VERAによる
ミラ型変光星T UMaの年周視差測定

Annual parallax mesurement of a Mira Variable Star T Ursae Majoris with VERA
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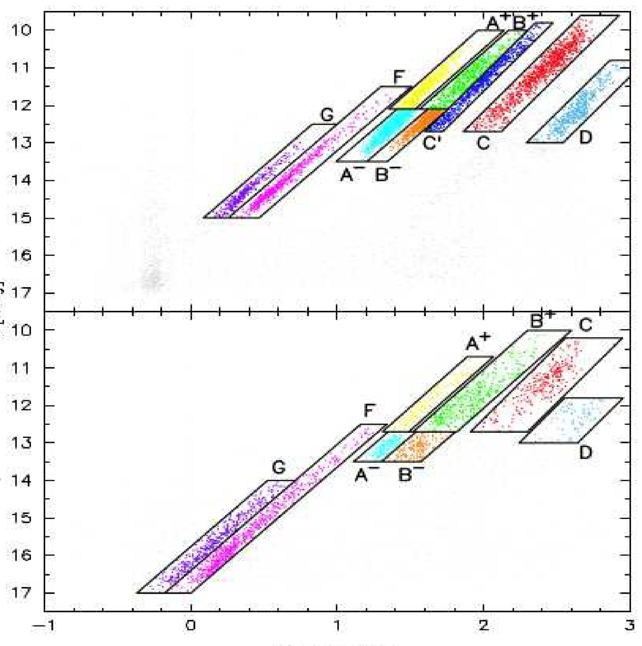
ミラ型変光星を含む長周期変光星には変光周期と明るさの間に周期光度関係(Period-Luminosity Relation;以下PLR)と呼ばれる量的な関係がある。鹿児島大学では国立天文台VERAによる高精度な年周視差の測定と、鹿児島大学1m光赤外線望遠鏡による見かけの等級と変光周期の測定を組み合わせて、天の川銀河内のミラ型変光星に対するPLRの確立を目標とした研究を行っている。現状ではVERA以外のVLBI観測を含めても距離と変光周期と見かけの明るさがそろった天体が十数個ほどしかなく、ある程度の精度での関係は求められているが、PLRの確立にはさらに多くの天体について観測を進める必要がある。今回、私たちはミラ型変光星T UMaの水メーザーをVERAによって観測し、その年周視差がπ=0.96±0.19ミリ秒角、距離が$D=1.05^{+0.25}_{-0.17}$kpcであることを求めた。また、鹿児島大学1m光赤外線望遠鏡より、この天体の変光周期は257日で、近赤外線Kバンド見かけ等級は2.79等が得られた。ここから、絶対等級は$-7.31^{+0.39}_{-0.47}$等と求められた。T UMaはVERAで観測されたミラ型変光星の中で最も短い変光周期を持つため、今後、他の天体とあわせて天の川銀河のミラ型変光星のPLRを明らかにするうえでも重要である。今回の結果から、T UMaはNakagawa et al.(2016)のPLRの外挿と誤差範囲で一致し、周期250日～450日の範囲が単一のベキ乗で表わせることがわかった。

1,Introduction

1.1 Object and PLR

Long Period Variable Stars have a linear relation between their absolute magnitude (M_K) and pulsation period (Log P), that is called Period-Luminosity Relation (PLR). This relation can be used to derive distances of the LPVs from their apparent magnitude (m_K) and period. Distance of far LPVs, whose annual parallaxes are too small to detect, can be determined based on the PLR. However, the current PLR was obtained from studies of LPVs in Large Magellanic Cloud (LMC) and Small Magellanic Cloud (SMC) (Fig.1). The metallicity of these clouds are different from Milky Way Galaxy, and also there are distance uncertainties for these clouds. So it is important to construct the relation in our own galaxy.



Ita et al. (2004)
Fig 1. PLR of LMC(Upper) and SMC(Lower). Mira Variable Stars is in C,C'

One of our aims is to determine the PLR of the Galactic Mira and to make Precise 3D map of Milky Way Galaxy.
We observe Milky Way Galaxy LPVs to determine their distances based on annual parallaxes with VERA and their pulsation periods and apparent magnitudes observed with Kagoshima University 1m Telescope. Current result of PLR of Galactic Mira is $M_K=-3.51\log P+1.09\pm0.07$ (Nakagawa et al. 2016) . However, the number of the sources is still small so we are observing more Mira variables with VERA and Kagoshima University 1m Telescope.

1.2 T UMa

T Ursae Majoris (T UMa) is a Mira Variable star in Ursa Major. It has the shortest pulsation period in the Mira Variables observed by VERA.

coordinate
R.A.12h36m23.46459s
Dec.+59d29'12.9746"
- Period 256.60 [days] (GCVS)[1]
- Parallax 0.80±1.39 [mas] (Hipparcos)

2,Observations&Data Reduction

2.1 VLBI Observations

- Telescope:VERA (Figure 2)
- Frequency:22GHz (K band)
- Date: 2009 Mar08 ~ 2010 Dec04
- Object:T-UMa
- Reference Sources :J1230+5830,J1248+5820
  (Only use J1230+5830 from the 7th observation)
- Number of observation:14

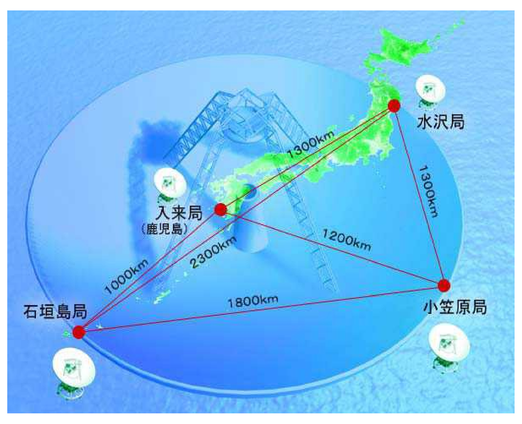


Fig 2. VERA Telescope[2]

2.2 Single-dish Observations

In parallel with the VLBI observations, a Flux density of H_2O maser has been monitored.

- Telescope:VERA Iriki station
- Observation Date:2009/01/21~2011/02/01
- Frequency:22GHz (K band)
- Object:T-UMa
- Integration time: 10 to 20 min
- Number of observation:22

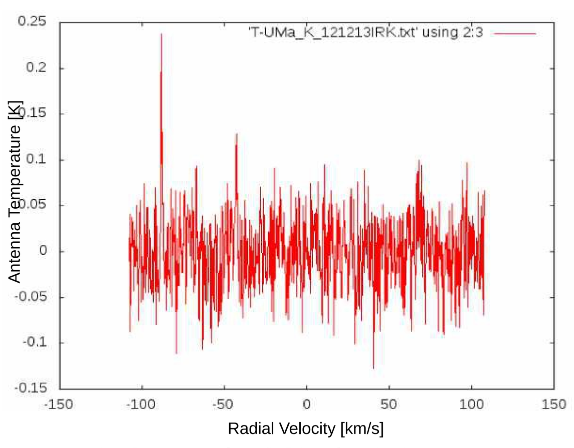


Fig 3. Result of Single dish observation Observation Date 2012/12/13

2.2 Data Reduction

Phase reference reduction was done using AIPS (Astronomical ImageProcessing System). We used the component of radial velocity of -88.55km/s. (Fig.3)

3,Results

3.1 Single-dish results

From the single-dish monitoring at Iriki, we obtained spectral profile and time variation of H_2O maser emission of T UMa (Figure 4).

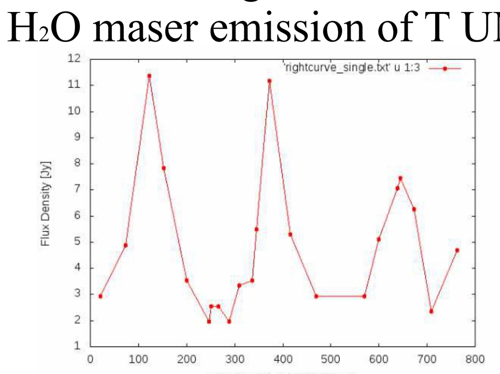


Fig 4. Time variation of H_2O maser emissions of component of radial velocity -88.55km/s.

3.2 VLBI results and parallax fitting

Maser position was confirmed at 8 epochs out of 14 observed epochs. We used 7 epochs for the parallax fitting. Observation on 2010 May18 was excluded from an annual parallax estimation because of a misidentification of the maser spot. Figure 5 shows parallactic oscillations along RA and Dec. Annual parallax(π), distance(D), and proper motion (μ_x,μ_y) were obtained as follows.

$$\pi = 0.96\pm0.19\text{[mas]} , D = 1.05^{+0.25}_{-0.17}\text{ [kpc]}$$

$$(\mu_x,\mu_y) = (-15.5\pm0.20,-8.09\pm0.54)\text{[mas/yr]}$$

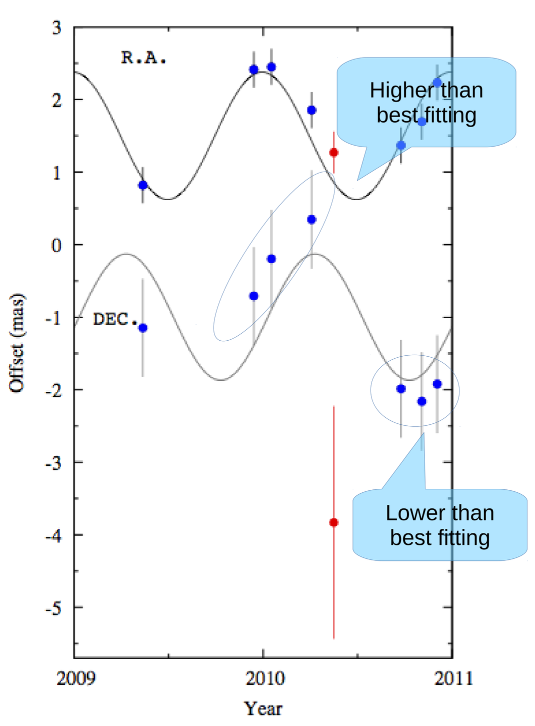


Fig 5. Parallactic motion in R.A.(above) and Dec. (below). Filled circles represent the maser position. Solid lines indicate the best fit model. Red symbols were not used in the fitting.

4,Discussion

Pulsation periods and apparent magnitudes were obtained from Kagoshima University 1m Telescope. Mean magnitudes and pulsation periods are 2.79 mag and 257 day, respectively. Absolute magnitude (M_K) is revealed using the apparent magnitude and distance obtained by VERA.

$$M_K=-7.31^{+0.39}_{-0.47}\text{ [mag]}$$

4.1 PLR fitting using T-UMa

We put the absolute magnitude of T UMa onto a previously reported PLR (Nakagawa et al. 2016) (Figure 6). Although T UMa has the shortest pulsation period in Mira Variables observed by VERA, we found that the PLR is consistent with the result of T UMa within its error.
According to Figure.6, M_K error of T UMa is larger than other sources observed with VERA. We think the large M_K error was caused by following two possible reasons in the fitting process,

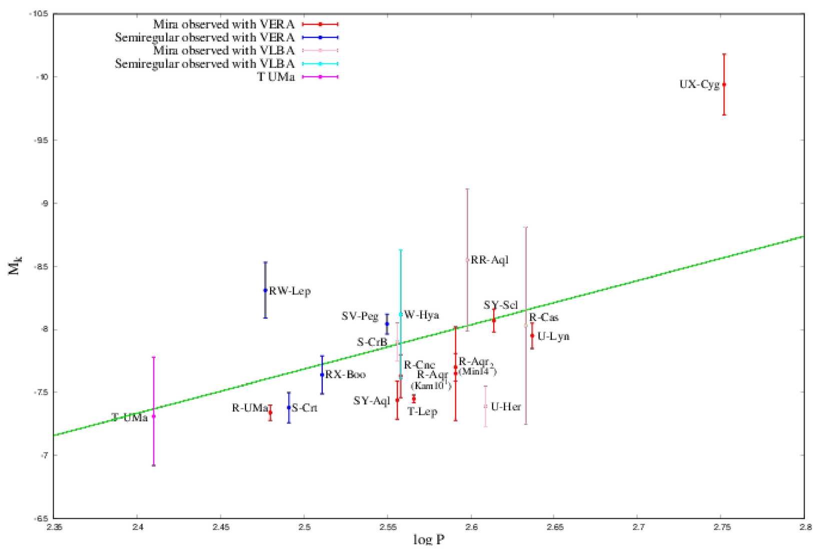


Fig.6 T UMa was plotted onto Nakagawa et al.(2016) graph. The green line is current result of PLR. Periods of RW-Lep, S-Crt, RX-Boo, and SV-Peg are multiplied by two and used.
[1] Kamohara et al. 2010
[2] Min et al. 2014

(1) Misidentification of maser spot or feature.
Figure 7 is an example of the maser spots showing two bright peaks in the same velocity channel. In figure 5, we presented our fitting result. Maser spots at three epochs (2009 Dec14, 2010 Jan17, Apr 05) are seen above the model, and the spots on next three epochs (2010 Sep 25, Nov04, Dec 04) are seen bellow the model. We think the deviations can be caused by the misidentification of the maser spot. Consideration of the light curve (Figure 4) and spatial structure of the maser spot is also important for more correct spot identification.

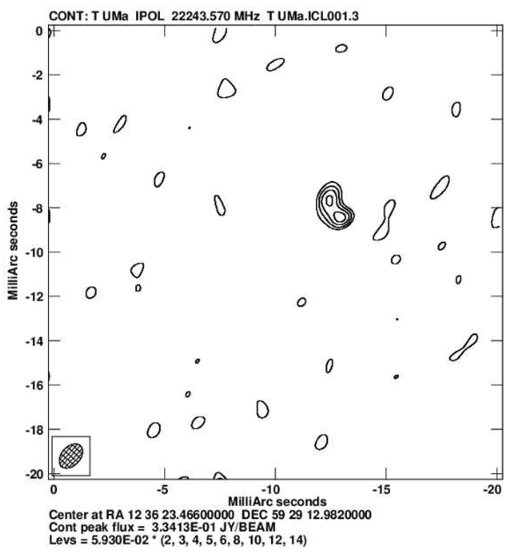


Fig.7 Separeted maser features. Observation Date 2010/11/04

(2)We used only one radial velocity component at present.
To minimize the errors, we have to include different velocity components. From result of parallax fitting of T UMa, we intend to reconsider identification of maser spot and to use different radial velocity components.

4.2 Future Works

In order to determine PLR of Galactic LPVs, we are observing and analysing other objects with VERA (Table 1). In the reduction of SY Aql, R Cnc and SV Peg, we determined their annual parallax and distance (Table 2). Movement in the celestial sphere is shown in Figure 8. Using these values, we plotted these objects in the PL plane (Fig. 6).

Table 1. Observing objects

Name	Type	P	Log P
SY Aql	Mira	359.7	2.556
R Cnc	Mira	361.6	2.558
SV Peg	SR	144.6	2.251
BX Eri	SR	165	2.217
NSV17351	OH/IR	---	---
R Peg	Mira	378.1	2.578
HS UMa	LPV	517.4	2.714
V637 Per	SR	---	---
U CVn	Mira	342.9	2.535

Table 2. Results From VERA

Name	Parallax [mas]	Distance [pc]	m_K	M_K
SY Aql	1.10±0.07	912±62.2	2.36	-7.44±0.15
R Cnc	3.84±0.29	260±20.0	-0.55	-7.63±0.17
SV Peg	3.021±0.110	331^{+13}_{-12}	-0.465	$-8.064^{+0.078}_{-0.081}$

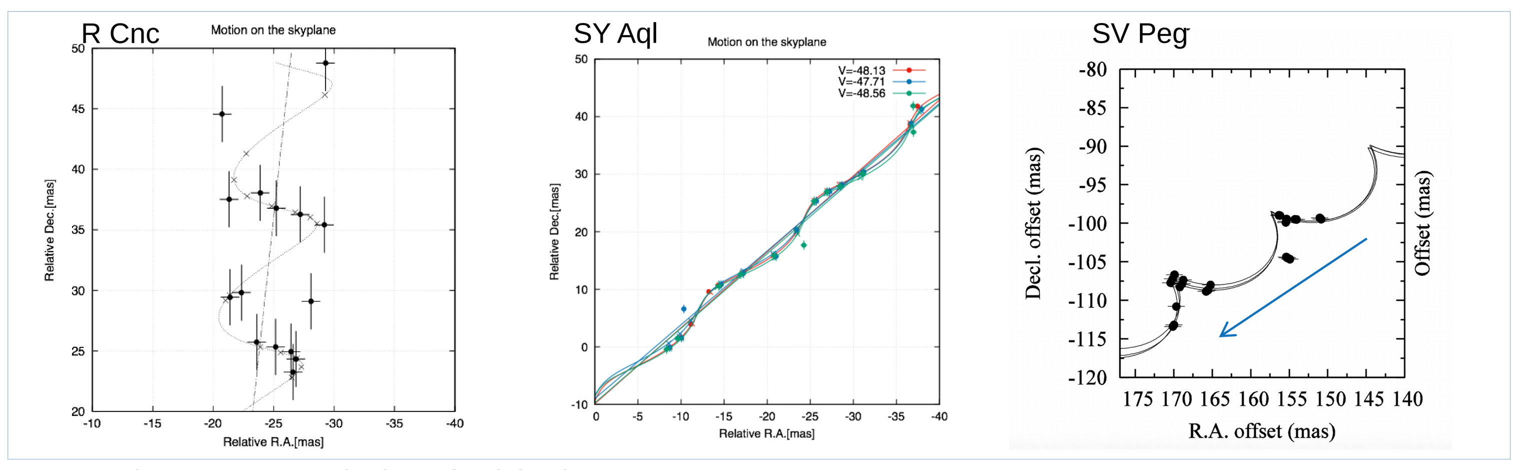


Fig. 8. Movement in the celestial sphere.

Observation of other sources started in the end of 2015, we detected H_2O maser spot in all sources. Figure 9 shows the phase-referenced image of V637 Per. In the reduction of V637 Per, the maser spot was found on all epochs. Good parallax estimation can be expected. We continue observations and data reductions of other LPVs including Mira Variables.

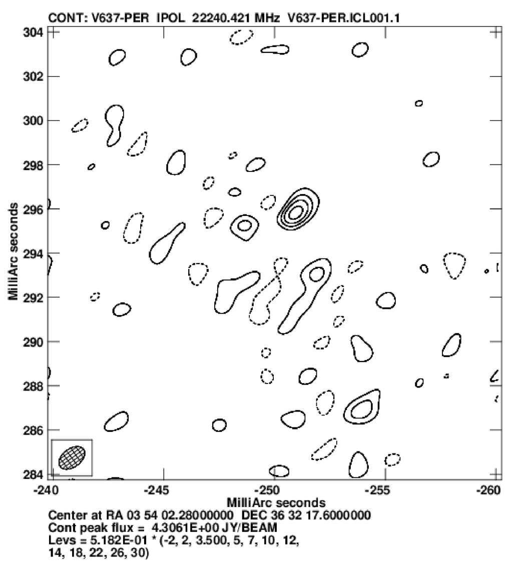


Fig 9. Phase referenced image of H_2O maser spot at the first epoch on Jan16 2016.

5,Reference

Nakagawa, A., Kurayama, T., Matsui, M., et al. 2016, PASJ,tmp,79N
Ita, Y., Tanab'e, T., Matsunaga, N., et al. 2004a, MNRAS, 347, 720
Nakagawa, A., Omodaka, T., Handa, T., et al. 2014, PASJ, 66, 101
van Leeuwen, F. 2007, Hipparcos, the New Reduction of the Raw Data.
Whitelock, P. A., Feast, M. W., & van Leeuwen, F. 2008, MNRAS,386, 313

[1]General Catalog of Variable Stars http://www.sai.msu.su/gcvs/index.htm
[2]NAOJ http://veraserver.mtk.nao.ac.jp/system/index-e.html