



# VERAを用いた長周期変光星の位置天文観測



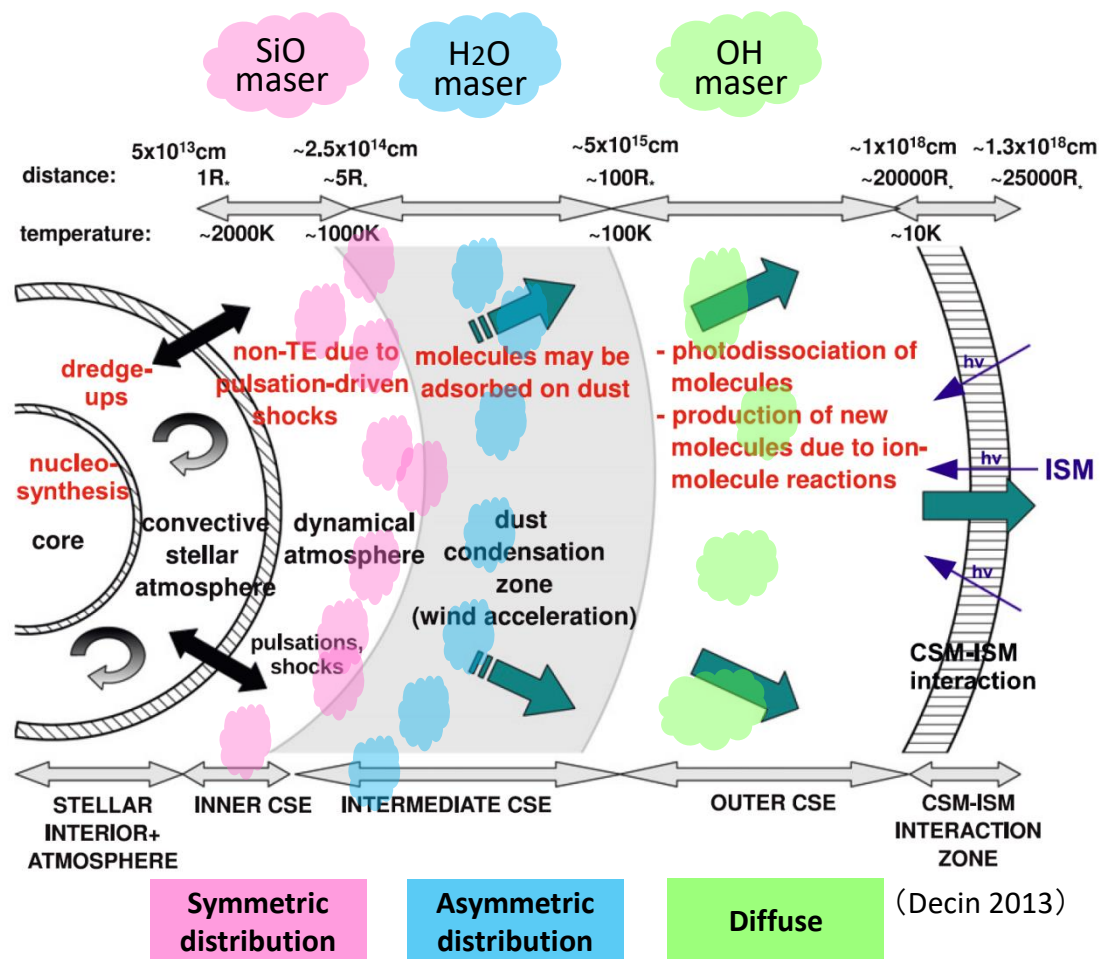
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## 1. VERAによるMira型変光星のVLBI位置天文観測の状況

- ・約80のプロジェクト天体
- ・変動フェーズや周期を考慮して選定
- ・年周視差、固有運動
- ・星周物質の運動

## 2. OH/IR星の位置天文観測

- ・星の特徴と観測のねらい
- ・Mira型プロジェクトとの関連



# 観測対象とするMira型変光星の性質

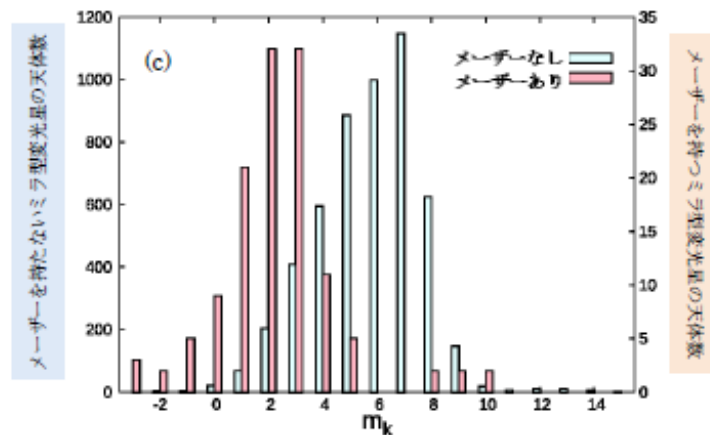
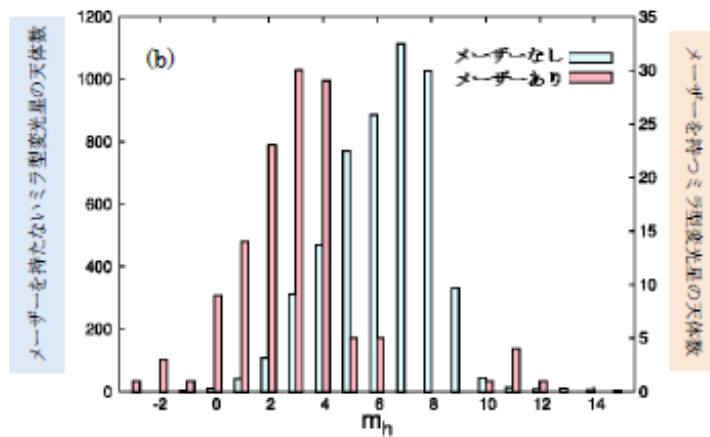
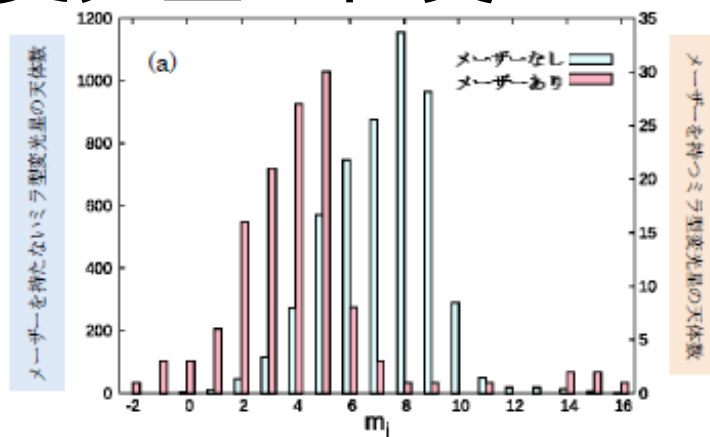
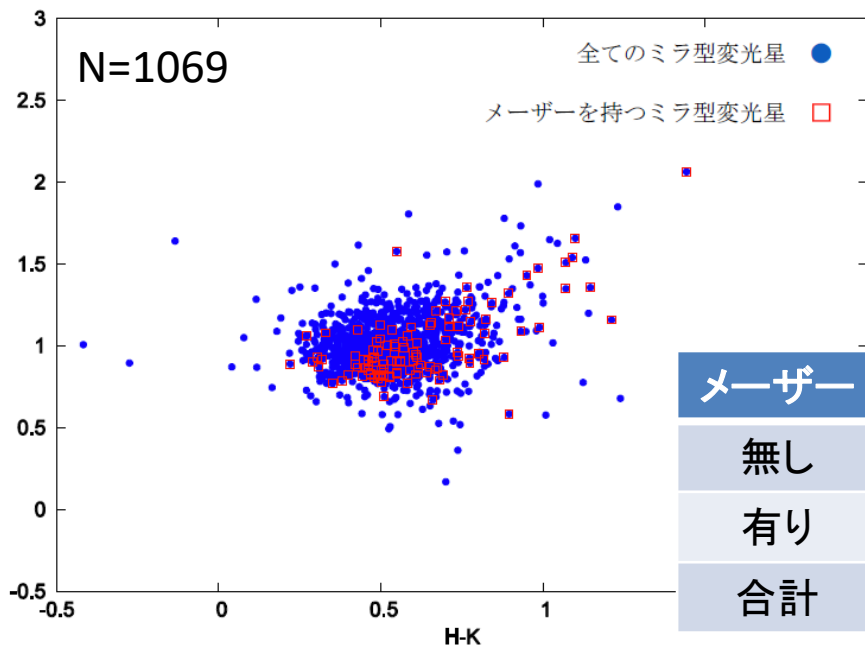
## 問題意識:

メーザーを持つミラと持たないミラで、  
周期光度関係に差はあるのか？

- ・SIMBADよりMiraを抽出
- ・メーザーのフラグの有無で区別
- ・近赤外の見かけ等級と数の関係(右図)



- ・見かけ等級に制限をかけることで、  
距離によるメーザー非検出の影響を除去  
 $m_J < 6.0$ ,  $m_H < 5.0$ ,  $m_K < 4.0$



# 観測対象とするMira型変光星の性質

## 色の比較

メーザーなし ■  
 メーザーあり ■

| (a) J-H | ピーク              | 半値幅  |
|---------|------------------|------|
| メーザーなし  | $0.95 \pm 0.004$ | 0.34 |
| メーザーあり  | $0.86 \pm 0.01$  | 0.25 |

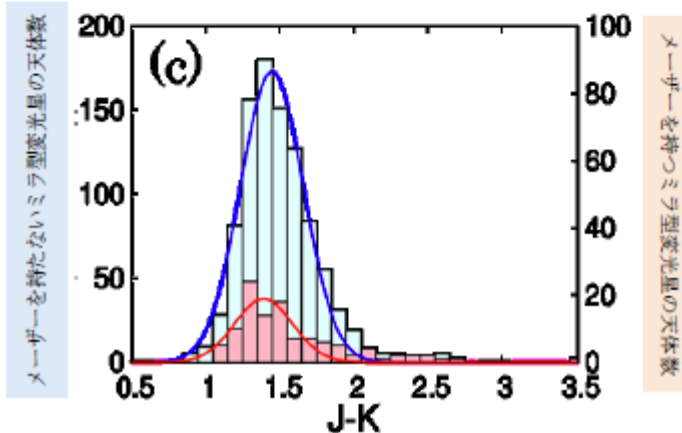
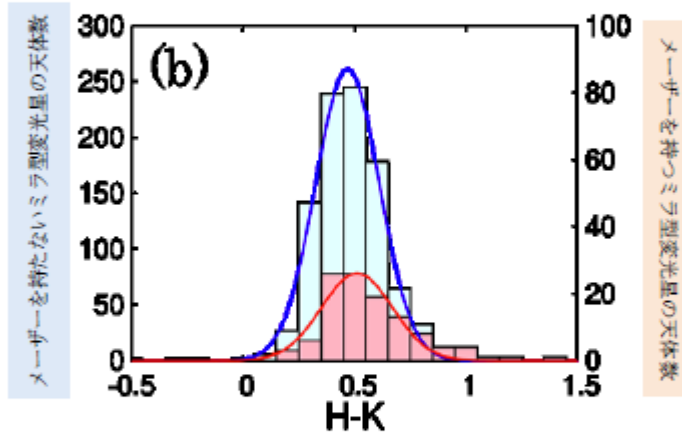
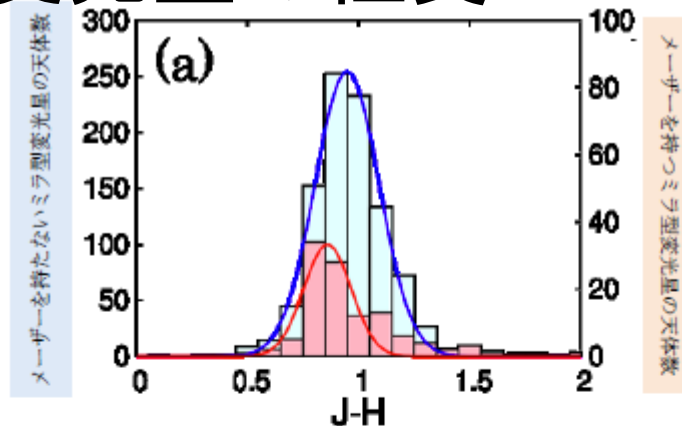
$$\Delta(J-H) = 0.09$$

| (b) H-K | ピーク              | 半値幅  |
|---------|------------------|------|
| メーザーなし  | $0.47 \pm 0.004$ | 0.34 |
| メーザーあり  | $0.51 \pm 0.01$  | 0.38 |

$$\Delta(H-K) = 0.04$$

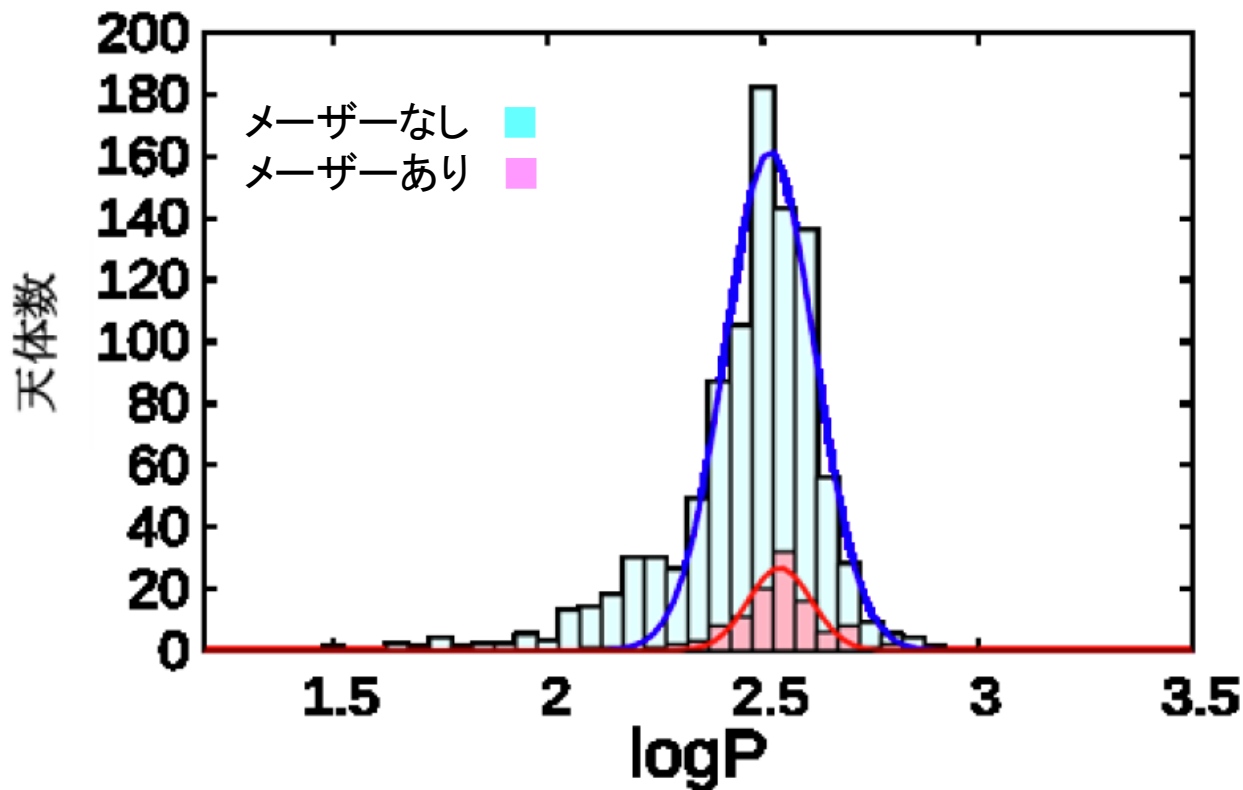
| (c) J-K | ピーク              | 半値幅  |
|---------|------------------|------|
| メーザーなし  | $1.45 \pm 0.007$ | 0.5  |
| メーザーあり  | $1.39 \pm 0.02$  | 0.46 |

$$\Delta J-K = 0.06$$



# 観測対象とするMira型変光星の性質

- 変光周期の比較



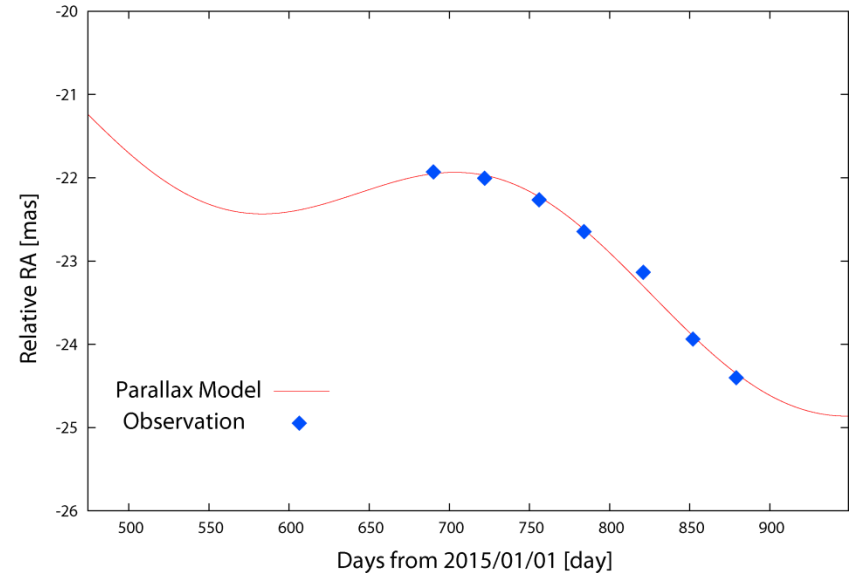
|        | ピークの位置           | 変光周期P[day]     |
|--------|------------------|----------------|
| メーザーなし | $2.52 \pm 0.005$ | $328 \pm 1.01$ |
| メーザーあり | $2.54 \pm 0.004$ | $346 \pm 1.01$ |

$$\Delta P [\text{day}] = 18$$

$$\Delta \text{Log} P = 0.02$$

# 最近の結果

- U CVn
  - 周期345日のミラ型変光星
- OH231.8+4.2 → 大山まど薫 (ポスター)
  - 原始惑星状星雲、ダスト発達、OH/IR星
  - 大規模な双極流
- OZ Gem → 山口凌平 (ポスター)
  - 周期598日、Kバンド絶対等級が暗い
  - 星周吸収による影響が顕著か？
- R Hya → 湯田晶斗 (ポスター)
  - 周期380日のミラ型変光星
  - 2016年のバースト後に観測開始
- R-Peg → 加世田大地 (ポスター)
  - 周期378日のミラ型変光星
  - 検出感度限界付近での年周視差計測
- AP Lyn → 森川雄斗 (ポスター)
  - 周期おそよ450日
  - VERA初期データの一つ



U CVn

Parallax =  $0.82 \pm 0.14$ [mas]

Distance =  $909 \pm 58$ [kpc] –

# 最近の観測結果(22GHz 水メーザー)

ポスター講演 湯田晶斗、加世田大地

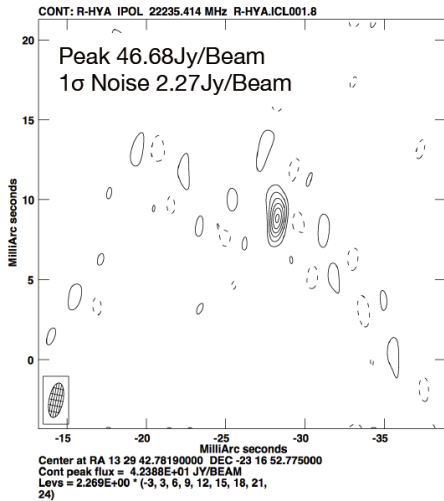


図 7. R-Hyaの2017年4月30日観測  
-7.59km/sのメーザーの位相補償マップ

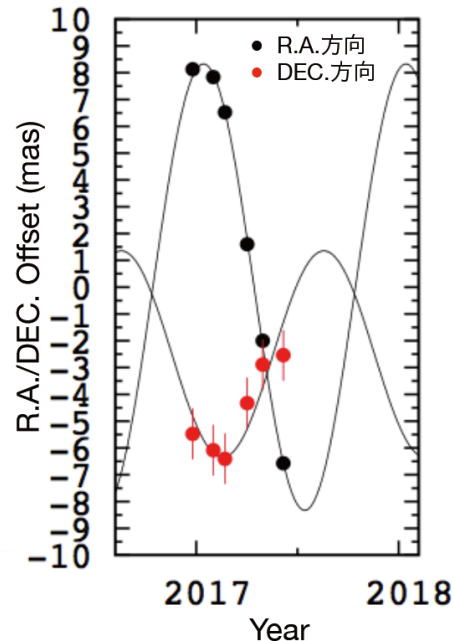


図 8. R-HyaのR.A./DEC.方向の運動

## R Hya

2016年冬にバースト(~1100 Jy) 22GHz  
同年12月からVLBI観測開始

Parallax =  $8.96 \pm 0.51$ [mas]  
Distance =  $0.11 \pm 0.01$ [kpc] –  
 $\mu_x = 52.87 \pm 2.08$ [mas/yr],  
 $\mu_y = 18.33 \pm 2.78$ [mas/yr]

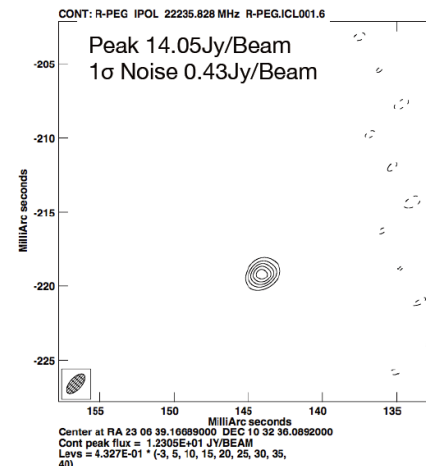


図 9. R-Pegの2016年5月31日観測  
23.60km/sのメーザーの位相補償マップ

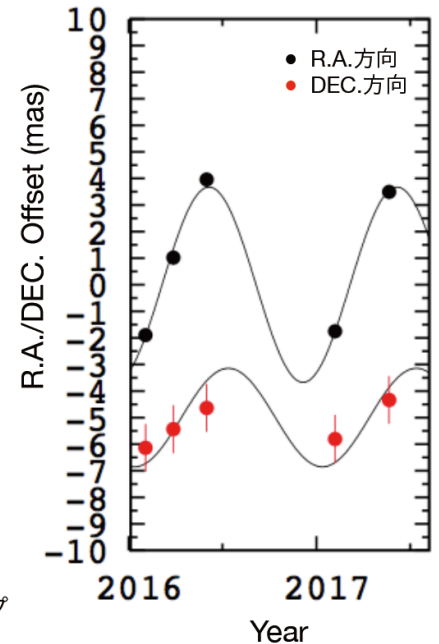


図 10. R-PegのR.A./DEC.方向の運動

## R Peg

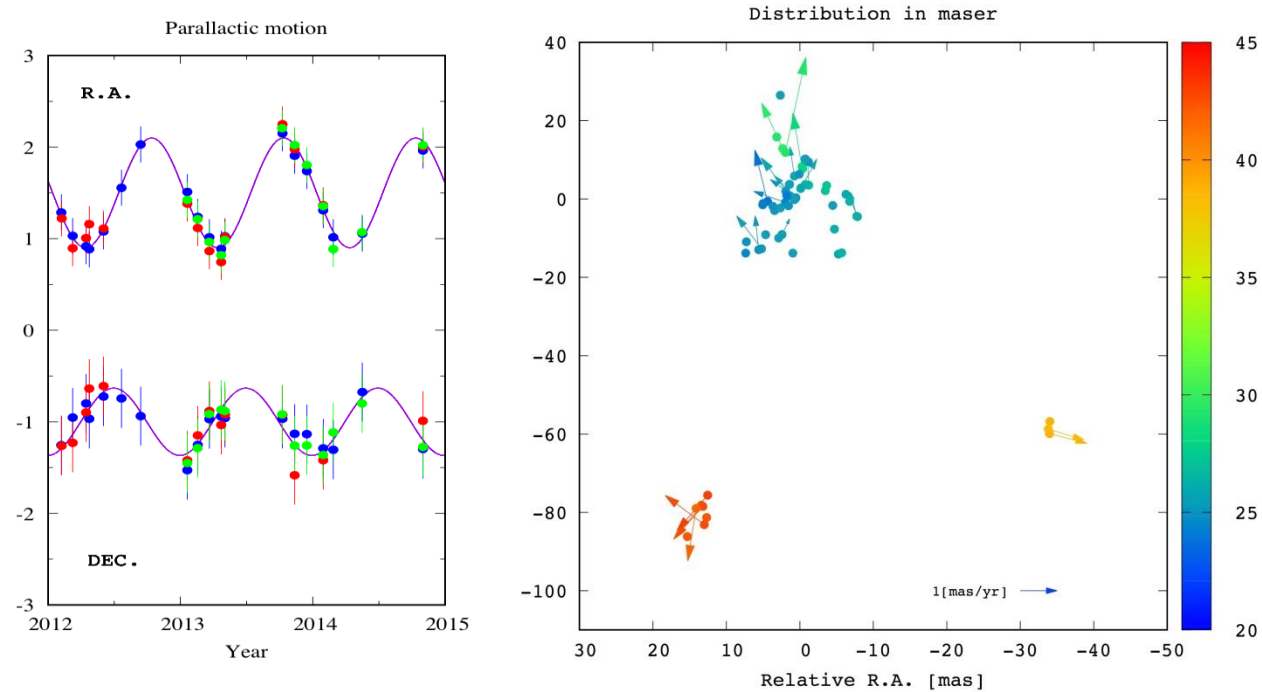
2016年2月からVLBI観測開始  
水メーザーの検出限界の上下を変動する

Parallax =  $3.98 \pm 0.21$ [mas]  
Distance =  $0.25 \pm 0.01$ [kpc]  
 $\mu_x = 1.55 \pm 0.26$ [mas/yr]  
 $\mu_y = -12.37 \pm 0.86$ [mas/yr]

# 最近の観測結果(22GHz 水メーザー)

ポスター講演 大山まど薫

## OH231.8+4.2 (QX Pup)



## OH231.8+4.2 (QX Pup)

Parallax =  $0.61 \pm 0.03$  [mas]

Distance =  $1.65 \pm 0.08$  [kpc]



大規模アウトフロー  
(Hubble telescope)



# AGB star distances from VLBI astrometry

| Source      | Type  | Parallax<br>[mas] | $P$<br>[day] | $\log P$ | $m_K$<br>[mag] | $M_K$<br>[mag] | Maser            | Reference <sup>†</sup><br>(Parallax, $m_K$ ) |
|-------------|-------|-------------------|--------------|----------|----------------|----------------|------------------|--|
| RW Lep      | SRa   | 1.62±0.16         | 150          | 2.176    | 0.639          | -8.31 ± 0.22   | H <sub>2</sub> O | kam14, a                                     |
| S Cr        | SRb   | 2.33±0.13         | 155          | 2.190    | 0.786          | -7.38 ± 0.12   | H <sub>2</sub> O | nak08, a                                     |
| RX Boo      | SRb   | 7.31±0.5          | 162          | 2.210    | -1.96          | -7.64 ± 0.15   | H <sub>2</sub> O | kam12, b                                     |
| T UMa       | Mira  | 0.96±0.15         | 257          | 2.410    | 2.60           | -7.49 ± 0.44   | H <sub>2</sub> O | ..., a                                       |
| Y Lib       | Mira  | 1.24±0.13         | 276          | 2.441    | 3.16           | -6.37 ± 0.23   | H <sub>2</sub> O | ..., a                                       |
| R UMa       | Mira  | 1.92±0.05         | 302          | 2.480    | 1.19           | -7.39 ± 0.06   | H <sub>2</sub> O | nak16, d                                     |
| U CVn       | Mira  | 0.82±0.14         | 345          | 2.538    | 2.84           | -7.59 ± 0.37   | H <sub>2</sub> O | ..., a                                       |
| SY Aql      | Mira  | 1.10±0.07         | 356          | 2.551    | 2.36           | -7.43 ± 0.14   | H <sub>2</sub> O | ..., a                                       |
| R Cnc       | Mira  | 3.84±0.29         | 357          | 2.553    | -0.97          | -8.05 ± 0.16   | H <sub>2</sub> O | ..., a                                       |
| W Hya       | SRa   | 10.18±2.36        | 361          | 2.558    | -3.16          | -8.12 ± 0.51   | OH               | vle03, c                                     |
| S CrB       | Mira  | 2.39±0.17         | 360          | 2.556    | 0.21           | -7.90 ± 0.15   | OH               | vle07, c                                     |
| T Lep       | Mira  | 3.06±0.04         | 368          | 2.566    | 0.12           | -7.45 ± 0.03   | H <sub>2</sub> O | nak14, c                                     |
| R Peg       | Mira  | 3.98±0.21         | 378          | 2.577    | 0.45           | -6.55 ± 0.11   | H <sub>2</sub> O | ..., a                                       |
| R Hya       | Mira  | 8.96±0.51         | 380          | 2.580    | -2.51          | -7.75 ± 0.12   | H <sub>2</sub> O | ..., a                                       |
| R Aqr       | Mira  | 4.7±0.8           | 390          | 2.591    | -1.01          | -7.65 ± 0.37   | SiO              | kam10, c                                     |
| R Aqr       | Mira  | 4.59±0.24         | 390          | 2.591    | -1.01          | -7.70 ± 0.11   | SiO              | min14, c                                     |
| RR Aql      | Mira  | 1.58±0.40         | 396          | 2.598    | 0.46           | -8.55 ± 0.56   | OH               | vle07, c                                     |
| U Her       | Mira  | 3.76±0.27         | 406          | 2.609    | -0.27          | -7.39 ± 0.16   | OH               | vle07, c                                     |
| SY Scl      | Mira  | 0.75±0.03         | 411          | 2.614    | 2.55           | -8.07 ± 0.09   | H <sub>2</sub> O | nyu11, b                                     |
| R Cas       | Mira  | 5.67±1.95         | 430          | 2.633    | -1.80          | -8.03 ± 0.78   | OH               | vle03, c                                     |
| U Lyn       | Mira  | 1.27±0.06         | 434          | 2.637    | 1.533          | -7.95 ± 0.10   | H <sub>2</sub> O | kam15, a                                     |
| OH231.8+4.2 | OH/IR | 0.55±0.05         | 551          | 2.741    | ...            | ...            | H <sub>2</sub> O | ...  |
| UX Cyg      | Mira  | 0.54±0.06         | 565          | 2.752    | 1.40           | -9.94 ± 0.24   | H <sub>2</sub> O | kur05, a                                     |
| OZ Gem      | Mira  | 1.00±0.18         | 598          | 2.777    | 3.00           | -7.00 ± 0.40   | H <sub>2</sub> O | ..., a                                       |
| V353 Pup    | ...   | 0.56±0.03         | 802          | 2.904    | 2.02           | -9.24 ± 0.12   | H <sub>2</sub> O | ..., a                                       |
| S Per       | SRc   | 0.413±0.017       | 822          | 2.915    | 1.33           | -10.59 ± 0.09  | H <sub>2</sub> O | asa10, b                                     |
| PZ Cas      | SRc   | 0.356±0.026       | 925          | 2.966    | 1.00           | -11.24 ± 0.16  | H <sub>2</sub> O | kus13, b                                     |
| VY CMa      | SRc   | 0.88±0.08         | 956          | 2.980    | -0.72          | -11.00 ± 0.20  | H <sub>2</sub> O | cho08, b                                     |
| NML Cyg     | ...   | 0.62±0.047        | 1280         | 3.107    | 0.791          | -10.25 ± 0.16  | H <sub>2</sub> O | zha12, a                                     |

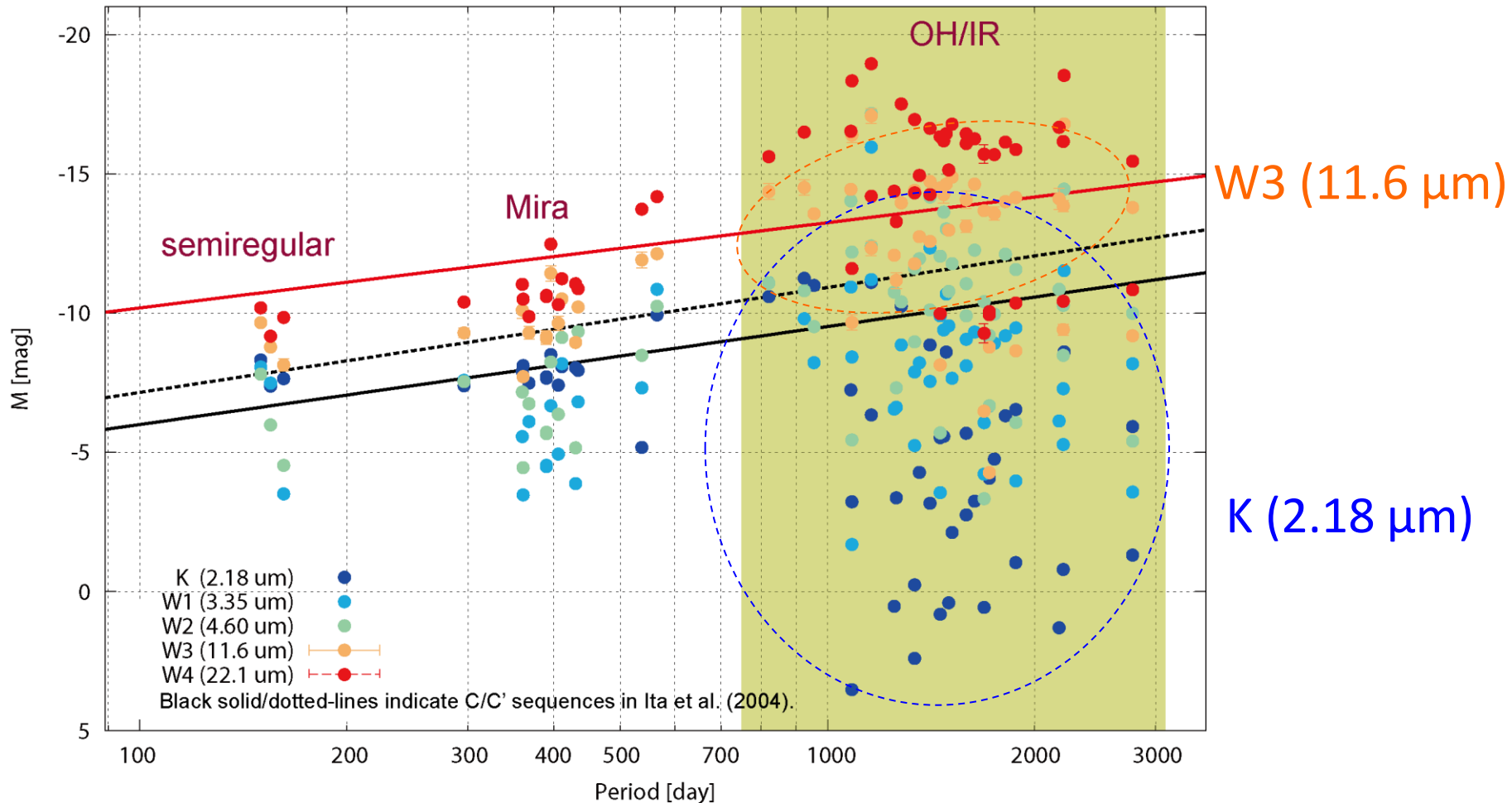




# Period luminosity relation of OH/IR stars ( $P > 1000d$ )

Mid-IR absolute magnitudes of  $\sim 20$  OH/IR stars with known distances.

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



➡ What can we do with the OH/IR stars ( $P > 1000 d$ ) ?

# OH/IR stars as new probes of the Galactic dynamics

Samples with various ages are needed for better understanding. ■ ■ ■ SFRs are very young,  $\sim 10^6$  yeas.

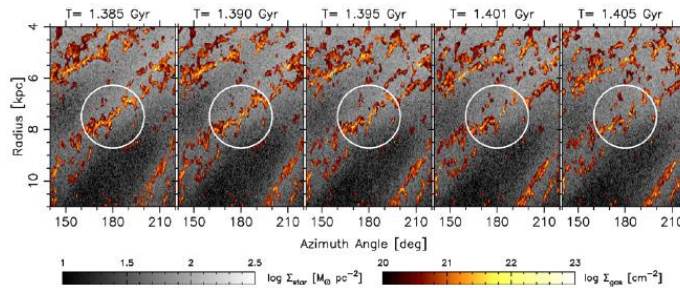
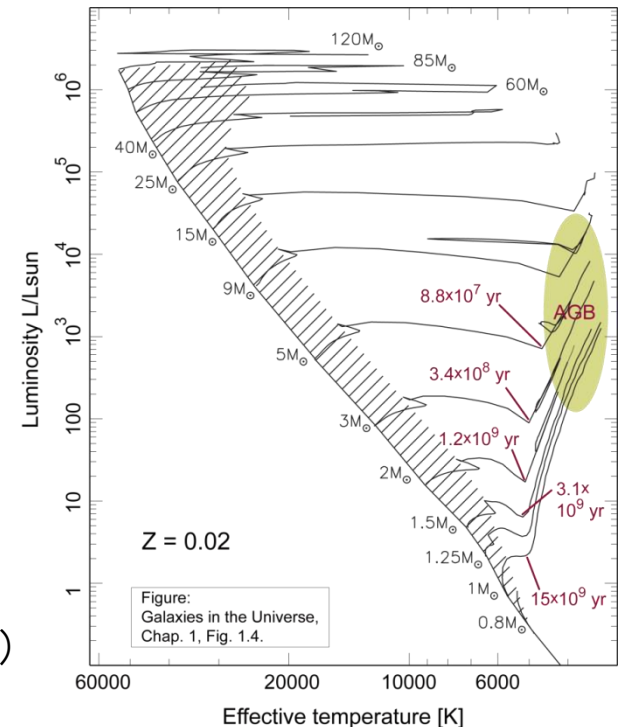
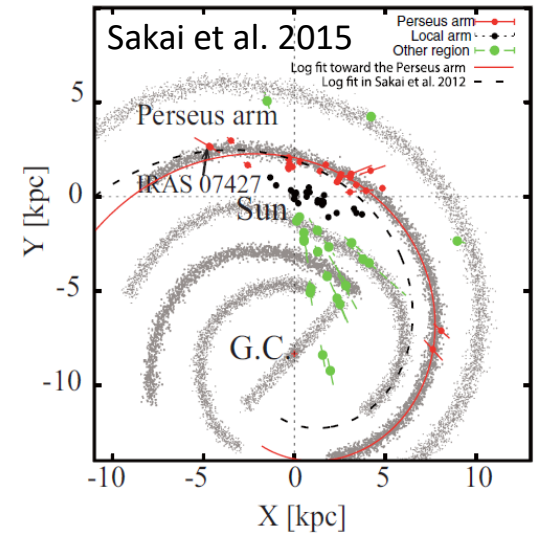


Figure 10. Same as Figure 8, but for snapshots every 5 Myr after  $t = 1.385$  Gyr.  
(An animation of this figure is available in the online journal.)

Wada et al. 2011



|     | Age            | Physics                      | Target                |
|-----|----------------|------------------------------|-----------------------|
| New | $\sim 10^6$ yr | Spiral arm                   | SRF, Giants           |
| ⇕   | $\sim 10^8$ yr | Bifurcating/<br>merging arms | Heavy<br>OH/IR star ? |
| Old | $\sim 10^9$ yr | Relaxed system               | Mira                  |

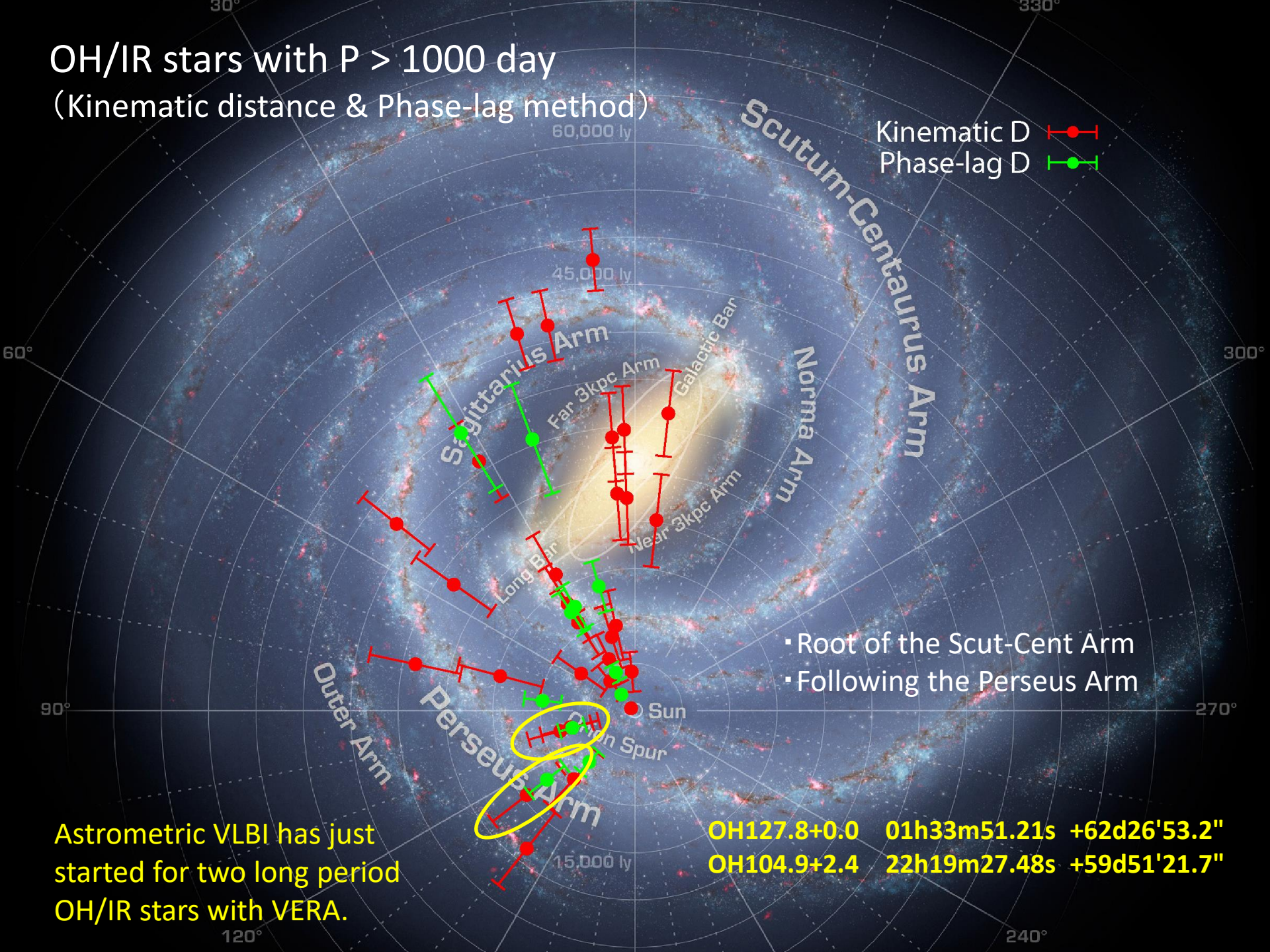
| Model | ↔ | Obs. |
|-------|---|------|
| ✓     | ↔ | ✓    |
| ✓     | ↔ | No   |
| ✓     | ↔ | ✓    |

- Period=1000 days →  $M \sim 4M_{\odot}$  (Feast 2008)
- Age :  $10^8 - 10^9$  yr



# OH/IR stars with $P > 1000$ day

(Kinematic distance & Phase-lag method)



Kinematic D ●  
Phase-lag D ●

- Root of the Scut-Cent Arm
- Following the Perseus Arm

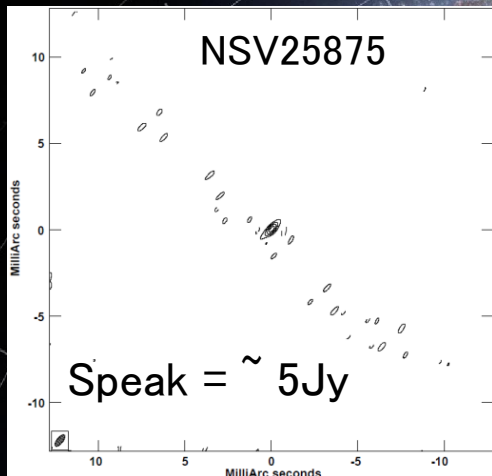
Astrometric VLBI has just started for two long period OH/IR stars with VERA.

OH127.8+0.0 01h33m51.21s +62d26'53.2"  
OH104.9+2.4 22h19m27.48s +59d51'21.7"



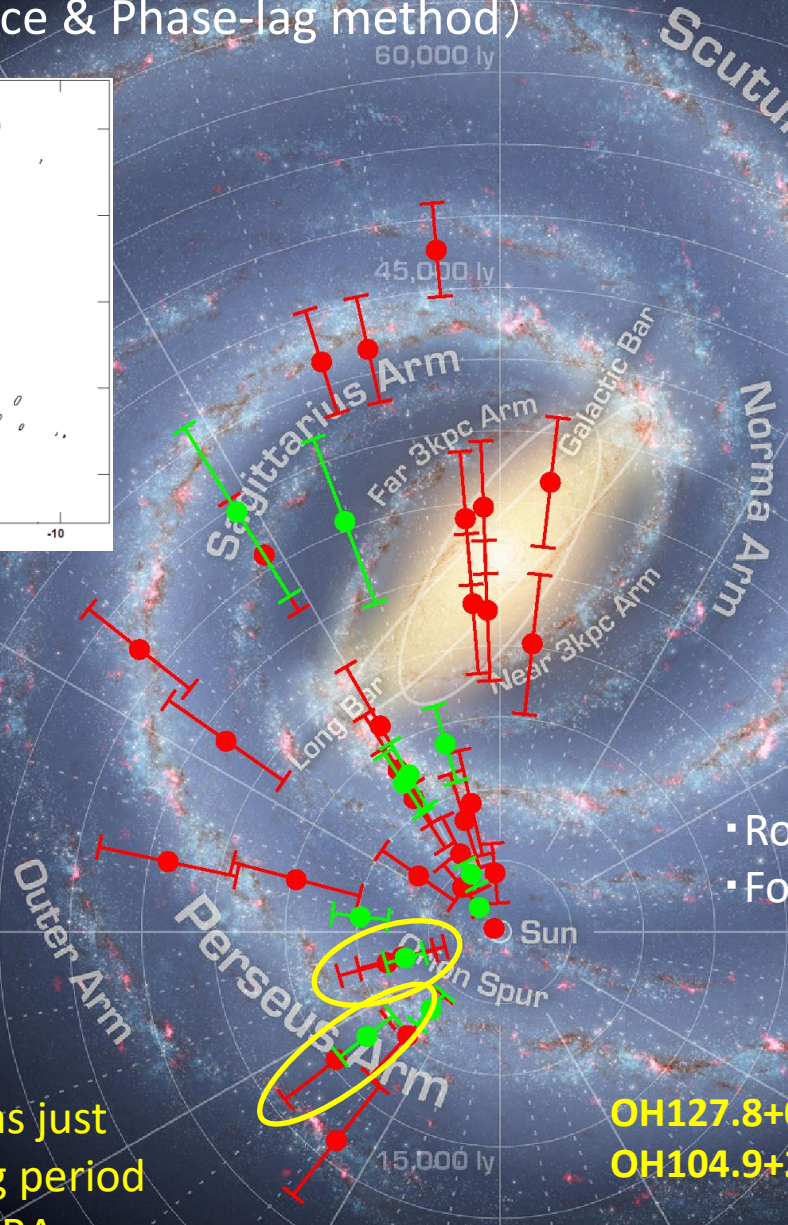
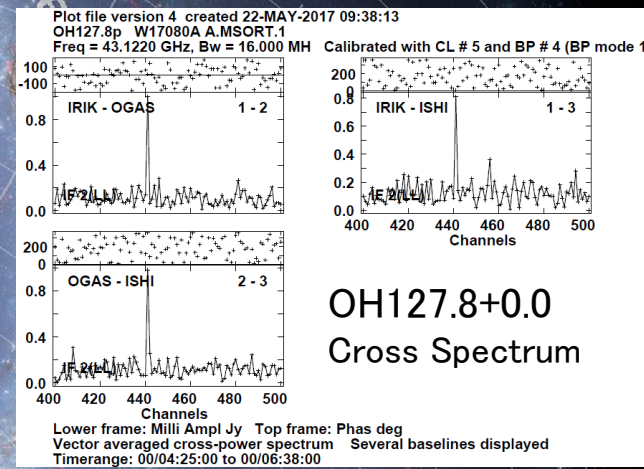
# OH/IR stars with $P > 1000$ day

(Kinematic distance & Phase-lag method)



Kinematic D ● — ●

Phase-lag D ● — ●



- Root of the Scut-Cent Arm
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Astrometric VLBI has just started for two long period OH/IR stars with VERA.

OH127.8+0.0 01h33m51.21s +62d26'53.2"  
 OH104.9+2.4 22h19m27.48s +59d51'21.7"

# Summary

## (1) Mira型変光星の位置天文観測

- VERA Phase-ref. VLBI at 22 GHz (H<sub>2</sub>O maser)
- Parallaxes of ~25 Galactic LPVs determined (Mira, Semiregular, OH/IR star)
- P-Mk relation ;  
$$M_k = -3.52 \log P + (1.09 \pm 0.14)$$
(Nakagawa et al. 2016)

▪ **Circumstellar extinction ?**

## (2) 長周期OH/IR星の位置天文への展開

- They offer unique samples for study dynamics of stars with age of  $\sim 10^8$  years
- VLBI astrometry with SiO masers has just started
- Existence of MIR P-M relation ?

