論文の内容の要旨

Study of VLBI astrometry toward the Galactic center with VERA
(VERA による銀河系中心方向の VLBI アストロメトリに関する研究)

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In this thesis, we present astrometric study of water maser sources toward the Galactic center region with the VLBI Exploration of Radio Astrometry (VERA). The central 300 pc of the Galaxy, which is called as the Central molecular zone (CMZ), has a remarkable non-circular motion compared with the Galactic disk. To explain the origin of the non-circular motion, a number of kinematic models are proposed using spectroscopic observations of interstellar medium. Proper motion measurement of a number of sources in the CMZ will enable us to constrain these models because most of models are constructed based on line-of-sight velocity observations. However, we cannot conduct astrometric observations for sufficient number of sources with the standard phase referencing observations of VLBI because position reference sources like QSOs and most of target maser sources toward the Galactic center are weak so that we cannot detect those signal within a short coherent time of about 1 minute. On the other hand, we have to measure the parallaxes of these target sources as well as the proper motions because the confusion of nearby foreground sources located along the same line-of-sight to the Galactic center is also problematic. We overviewed the problems in understanding the kinematics of the CMZ, and basic theories of interferometer and data reduction of VLBI in Chapter 1 and 2.

In Chapter 3, we developed a new observation technique, the triangle phase referencing

observations, which enable us to detect weak maser sources which cannot be detected by the standard phase referencing technique. The triangle phase referencing uses a strong phase reference maser (PRM) in addition to a position reference QSO (PRQ) and a target maser (TM) of which we want to obtain the parallax and proper motion. We conducted test observations of the triangle phase referencing for W3OH region to evaluate the accuracy of astrometric results obtained by the triangle phase referencing technique. As a result, we obtained the systematic position error in the triangle phase referencing technique of 37 μas. This was smaller than the position error caused by the thermal noise (38—95 μas). Parallax and proper motion fitting also indicated that the fitted values of the parallax and proper motions obtained by the triangle phase referencing were consistent with those by the normal phase referencing within errors. Thus, the triangle phase referencing can be applied without significant error increase. It makes possible to measure the proper motions and to distinguish between nearby source and the Galactic center source by parallax measurement.

Chapter 4 and 5 show astrometric observations for water maser sources associated with the Sgr D HII region and the Sgr B2 complex, respectively. These two sources have relatively strong flux densities toward the Galactic center region, and the triangle phase-reference is not required. We obtained the parallax of Sgr D as $\pi = 0.423 \pm 0.083$ mas, corresponding to $d = 2.36^{+0.58}_{-0.39}$ kpc. Our results are the first accurate distance measurement of the Sgr D HII region, suggesting that the Sgr D HII region is located at the foreground of the Galactic center and the Scutum arm of the Galaxy. For the Sgr B2 complex, we measured detailed 3-dimentional motions of water masers associated with Sgr B2M, N, and S in the Sgr B2 complex for the first time. Our results of parallax and proper motions, $\pi = 0.133 \pm 0.038$ mas and $(\mu_l \cos b, \mu_b) = (-3.72 \pm 0.22, -0.49 \pm 0.23)$ mas/yr prefer open-obit model of the CMZ although the predicted proper motions for the open-orbit at this position contain large errors.

In Chapter 6, we conduct the triangle phase referencing observations for weak maser sources toward the Galactic center region. As a phase reference maser (PRM) we used a strong maser spot in Sgr B2M. The target masers are water maser sources associated with G359.94-00.14 and G000.16-00.44. G359.94-00.14 is a Young stellar object (YSO) located at very vicinity of Sgr A* in projection, and G000.16-00.44 is a star-forming region. Both of water maser sources are so weak that we cannot detect the maser spot with the standard phase referencing technique. Using the triangle phase referencing, we succeeded to detected masers, and to measure their absolute positions. For G000.16-00.44, we measured the parallax and proper motions as $\pi = 0.645 \pm 0.074$ mas and $(\mu_{RA}, \mu_{Dec}) = (-0.51 \pm 0.13, -0.77 \pm 0.15)$ mas/yr, and it suggested that G000.16-00.44 is located at the Sagittarius arm. For G359.94-00.14, unfortunately, the flux of the maser source decreased under the detection limit of the triangle phase referencing (< 1Jy) after mid 2016. The

parallax for G000.16-00.44 can be measured for the first time by detecting weak maser spots using the triangle phase referencing.

In summary, we developed a new phase referencing technique, the triangle phase referencing, to measure parallaxes and proper motions for weaker maser sources which could not be detected by the standard phase referencing toward the Galactic center. The new technique successfully detected weak maser sources down to about 1 Jy. This enabled us to increase the number of sources for which we can conduct astrometric observations with VLBI, and to distinguish between the nearby and the Galactic center sources located at the same line-of-sight direction. Our works in this thesis demonstrate that the future VLBI observations toward the Galactic center enable us to constrain the kinematics model of the CMZ.