VERAによる長周期変光星の位置天文観測

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ミラ型変光星を含む長周期変光星（LPV）は太陽の 1−8 倍の質量を持つ。質量放出は激しく、宇宙の化学組成においても重要な役わりをもつ。この種の星では明るさと変光周期の比例関係（周期光度関係；Peirod-luminosity relation；PLR）が知られており、VERA プロジェクトの科学目標の一つはこの関係を我々の天の川銀河独自で確立することである。我々はミラ型変光星を中心にこれまで多くの LPV の位置天文観測を行ってきた。ポスターでは VLBA による計測結果とあわせてこれまでの結果を示した。

星周物質の運動の導出法として HIPPARCOS による計測との差分を用いる手法を試みた。この際、バイナリー運動の可能性を検討する必要がある。本解析からはバイナリーについての強い制限を加えることは難しかったが、少なくとも 0.5km/s/yr より大きな加速度は検出できなかった。近く打ち上げが予定される Nano-JASMINE には GAIA では困難な近傍ミラ型変光星（D= 数百 pc）の固有運動測定が期待される。このポスターで論じる VERA の測定と結びつける方法により、内部運動やバイナリー運動についてより精度の高い議論が期待できる。

1. Mira 型変光星の位置天文観測

1.1 Source selection and single dish monitoring

In table 1, we show a part of our target sources. Long period variables (LPVs) including Miras and semiregular variables are presented with Pulsation periods (P). Figure 1 shows a period distribution of ~800 Miras in Feast et al. (2000) and our ~80 targets. Period average of ~80 Miras with water maser emisison is 407 day (LogP = 2.61), which is longer than that of 338 day (LogP = 2.53) of the sources in Feast et al. (2000).

To determine a beginning of the series VLBI observations, we monitor >250 LVPs at Iriki station (Shintani et al. 2008). Intensity of ~10 Jy is a threshold of a successful detection in VLBI with VERA.

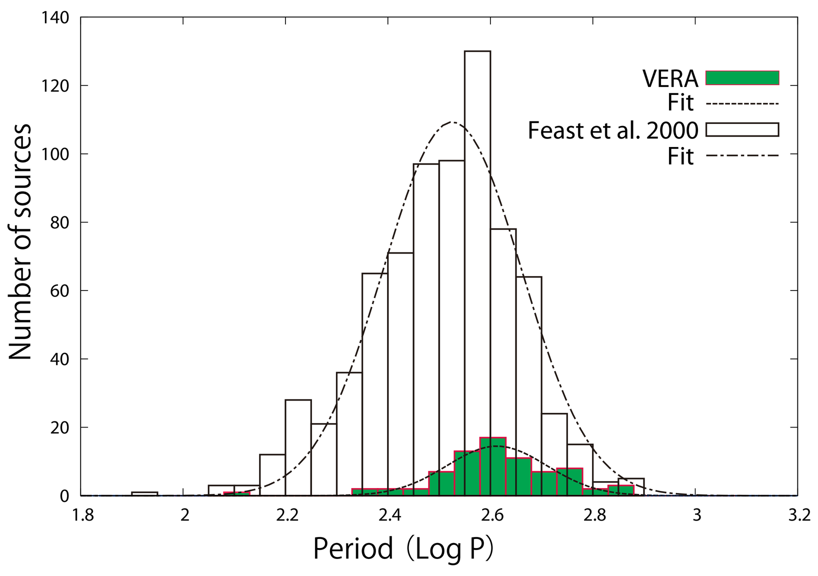

Fig.1. Period distribution of Mira variables in Feast et al. (2000) (white) and our targets (green).

Table1: Target Sources

Name	P	LogP	Type
SY Scl	415	2.62	Mira
WX Psc	660	2.82	Mira
RU Ari	354	2.55	SR
T Lep	368	2.57	Mira
BW Cam	---	---	Mira
RW Lep	150	2.18	SR
BX Cam	454	2.66	Mira
U Ori	368	2.57	Mira
AP Lyn	450	2.65	Mira
U Lyn	434	2.64	Mira
GX Mon	527	2.72	Mira
Z Pup	509	2.71	Mira
QX Pup	---	---	Mira
R Cnc	362	2.56	Mira
X Hya	301	2.48	Mira
R UMa	302	2.48	Mira
S Crt	155	2.19	SR
VX UMa	215	2.33	Mira
T UMa	257	2.41	Mira
RS Vir	354	2.55	Mira
FV Boo	340	2.53	SR
W Hya	361	2.56	Mira
RX Boo	278	2.44	SR
Y Lib	276	2.44	Mira
S CrB	360	2.56	Mira
SW Lib	292	2.47	Mira
FS Lib	415	2.62	Mira
IRC+10374	---	---	Mira
IRC-20540	510	2.71	Mira
SY Aql	356	2.55	Mira
SV Peg	145	2.16	SR
R Aqr	390	2.59	Mira

1.2 VLBI observation

We conduct phase referencing VLBI observation at 22 GHz with typical duration of 1.5 − 2.0 years. Interval is ~1 month.

2. VLBIによるLPVの測距と周期光度関係

In the last decade, astrometric VLBI has been played an important role for determining annual parallaxes of the Galactic LPVs. Table 2 shows all parallaxes measured with VLBI method (VLBA and VERA). Red giants and OH/IR stars are also included in the table. Errors of absolute magnitude are based on their distance errors.

In the red-colored plot of figure 2, we show a distribution of the Galactic LPVs on absolute magnitude Mk − LogP plane. Red solid line indicate a PLR determined in our previos work (Nakagawa et al. 2014). Result by Ita et al. (2004) is superposed to find sequences for several types of variables.

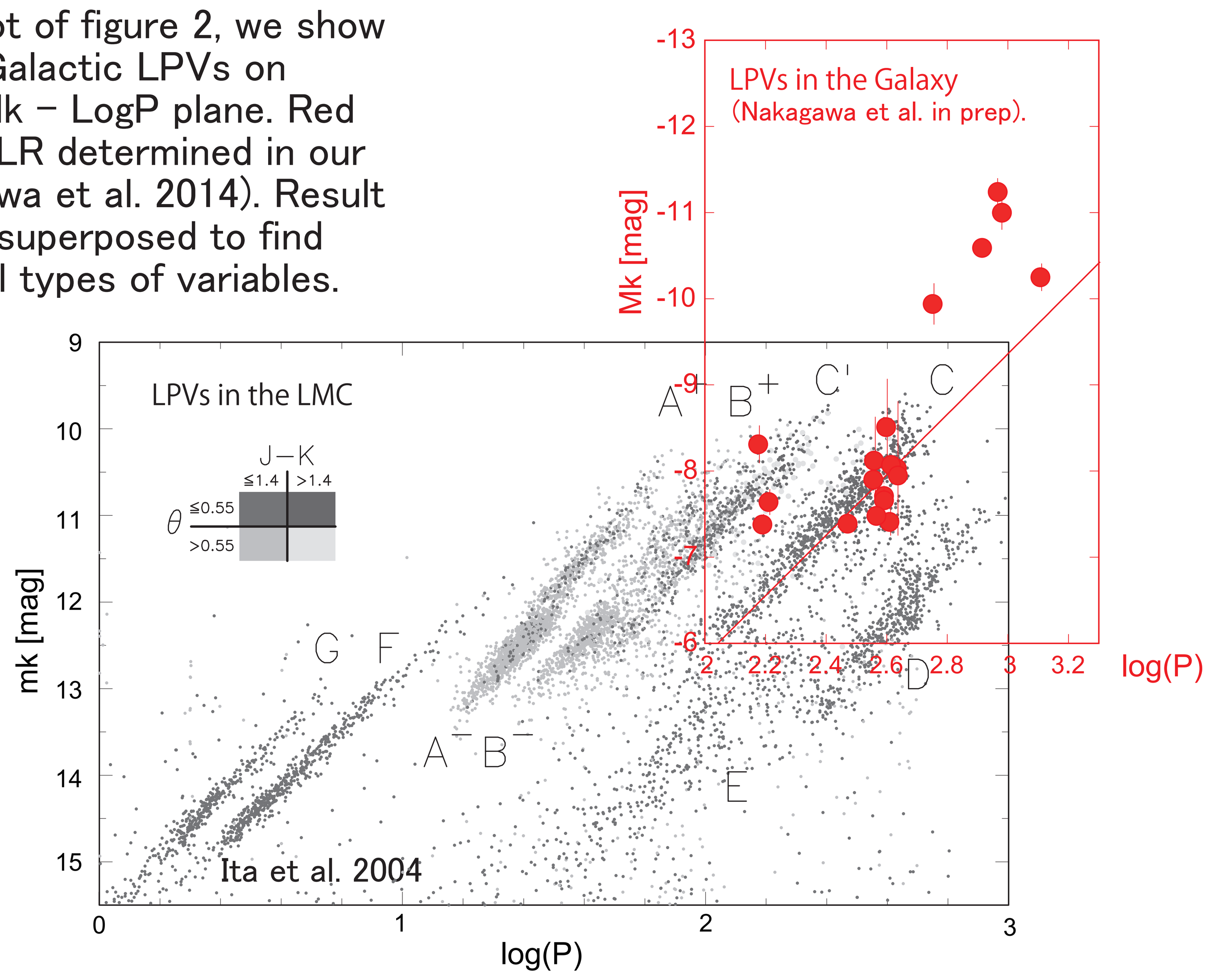

Fig.2. LPV source distribution in the Galaxy (red) and LMC (gray, Ita et al. 2004) on Mk - LogP plane. Distance of 49.89 kpc is assumed to the LMC.

Table2: Results from VLBI astrometry

Source	Type	Parallax† [mas]	P [day]	LogP	m_K‡ [mag]	M_K [mag]	Maser	Ref.
W Hya	SRa	10.18±2.36	361	2.558	-3.16	-8.12±0.51	OH	vle03
R Cas	Mira	5.67±1.95	430	2.633	-1.80	-8.03±0.78	OH	vle03
UX Cyg	Mira	0.54±0.06	565	2.752	1.40	-9.94±0.24	H2O	kur05
S CrB	Mira	2.39±0.17	360	2.556	0.21	-7.90±0.15	OH	vle07
U Her	Mira	3.76±0.27	406	2.609	-0.29	-7.41±0.16	OH	vle07
RR Aql	Mira	1.58±0.40	396	2.598	0.50	-8.51±0.56	OH	vle07
S Crt	SRb	2.33±0.13	155	2.190	0.786	-7.38±0.12	H2O	nak08
VY CMa	SRc	0.88±0.08	956	2.980	-0.72	-11.00±0.20	H2O	cho08
S Per	SRc	0.413±0.017	822	2.915	1.33	-10.59±0.09	H2O	asa10
R Aqr	Mira	4.7±0.8	390	2.591	-1.02	-7.66±0.37	SiO	kam10
SY Scl	Mira	0.75±0.03	411	2.614	2.55	-8.07±0.09	H2O	nyu11
RX Boo	SRb	7.31±0.5	162	2.210	-1.96	-7.64±0.15	H2O	kam12
NML Cyg		0.620±0.047	1280	3.107	0.791	-10.25±0.16	H2O	zha12
PZ Cas	SRc	0.356±0.026	925	2.966	1.00	-11.24±0.16	H2O	kus13
T Lep	Mira	3.06±0.04	368	2.566	0.09	-7.48±0.03	H2O	nak14
RW Lep	SRa	1.62±0.16	150	2.176	0.639	-8.31±0.22	H2O	kam14
R Aqr	Mira	4.59±0.24	390	2.591	-1.02	-7.71±0.11	SiO	min14
U Lyn	Mira	1.27±0.06	434	2.637	1.533	-7.95±0.10	H2O	kam15
R UMa	Mira	1.92±0.05	296	2.471	1.19	-7.39±0.06	H2O	This study

Ref. vle03 : Vlemmings et al. 2003, kur05 : Kurayama et al. 2005, vle07 : Vlemmings & van Langevelde 2007, nak08 : Nakagawa et al. 2008, cho08 : Choi et al. 2008, asa10 : Asaki et al. 2010, kam10 : Kamohara et al. 2010, nyu11 : Nyu et al. 2011, kam12 : Kamezaki et al. 2012, zha12 : Zhang et al. 2012, kus13 : Kusuno et al. 2013, nak14 : Nakagawa et al. 2014, kam14 : Kamezaki et al. 2014, min14 : Min et al. 2014, kam15 : Kamezaki et al. 2015.

3. Mira 型変光星 R UMa の観測

3.1 Parallax measurement

Using 12 maser spots, an annual parallax of R UMa was determined to be 1.92±0.05 mas, corresponding to a distance of 520±14 mas. Figure 3 shows parallactic motions in R.A. and Dec.

3.2 Maser spot distribution

Distribution of the maser spots around R UMa (Figure 4). Color indicate radial velocity. A cross mark is an estimated positon of central star from a consideration of the distribution. The map is 146 au square. An estimated shell with a radiusof 85 mas is presented with a dotted circle.

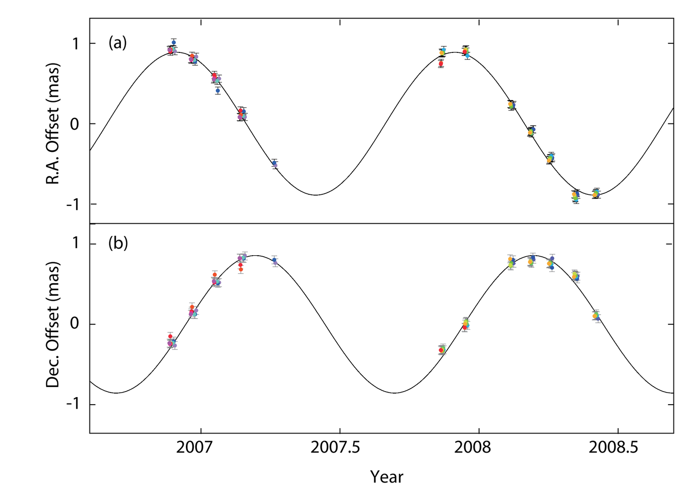

Fig.3. R UMa, parallactic motion.
(Nakagawa et al. in prep).

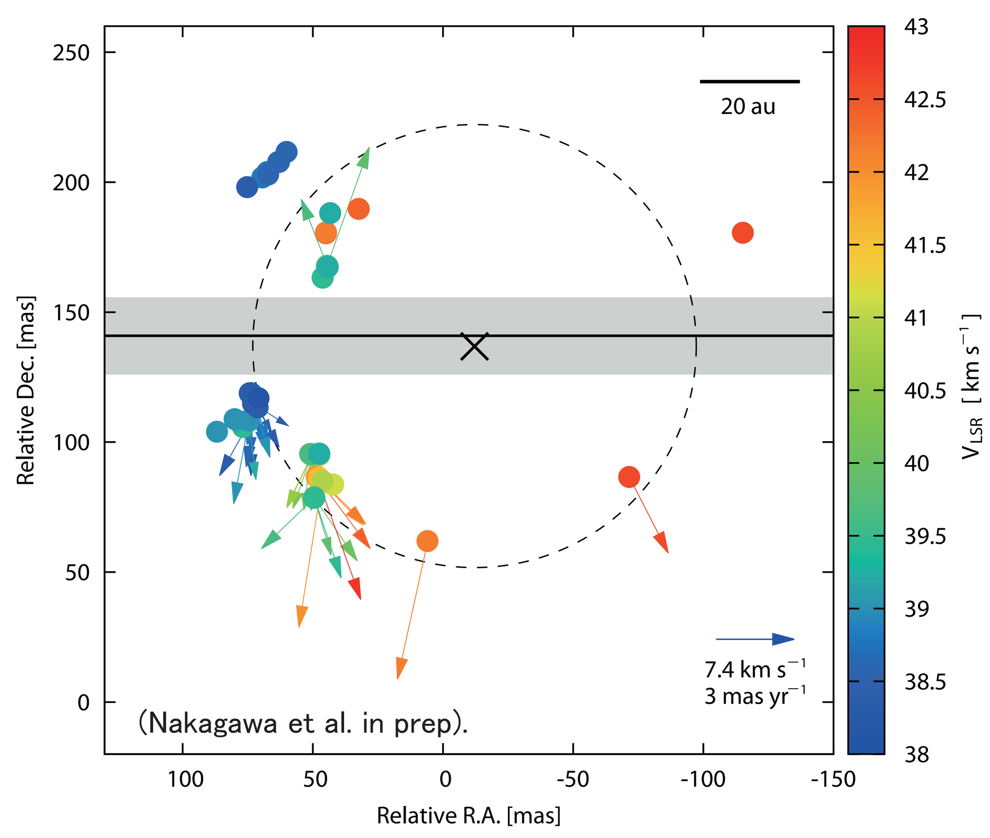

Fig.4. Distribution of water masers in R UMa. A cross mark indicate an estimated star posion.

3.3 Maser internal motion revealed from VERA and HIPPARCOS astrometry

Kinematics of circumstellar matter from VLBI method based on "pattern matching".
—No definitive position reference (photosphere is not observable)
—We estimate internal motions of maser spots by subtracting "average motion"
—Difficulty for determining the "average motion" with few masers

In figure 4, we derived the internal motions by subtracting HIPPARCOS proper motion (μ_x, μ_y) = (−40.51, −22.66) mas/yr from our VLBI measurements of each maser spot. VLBI proper motion accuracy of the spots was ~0.2mas/yr.

$$\begin{aligned} \mu\_VERA &= \mu\_sys + \mu\_int \\ -)\ \mu\_HIP &= \mu\_sys \\ \hline \mu\_VERA - \mu\_HIP &= \mu\_int \end{aligned}$$

Figure 5 shows an internal motion velocity gradient along DEC axis found from our analysis. Vy = 0 gives a Y = ~140 mas, which is indicated with a holizontal line in figure 4 with peripheral gray region indicatig its error.

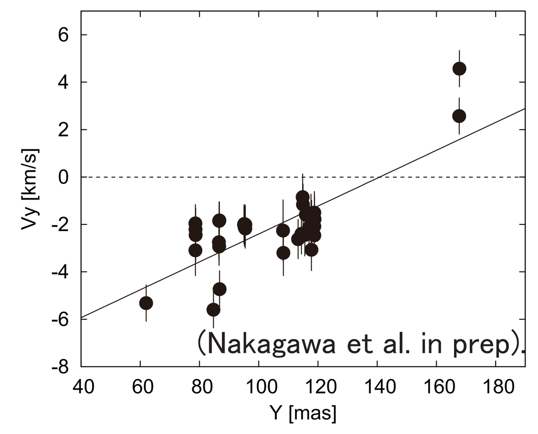

Fig.5. Internal motion velocity gradient of maser spots alog DEC.

Actually, we have to pay attention to effects of "binary system". The μ_bin and μ_bin' indicate velocity vectors of binary motion on Hipparcos and VERA observation dates.

$$\begin{aligned} \mu\_VERA &= \mu\_sys + \mu\_bin' + \mu\_int \\ -)\ \mu\_HIP &= \mu\_sys + \mu\_bin \\ \hline \mu\_VERA - \mu\_HIP &= \Delta\mu\_bin + \mu\_int \end{aligned} \qquad (\Delta\mu\_bin = \mu\_bin' - \mu\_bin)$$

Time differential of μ_VERA−μ_HIP include an acceleration of binary system. In next section, we consider the effect of binary motion, and try to give a constraint on binary scenario of R UMa.

3.4 Constraint on binary scenario

Since we did not detect difference of systematic motions between HIP and VERA larger than ~2 mas/yr (=~5 km/s), an acceleration due to a binary motion can be estimated to be < 0.5 km/s/yr (5 km/s was devided by an interval of 10 yr between HIP and VERA). In a radial velocity, we could not find any difference in Vslr of R UMa from literatures.

Gray scale of figure 6 gives a companion mass in unit of Msun as a function of orbit semimajor axis and acceleraion. If we assume the acceralation of 0.5 km/s/yr as an upper limit, and also assume a companion mass larger than 0.5 Msun, a semimajor axis should be larger than ~14 au.

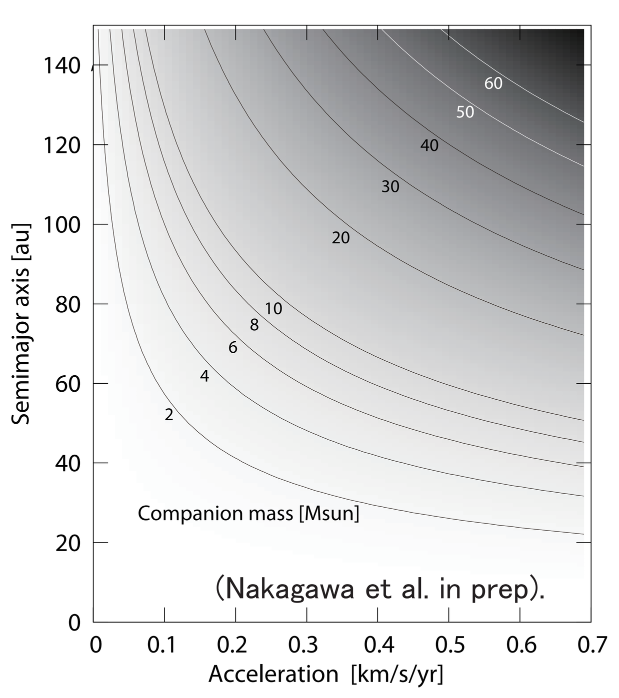

Fig.6. Biary orbit semimajor axis, acceleration of binary motion and companion mass.

Of course, we can not reject a single star scenario.

For very bright stars, like nearby Milas, Nano-JASMINE will be a powerful and promising telescope to determine their proper motions. In near future, more accurate proper motions from new satellites will be tied up with VLBI measurements of maser spots. With the same method as this study, circumstellar dynamics and binary scenario of many sources can be studied.