Cosmic Masers: Proper Motion toward the Next-Generation Large Projects
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Astrometric observations of water maser sources toward the Galactic Center with VLBI

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Abstract. The Central Molecular Zone (CMZ) in the Galactic Center region shows outstanding non-circular motion unlike the Galactic disk. While several models describing this non-circular motion have been proposed, a uniform kinematic model of the CMZ orbit has not yet emerged. To uncover the dynamics of the Galactic center region, we conducted VLBI astrometric observations of 22 GHz water maser sources towards the Galactic center using VERA. By measuring parallaxes and proper motions, we can determine whether each source is actually located in the CMZ or not, and identify the three-dimensional positions and velocities in the non-circular orbit if the source is indeed located in the CMZ. We present the results of our astrometric study for several maser sources associated with molecular clouds towards the Galactic center. The astrometric observations toward Sgr B2(M) indicated that Sgr B2 complex is moving toward the positive Galactic longitude relative to Sgr A*.

Keywords. Galaxy:kinematics and dynamics, masers, instrumentation:interferometers, parallaxes

1. Introduction

The Central Molecular Zone (CMZ) of our Galaxy, which ranges from -2 to $+2$ degrees of the Galactic longitude, has very peculiar properties. Star formation activity in this region is quite inactive despite high molecular gas density ($n = 10^3$–10^5 cm^{-3}) and wide line width ($\Delta V = 20$–50 km s^{-1}) (Morris & Serabyn 1996). Two representative models are proposed to explain these properties in the CMZ. First model is closed orbit model proposed by Molinari *et al.* (2011). In this mode, the orbital velocity is constant, and the star formation is triggered by cloud-cloud collision in the intersection between different orbits. Another model is open orbit model proposed by Kruijssen *et al.* (2015). In open orbit model, the tidal compression in the orbit triggers the star formation. Understanding the dynamical model of the CMZ is important to study not only whole property of the CMZ but also star-formation of individual molecular cloud in the CMZ. Three-dimensional velocity information will be critical for constraining the orbital models of the CMZ because most proposed models are devised to reproduce the line-of-sight velocity profiles of the molecular clouds in this region.

Table 1. Parallax and proper motions toward the Galactic center.

Target	Parallax (mas)	Distance (kpc)	$\mu_\alpha \cos\delta$ (mas yr^{-1})	μ_δ (mas yr^{-1})	$V_{\rm LSR}$ (km s^{-1})
Sgr B2(M)	0.133±0.0038	$7.5^{+3.0}_{-1.7}$	-2.17 ± 0.03	-2.63 ± 0.06	+60
G000.16-00.44	–	–	0.35 ± 0.52	-1.46 ± 0.57	+10
G359.94-00.14	–	–	-1.69 ± 0.26	-0.37 ± 0.30	−35
G000.21-00.00	–	–	-0.93 ± 0.89	0.35 ± 0.50	+47

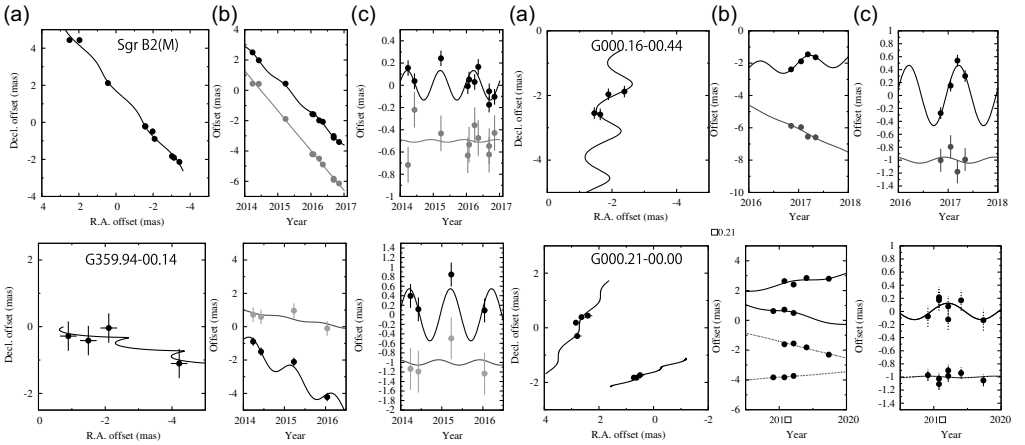

Figure 1. Astrometric results for four target sources. (a) Absolute proper motions of the maser source. The filled circles show the observed points from phase referencing. (b) Motions toward right ascension and declination as a function of time. The black circles show the motion in the right ascension direction, and the gray circles show the motion in the declination direction. (c) Results of parallax fitting. Error bars are evaluated so that a χ^2 value in the model fitting become unity.

2. Observations

We conducted VLBI monitoring observations of four 22 GHz H_2O maser sources using VERA (VLBI Exploration of Radio Astrometry). Using the dual-beam system of VERA, the target sources and a position reference source, i.e., J1745-2820, were simultaneously observed. Target sources and the number of observations for each source are listed in Table 1.

3. Results and Discussion

We succeeded to measure parallaxes and proper motions for Sgr B2(M), and to measure proper motions for G000.16-00.44, G359.94-00.14, and G000.21-00.00. Figure 1 shows astrometric results for each target source. From parallax and proper motion, Sgr B2(M) is located at the Galactic center distance, and moving toward positive Galactic longitude. G359.94-00.14 and G000.21-00.00 show proper motions moving toward positive Galactic longitude, suggesting that these sources are located at closer side of CMZ. Note that it is necessary to conduct a more detailed investigation, incorporating information such as annual parallax to conclude whether these sources reside at CMZ.

The results from proper motion measurements suggest a preference for the open orbit model among the dynamic models of the CMZ, yet a definitive distinction requires observations of a greater number of sources. In order to increase the number of sources available for astrometric observation, we are considering investigations of other types of masers, such as SiO masers, and observations with larger arrays, like EAVN (East Asian VLBI Network).

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