Astrometry of the Galactic Miras and LPVs with a Japanese VLBI array “VERA”

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- Mass: 1~8 M\(_\odot\) (Mira: 1~2.5 M\(_\odot\) ?)
- C/O-core, He-shell, H-rich envelope → O-rich/C-rich
- Period: 100~1000 d, P>1000 d
- Chemical enrichment of the universe
- Distance indicator

**Two main topics**
(1) Mira Period – M(K) relation
(2) OH/IR Period – M(mid-IR) relation

https://www.cfa.harvard.edu/~mmarengo/me/agn.html
VLBI monitoring observations with VERA

VLBI monitoring with 1 month interval.

We need 1.5 ～ 2 yr to derive a parallax.
Parallax measurements

Motions on the sky plane

- S Crt (SR): Nakagawa et al. 2008

Parallactic oscillation

- R UMa (Mira): (Nakagawa et al. 2016)

H₂O 22GHz
**Latest results from VLBI astrometry**

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>Parallax [mas]</th>
<th>P [day]</th>
<th>LogP</th>
<th>mK [mag]</th>
<th>MK [mag]</th>
<th>Maser</th>
<th>Reference (Parallax,mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RW Lep</td>
<td>sra</td>
<td>1.62±0.16</td>
<td>150</td>
<td>2.176</td>
<td>0.639</td>
<td>-8.31±0.22</td>
<td>H2O</td>
<td>kam14, a</td>
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<tr>
<td>S Crt</td>
<td>srb</td>
<td>2.33±0.13</td>
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<td>RX Boo</td>
<td>srb</td>
<td>7.31±0.5</td>
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<td>-1.96</td>
<td>-7.64±0.15</td>
<td>H2O</td>
<td>kam12, b</td>
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<tr>
<td>T UMa</td>
<td>Mi</td>
<td>0.96±0.15</td>
<td>257</td>
<td>2.410</td>
<td>2.60</td>
<td>-7.49±0.44</td>
<td>H2O</td>
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<tr>
<td>Y Lib</td>
<td>Mi</td>
<td>1.24±0.13</td>
<td>276</td>
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<td>-6.37±0.23</td>
<td>H2O</td>
<td>in prep., a</td>
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<tr>
<td>R UMa</td>
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<tr>
<td>SY Aql</td>
<td>Mi</td>
<td>1.10±0.07</td>
<td>356</td>
<td>2.551</td>
<td>2.36</td>
<td>-7.43±0.14</td>
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<tr>
<td>R Cnc</td>
<td>Mi</td>
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<td>-8.05±0.16</td>
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<td>in prep., a</td>
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<tr>
<td>W Hya</td>
<td>sra</td>
<td>10.18±2.36</td>
<td>361</td>
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<td>-3.16</td>
<td>-8.12±0.51</td>
<td>OH</td>
<td>vle03, c</td>
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<tr>
<td>S CrB</td>
<td>Mi</td>
<td>2.39±0.17</td>
<td>360</td>
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<tr>
<td>T Lep</td>
<td>Mi</td>
<td>3.06±0.04</td>
<td>368</td>
<td>2.566</td>
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<td>-7.45±0.03</td>
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<tr>
<td>R Aqr</td>
<td>Mi</td>
<td>4.7±0.8</td>
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<td>SiO</td>
<td>kam10, c</td>
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<tr>
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<td>Mi</td>
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<td>U Her</td>
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<td>Mi</td>
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<td>OH231.8+4.2</td>
<td>OH/IR</td>
<td>0.55±0.05</td>
<td>551</td>
<td>2.741</td>
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<td>in prep.</td>
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<td>UX Cyg</td>
<td>Mi</td>
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<td>565</td>
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<tr>
<td>S Per</td>
<td>src</td>
<td>0.413±0.017</td>
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<td>asa10, b</td>
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<td>PZ Cas</td>
<td>src</td>
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<td>1.00</td>
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<td>VY CMa</td>
<td>src</td>
<td>0.88±0.08</td>
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<td>NML Cyg</td>
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<td>0.62±0.047</td>
<td>1280</td>
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<td>0.791</td>
<td>-10.25±0.16</td>
<td>H2O</td>
<td>zha12, a</td>
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</tbody>
</table>
Period- Mk relation of Mira and SR variables based on VLBI astrometry

\[ \text{Mk} = -3.52 \log P + (1.09 \pm 0.14) \]

More sources are needed to solve a zero-point with better accuracy.
Period luminosity relation of OH/IR stars ($P > 1000d$)

Mid-IR absolute magnitudes of OH/IR stars with known distances.

Distances from

1. Phase-lag method (Engels et al. 2015)
2. Kinematic distance

Black solid/dotted lines indicate $C/C'$ sequences in Ita et al. (2004).
Period luminosity relation of OH/IR stars \((P > 1000d)\)

Mid-IR absolute magnitudes of OH/IR stars with known distances.

Distances from

1. Phase-lag method (Engels et al. 2015)
2. Kinematic distance

\[
M_{W3} = -3.1(\pm 2.6) \log P - 4.1(\pm 8.1)
\]

What can we do with the relation of OH/IR stars?
Study of the Galactic kinematics

SFRs and RSG are used as probes to study the Galactic kinematics.

- They are very young, \( \sim 10^6 \) yeas. Sample property is uniform.

If we can construct PLR of OH/IR with \( P>1000d \), they can offer a new disk tracer...
OH/IR stars as a new tracers of the study of the Galactic kinematics

- Period=1000 days → M=\sim 4\text{Msun} (Feast 2008)
- Age : 10^8 - 10^9 yr
- Probes with various ages are needed
- Calibration of mid-infrared PLR of OH/IR stars.
- Astrometry: VLBI (OH/SiO/H2O masers)

Wada et al. 2011

Figure 10. Same as Figure 8, but for snapshots every 5 Myr after \( t = 1.385 \text{ Gyr} \).

(A n animation of this figure is available in the online journal.)
OH/IR stars with $P > 1000d$

Yamashita (Thesis 2016)

- **W3-band**

K-band light curve
Kagoshima university 1m-telescope.

- **Kinematic distances**
To construct Mid-IR PL-relation of OH/IR stars, astrometry of OH/IR stars is important.

- **VLBI**: OH, H2O, SiO masers

- **Gaia**: OH/IR stars may be invisible
- **JASMINE**: infrared satellite for Galactic bulge stars

Gabor et al. in prep.
Summary
— Astrometric study of the Galactic LPVs —

(1) **Mira & Semiregular variables**
- Phase-referencing VLBI at 22 GHz with VERA
- Parallaxes of ~15 Miras and SRs were determined
- Period-Mk relation; $M_k = -3.52 \log P + (1.09 \pm 0.14)$ (Nakagawa et al. 2016)
- 10 more sources are required to accomplish zero-point accuracy of 0.1 mag.

(2) **OH/IR stars**
- Mid-infrared Period-M relation can be confirmed
- Kinematics of stars with age of $\sim 10^8$ years → They are unique sample for comparison with theoretical model
- VLBI astrometry using OH/H2O/SiO masers is important

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Wada et al. 2011

Nakagawa et al. 2016

Gabor in prep.