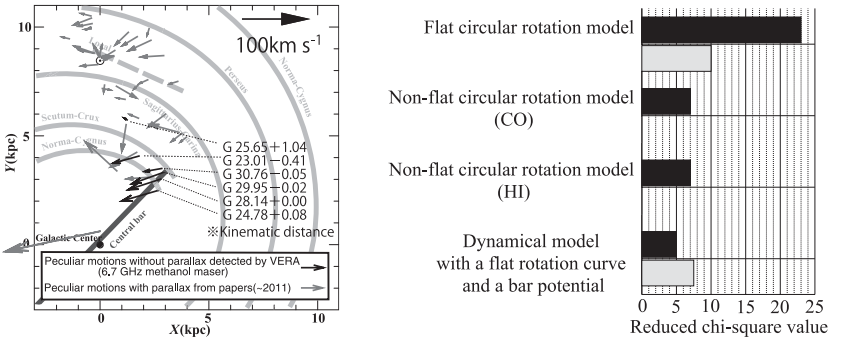

Figure 1. Left: Absolute proper motions of SFRs on the galactic plane at (R_0, Θ_0, $U_{\odot HIP}$, $V_{\odot HIP}$, $W_{\odot HIP}$)=(8.5 kpc, 220 km s^{-1}, 10 km s^{-1}, 5.25 km s^{-1}, 7.17 km s^{-1}). Right: Reduced chi-square values of each model via VLBI 3-D data (black), and each model via HI terminal velocity (gray).

phase-reference sources with VERA within 4° separation from the target maser sources. We observed the ten sources every few months until May 2011. The typical size of synthesized beam is ∼3×6 - 5×10 mas^2.

In figure 1, the accurate proper motions obtained by our observations are plotted using kinematic distance with other parallax measurement data. Except G 25.65+1.04, all our sources have a similar trend in proper motion, much slower than 220 km s^{-1} galactic rotation

3. Discussion

We compared our observed 3-D data with some kinematic models (the galactic longitude [deg], proper motions for the direction of the galactic longitude [mas yr^{-1}] and the systemic velocities [km s^{-1}]). In this comparison, we also used data of G 23.01−0.41, G 23.44−0.18 and G 23.65−0.127 from Brunthaler *et al.* (2009) and Bartkiewicz *et al.* (2008). These three sources also satisfy our selection criteria.

We found our 3-D data sample cannot be reproduced by a flat rotation model with Θ_0=220 km s^{-1}. However, our data are consistent with both existing rotation curves with HI/CO and the dynamical model with a bar (Wada 1994; Sakamoto *et al.* 1999). From the dynamical model and VLBI data, an acceptable parameter of the inclination angle of the Galactic bar was derived as ∼35°. This is consistent with previous studies. Thus, the observed VLBI proper motions can be explained better with the Galactic bar. In time, if more sources can be observed, the HI/CO rotation curve and the dynamical model may be discriminated better.

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