A Giant Step: from Milli- to Micro-arcsecond Astrometry
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Astrometry of Galactic star-forming regions with VERA

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Abstract. We present an overview of recent astrometric results with VERA. Since 2004, we have been conducting astrometry of tens of Galactic maser sources with VERA, and recently obtained trigonometric parallaxes for several sources, with distances ranging from 180 pc to 5.3 kpc. In this paper, we briefly summarize the results for Galactic star-forming regions, including S269, Orion-KL, NGC 1333, ρ-oph, NGC 281 and others.

Keywords. astrometry, Galaxy: disk, stars: formation

1. VERA project

VERA (VLBI Exploration of Radio Astrometry) is a new VLBI array dedicated to phase referencing VLBI astrometry. This array consists of four 20-m radio telescopes spread over Japan, with a maximum baseline length of 2300 km. VERA's 20m telescopes are operated in the dual beam regime, so that one can simultaneously observe a reference and a target source to cancel out the phase fluctuations caused by tropospheric variations. VERA's main goal is to explore the 3-D structure and dynamics of the Galaxy based on astrometry of ∼1000 of Galactic maser sources (for more details on the VERA project, see Kobayashi *et al.* 2008).

2. Overview on recent results

Since 2004 we have been conducting astrometric observations of tens of maser sources, and recently we have succeeded in measuring trigonometric parallaxes and proper motions of some maser sources. One of the highlights is a parallax measurement of the star-forming region S269 (Honma *et al.* .2007). The parallax of S269 was measured to be $\pi = 189 \pm 8$ μas (D=5.28 $\pm$ 0.24 kpc), providing one of the largest distances measured by means of trigonometric parallax. Proper motions of S269 H_2O masers were used to constrain the Galactic rotation velocity at the position of S269 (located at 13 kpc from the Galaxy center), demonstrating that the rotation curve of the Galaxy is basically flat out to 13 kpc (Honma *et al.* .2007).

The other major result recently obtained with VERA is the distance measurement of Orion-KL, which is one of the most important star-forming regions in the Galaxy. Hirota *et al.* (2007) determined the parallax of Orion-KL H_2O maser as π=2.29 $\pm$ 0.1 mas

(D=437 ± 19 pc). This value is slightly smaller than previous estimates of ∼ 480 pc, but still is in good agreement with recent measurements using VLBA (Sandstrom *et al.* 2007; Menten *et al.* 2007). The distance of the ρ-Oph cloud was also measured with VERA by Imai *et al.*(2007), providing the distance of 178^{+18}_{-37} pc. This result is consistent with the results obtained by Loinard et al. (2008) based on VLBA parallax measurements of radio-emitting young stars in this region. For other nearby star-forming regions, Hirota *et al.*(2008) obtained the parallax distance of NGC 1333 to be D=235 ± 18 pc.

Another interesting results from VERA is the absolute proper motion measurements for NGC 281 (Sato *et al.* 2007). This star-forming region is associated with an HI "super-bubble", being located ∼300 pc away from the Galactic plan. Sato *et al.*(2007) found that NGC 281 system is moving away from the Galactic plane at the velocity of ∼20 km/s, which strongly supports an idea that a super-bubble was formed by a blow-out from the Galactic plane, most likely by supernovae.

In addition to star-forming regions, VERA also observed masers in late-type stars. Choi *et al.*(2008) recently succeeded in astrometry of a super giant star VY CMa, providing the parallax distance of 1.1 ± 0.1 kpc. They also matched the H_2O maser map with the SiO maser map and determined a position in the H_2O maser map, from which maser spots show rapid expansion away from the central star, explained by the mass loss in this star. Similarly, the study of a semi-regular variable S Crt (Nakagawa *et al.* 2008) provides the parallactic distance of 430 ± 25 pc.

Summarizing the current status, so far we have detected parallaxes for 7 sources, with distances ranging from 180 pc to 5.3 kpc. We are going to observe 70–80 maser sources every year, and in the next 12–15 years VERA will observe ∼1000 Galactic maser sources to precisely locate them in the Galaxy's disk. Similar astrometric studies of methanol maser sources are also being conducted with VLBA (Reid 2008), and finally Gaia (Lindegren et al. 2008) is also going to conduct kpc-scale astrometry by observing billions of stars in the Galaxy. Thus by 2020, when the results of all these projects become available, our knowledge on the Galaxy structure will be revolutionized with the help of high-precision astrometry both in radio and optical wavelengths.

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