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ASTROMETRIC OBSERVATION OF MIRA VARIABLES WITH VERA

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ABSTRACT

The calibration of the period luminosity relation (PLR) for Galactic Mira variables is one of the principle aims of the VERA project. We observe H_2O maser emission at 22 GHz associated with Mira variables in order to determine their distances based on annual parallaxes. We conduct multi-epoch VLBI observations over 1–2 years with a typical interval of one month using VERA in order to obtain annual parallaxes with an accuracy of better than than 10%. Recently, the annnual parallax of T Lep was determined to be 3.06±0.04 mas corresponding to a distance of 327±4 pc (Nakagawa et al., 2014). The circumstellar distribution and kinematics of H_2O masers was also revealed. With accurate distances to the sources, calibrations of K-band absolute magnitudes (M_K) can be improved compared to conventional studies. By compiling Mira variables whose distances were determined with astrometric VLBI, we obtained a PLR of $M_K = 3.51\ \log P + 1.37 \pm 0.07$.

Key words: Astrometry: masers (H_2O) stars: individual (T Lep) stars: variables

1. ASTROMETRY OF MIRA VARIABLES

Mira variables are pulsating stars with periods of 100–1000 days, showing rapid mass loss before ejecting their outer layers as planetary nebula shells. Accurate distance to the sources helps us to understand the nature of the variables. Although a narrow PL relation for Miras in the Large Magellanic Cloud (LMC) was found (Feast et al., 1989), the same relation for Galactic Miras has not been precisely obtained because of large errors. Such large errors arise from the ambiguity of absolute magnitudes resulting directly from inaccurate distances for each object. Using absolute magnitudes derived from accurate distances measured with VERA, we can investigate the precise PL relation in the Galaxy. Once we have calibrated the relation based on the absolute distance, we can convert the pulsation period to distance for many Galactic variables.

2. OBSERVATIONS AND DATA REDUCTION

2.1. Source selection and Single Dish Monitoring

H_2O maser emission around long period variables is so bright and compact that they are good targets for VLBI as a tracer of their motion. Miras and semiregular variables are our target sources. Figure 1 shows the period distribution of ∼800 Mira variables in Feast et al. (2000) and our ∼80 target sources. The average period of ∼80 Miras having H_2O maser emission is 407 days ($\log P = 2.61$), which is longer than the average of 338 days ($\log P = 2.53$) for the sources in Feast et al. (2000). To find new candidates for our astrometric VLBI, we monitored ≥250 long period variables at 22 GHz with single-dish observation at Iriki. Time variations of potential targets were also obtained.

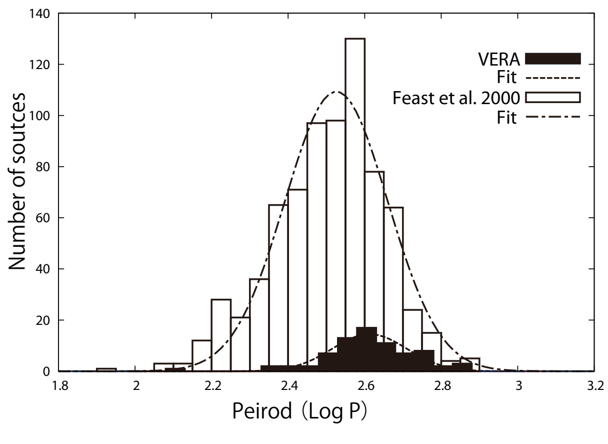

Figure 1. Period distribution of Mira variables in Feast et al. (2000) (open) and our targets (filled).

2.2. VLBI OBSERVATIONS

We conducted 22 GHz multi epoch VLBI observations using VERA, which is a Japanese VLBI project dedicated to Galactic astrometry. Maser sources and QSOs are observed simultaneously with a dual-beam installed in VERA, and the position of the maser spots can be de-

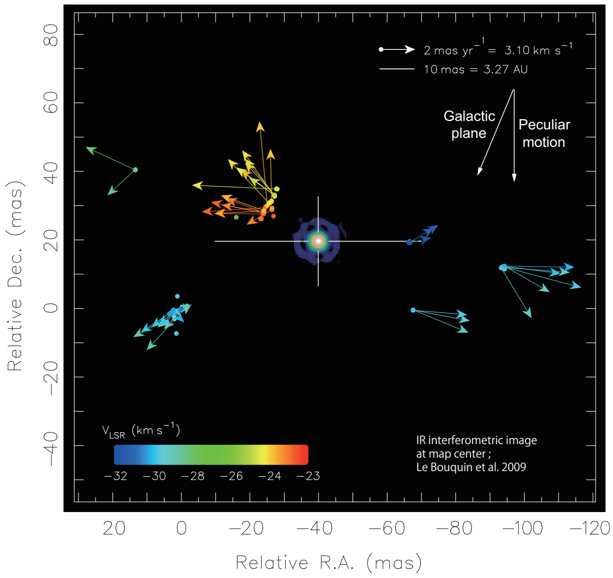

Figure 2. H_2O maser distribution in T Lep. Superposition of VLTI infrared interferometric image and H_2O maser distribution obtained with VERA. Color image at the center of this figure is an image obtained with VLTI. H_2O masers observed with VERA are distributed in the outer area of this figure. Colors of filled circles indicate their V_{LSR}. Color of the central star is unrelated to the color index of the maser.

termined with respect to the adjacent QSO. We derive the parallax and linear proper motion using the results from sequential VLBI observations.

3. RECENT RESULTS AND DISCUSSION

3.1. Parallax Measurements

Recently, we measured the distance of the Mira variable T Lep. Of the H_2O maser spots detected in a V_{LSR} range of −32 to −23 km s^{-1}, V_{LSR} = −29.73 km s^{-1} was continuously bright during our VLBI monitoring period. By tracing the sky position of the maser, the annual parallax was estimated to be 3.06±0.04 mas, corresponding to a distance of 327±4 pc.

3.2. Properties of the Source

We also revealed the distribution of maser spots around T Lep together with their internal kinematics (Figure 2). The color image at the map center is obtained from the VLTI infrared interferometer (Le Bouquin et al., 2009). Using our measured distances, the angular radii of the photosphere (2.9 mas) and molecular layer (7.5 mas) in Le Bouquin et al. (2009) can be converted to linear sizes of 0.95 AU (=204 $R_\odot$) and 2.45 AU (=527 $R_\odot$), respectively.

3.3. Period Luminosity Relation

Table 1 shows parallaxes of variables stars measured with astrometric VLBI (VERA and VLBA). Errors in absolute magnitudes are attributed to the parallax errors. Based on these VLBI results, we obtained a period luminosity relation for Galactic Mira variables of (bold

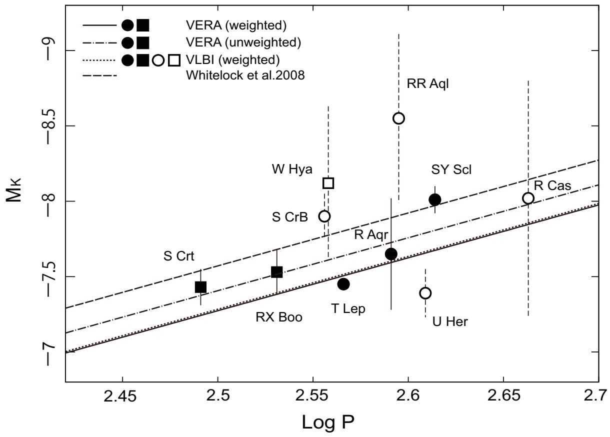

Figure 3. Period−luminosity relation derived from astrometric VLBI observations. Filled symbols represent absolute magnitudes M_K derived from VERA observations. Open symbols represent those from other VLBI observations conducted by Vlemmings et al. (2003) and Vlemmings et al. (2007). Square symbols are used to denote semiregular variables. Dashed line shows the relation reported by Whitelock et al. (2008).

line in Figure 3), $M_K = -3.51 \log P + 1.37 \pm 0.07$. We solved for the zero point of 1.37 ± 0.07 through an un-weighted least squares fitting. The slope of −3.51 (Whitelock et al., 2008) was fixed. Various fitting results are also shown in the same figure. We are now observing new sources to continue further calibration.

Table 1
RESULTS FROM VLBI ASTROMETRY.

Source	Parallax† [mas]	Log$P$	M_K [mag]
T Lep	3.06±0.04[(a)]	2.566	−7.45 ± 0.03
S Crt	2.33±0.13[(b)]	2.190	−7.43 ± 0.12
R Aqr	4.7±0.8[(c)]	2.591	−7.65 ± 0.37
SY Scl	0.75±0.03[(d)]	2.614	−8.01 ± 0.09
RX Boo	7.31±0.5[(e)]	2.531	−7.53 ± 0.15
S CrB	2.39±0.17[(f)]	2.556	−7.90 ± 0.15
U Her	3.76±0.27[(f)]	2.609	−7.39 ± 0.16
RR Aql	1.58±0.40[(f)]	2.595	−8.55 ± 0.56
W Hya	10.18±2.36[(g)]	2.558	−8.12 ± 0.51
R Cas	5.67±1.95[(g)]	2.663	−8.02 ± 0.78

† [(a)]Nakagawa et al., 2014, [(b)]Nakagawa et al., 2008, [(c)]Kamohara et al., 2010, [(d)]Nyu et al., 2011, [(e)]Kamezaki et al., 2012, Vlemmings et al., [(f)] 2007, and [(g)]2003.

REFERENCES

Feast, M. W., et al., 1989, A Period-Luminosity-Colour Relation for Mira Variables, MNRAS, 241, 375
Feast, M. W., et al., 2000, Mira Kinematics from Hipparcos

Data: a Galactic Bar to beyond the Solar Circle, MNRAS, 317, 460
Kamezaki, T., et al., VLBI Astrometry of the Semiregular Variable RX Bootis, PASJ, 64, 7
Kamohara, R., et al., VERA Observations of SiO Maser Emission from R Aquarii, A&A, 510, A69
Le Bouquin., et al., Pre-maximum Spectro-imaging of the Mira Star T Leporis with AMBER/VLTI, A&A, 496, L1
Nakagawa, A., et al., VLBI Astrometry of AGB Variables with VERA — A Semiregular Variable S Crateris —, PASJ, 60, 1013
Nakagawa, A., et al., VLBI astrometry of AGB Variables with VERA: A Mira-type Variable T Lepus, Accepted to PASJ, arXiv:1404.4463
Nyu, D.et al., Astrometry of AGB Variables with VERA: Annual Parallax and the Orbit of SY Sculptoris in the Galaxy, PASJ, 63, 63
Vlemmings, W. H. T., et al., VLBI Astrometry of Circumstellar OH Masers: Proper Motions and Parallaxes of Four AGB stars, A&A, 407, 213
Vlemmings, W. H. T., et al., Improved VLBI Astrometry of OH Maser Stars, A&A, 472, 547
Whitelock, P., et al., AGB Variables and the Mira Period-luminosity Relation, MNRAS, 386, 313