新しいディスクトレーサーとしての長周期OH/IR星位置天文

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1　Aim, Method of astrometric study of Miras and LPVs using VERA

2　Current results

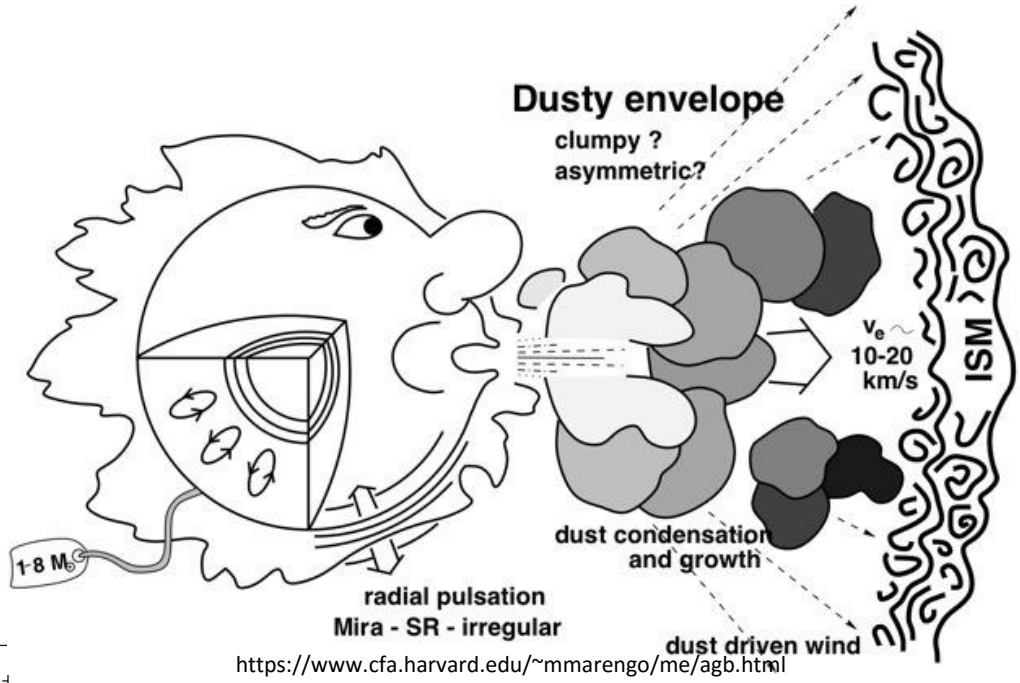
- Period–luminosity relation
- Circumstellar kinematics

3　Future prospects of the Galactic LPV studies based on astrometry

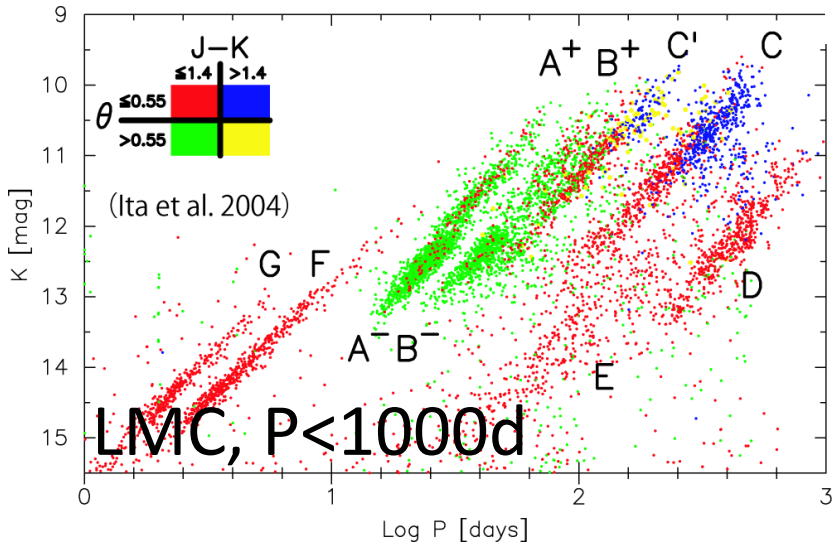
- Construction of PLR of the Galactic OH/IR stars (P>1000d)

Mira and other long period variables

- Mass 1～3 Msun （1～8 Msun）
- C/O-core, He-shell, H-rich envelope
  - O-rich, C-rich
- Period 100～1000 d, P>1000d
- Period-luminosity (MK) relation
  → Distance indicator
- High mass loss ratio
  → Chemical enrichment of the universe
- Thick disk star
- Large velocity dispersion



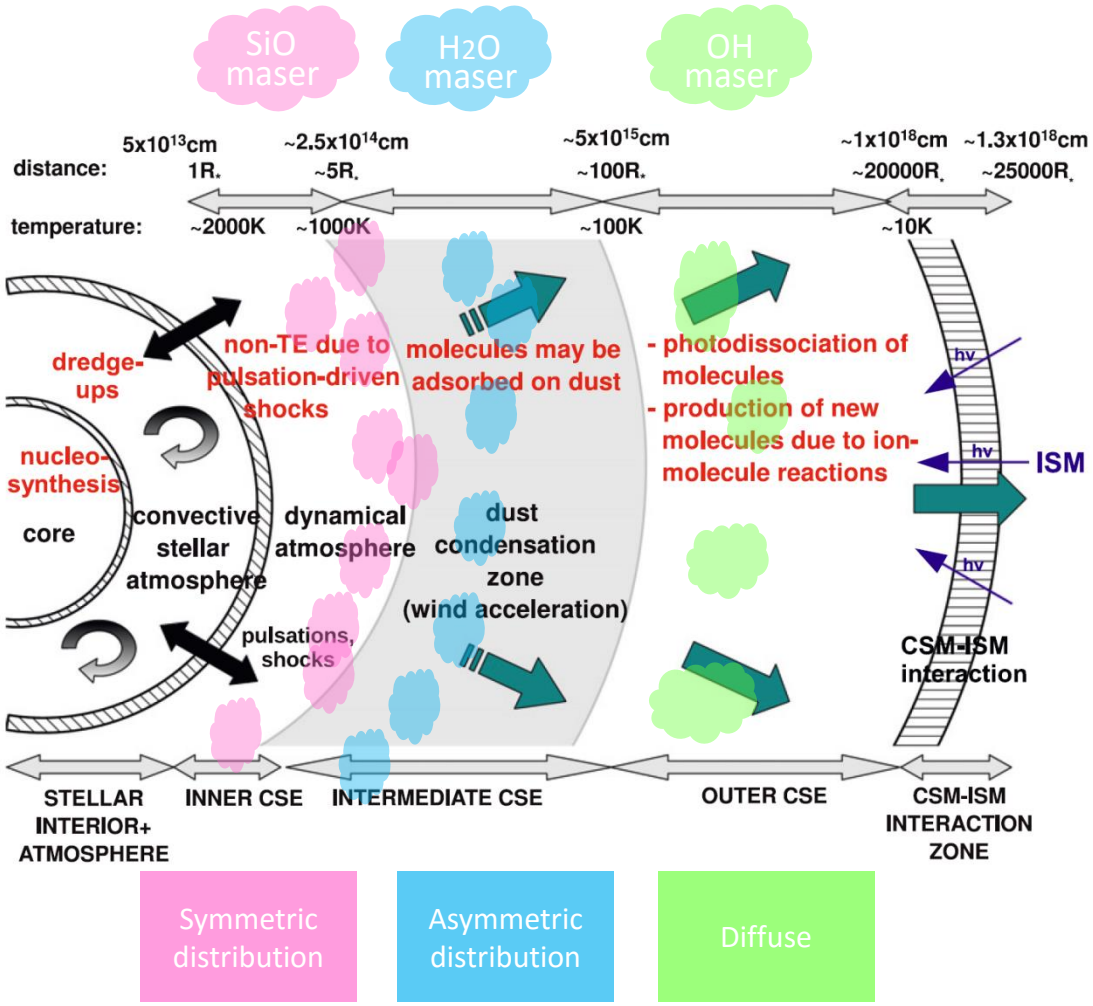
https://www.cfa.harvard.edu/~mmarengo/me/agb.html



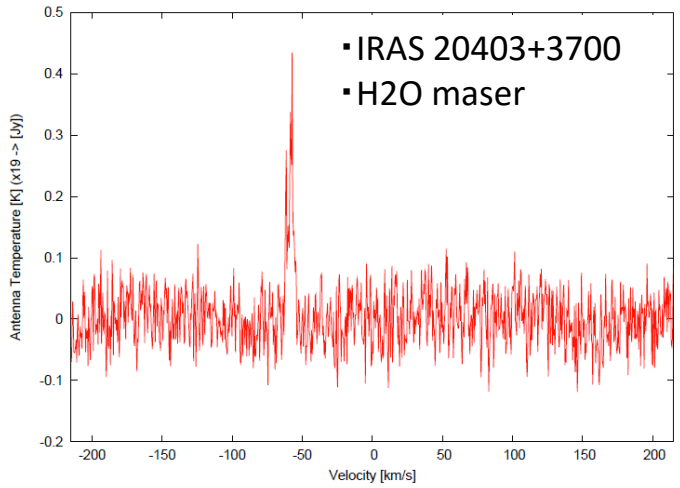
A+	Cyan	RGB variables and metal-poor and old AGB variables
A-	Yellow	Less regularly pulsating AGB variables
B-	Orange	RGB variables and metal-poor and old AGB variables
B+	Green	Less regularly pulsating AGB variables
C'	Blue	Mira variables pulsating in the first-overtone mode
C	Red	Mira variables pulsating in the fundamental mode
D	Steel-blue	Some obscured variables and unknown variables
F	Magenta	Cepheid variables pulsating in the fundamental mode
G	Purple	Cepheid variables pulsating in the first-overtone mode

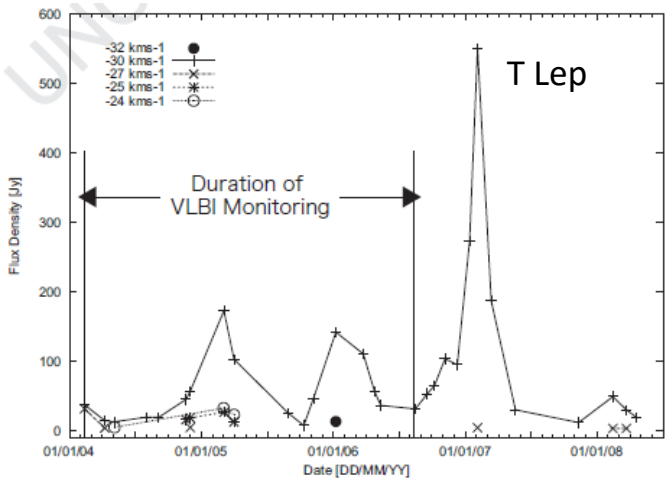
Masers in Miras

- Long term monitoring of H2O masers (2003～)
- Interval ~1 month

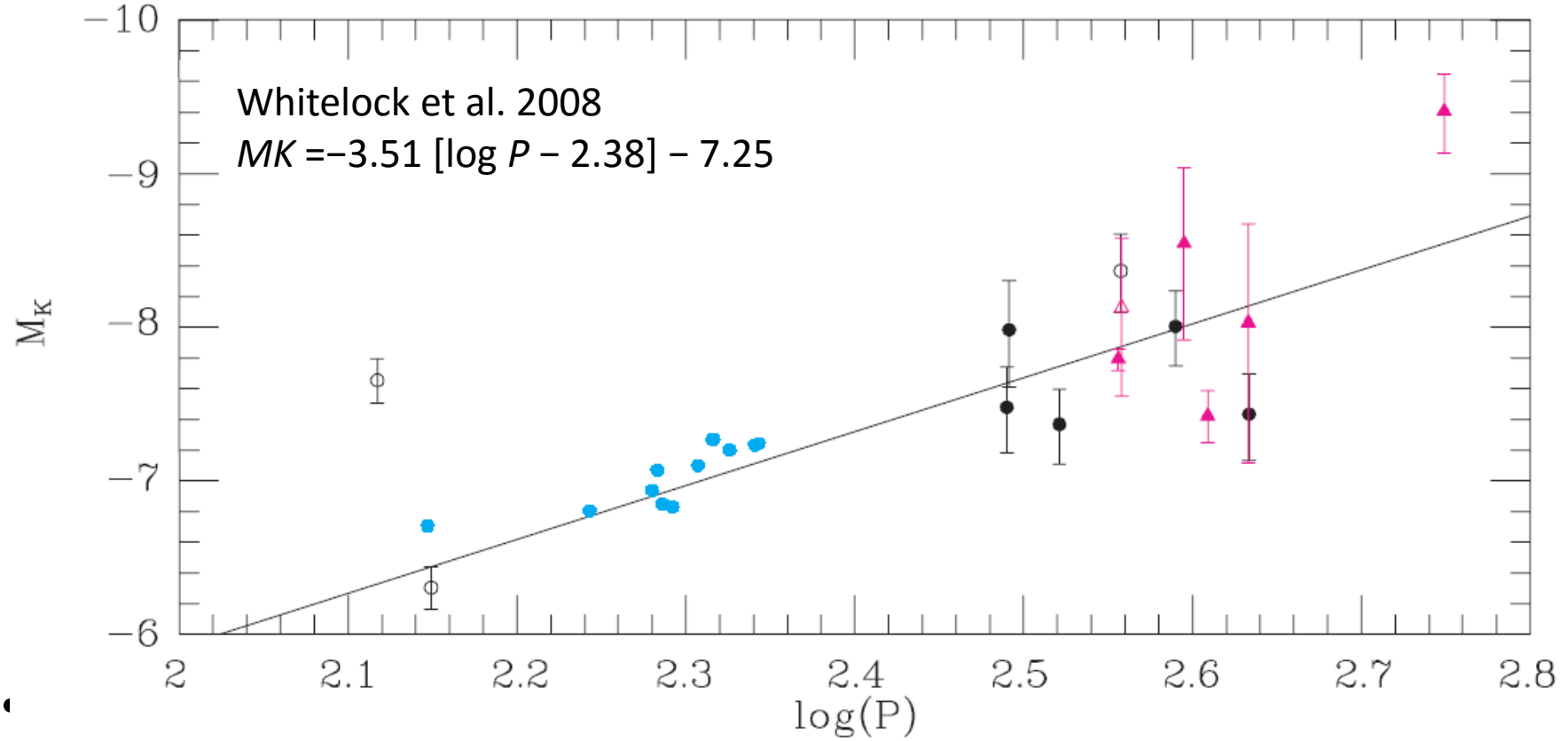


Results of Single-dish monitoring at VERA Iriki station.





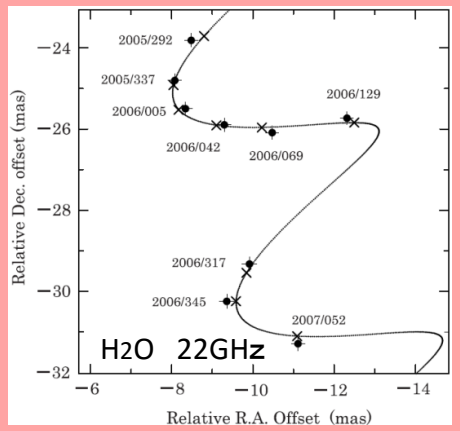
Period-Luminosity Relation (PLR)



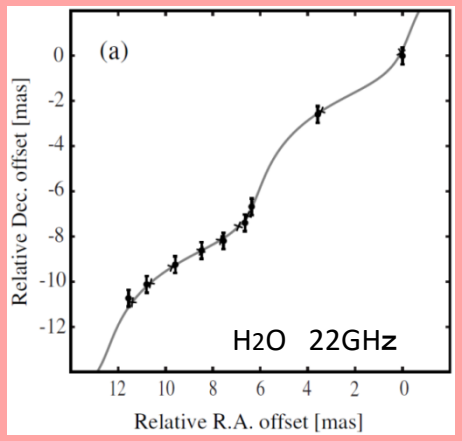
- Method:
  - (1) Distance measurements using annual parallax (VLBI astrometry)
  - (2) Convert apparent magnitudes(m_k) to absolute magnitudes(M_k)

Parallax measurements : Mira and SR

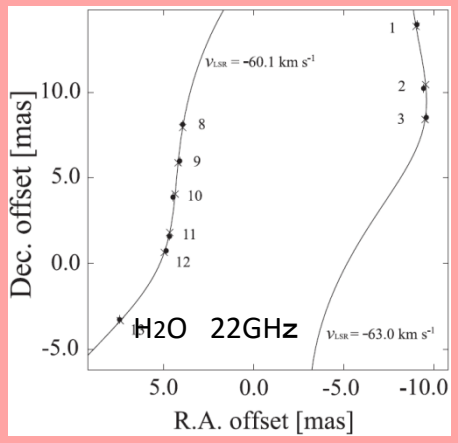
Motions on the sky plane



S Crt (SR) : Nakagawa et al. 2008

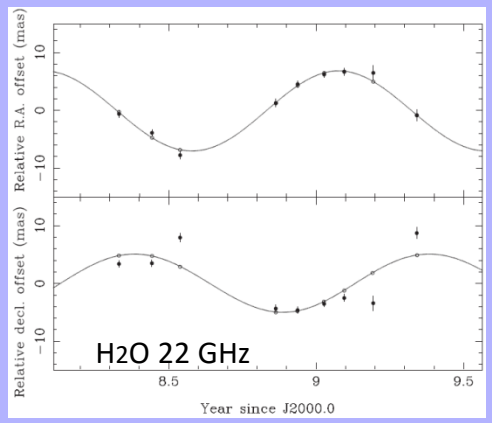


SY Scl (Mira) : Nyu et al. 2012

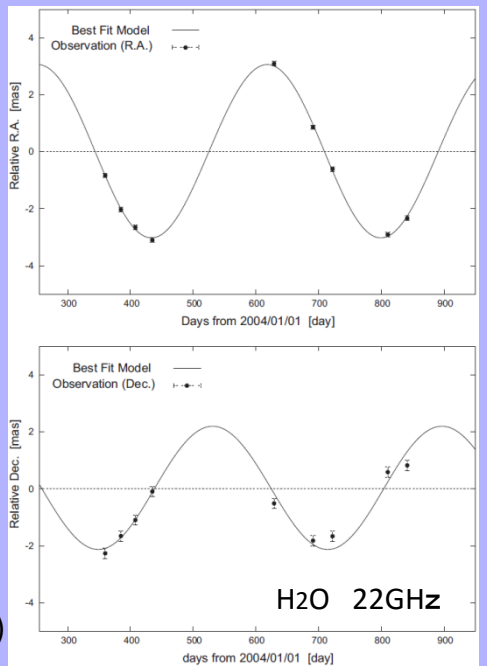


RW Lep (SR) : Kamezaki et al. 2014

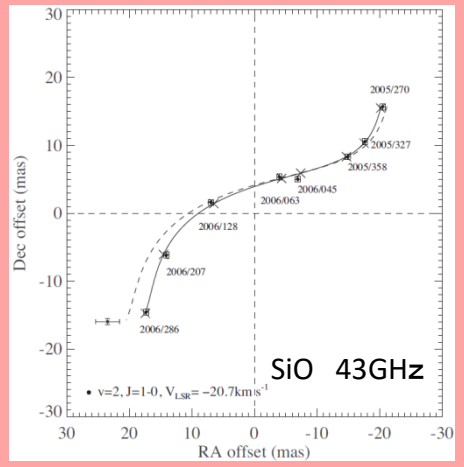
Parallactic oscillation



RX Boo (SR) : Kamezaki et al. 2012



T Lep (Mira) : (Nakagawa et al. 2014)



R Aqr (Mira) : Min et al. 2014

Latest results :
PLR of the Galactic LPVs based on astrometric VLBI

18 Galactic LPVs from VLBI method VERA

Source	Type	Parallax [mas]	P [day]	Log$P$	m_K [mag]	M_K [mag]	Maser	Reference† (Parallax, m_K)
RW Lep	SRa	1.62±0.16	150	2.176	0.639	-8.31 ± 0.22	H_2O	kam14, a
S Crt	SRb	2.33±0.13	155	2.1	0.786	-7.38 ± 0.12	H_2O	nak08, a
RX Boo	SRb	7.31±0.5	162	2.2	−1.96	-7.64 ± 0.15	H_2O	kam12, b
R UMa	Mira	1.97±0.05	302	2.4	1.19	-7.34 ± 0.06	H_2O	···
W Hya	SRa	10.18±2.36	361	2.5	−3.16	-8.12 ± 0.51	OH	vle03, c
S CrB	Mira	2.39±0.17	360	2.5	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_2O	nak14, c
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_2O	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_2O	kam15, a
UX Cyg	Mira	0.54±0.06	565	2.752	1.40	-9.94 ± 0.24	H_2O	kur05, a
S Per	SRc	0.413±0.017	822	2.915	1.33	-10.59 ± 0.09	H_2O	asa10, b
PZ Cas	SRc	0.356±0.026	925	2.966	1.00	-11.24 ± 0.16	H_2O	kus13, b
VY CMa	SRc	0.88±0.08	956	2.980	−0.72	-11.00 ± 0.20	H_2O	cho08, b
NML Cyg	—	0.62±0.047	1280	3.107	0.791	-10.25 ± 0.16	H_2O	zha12, a

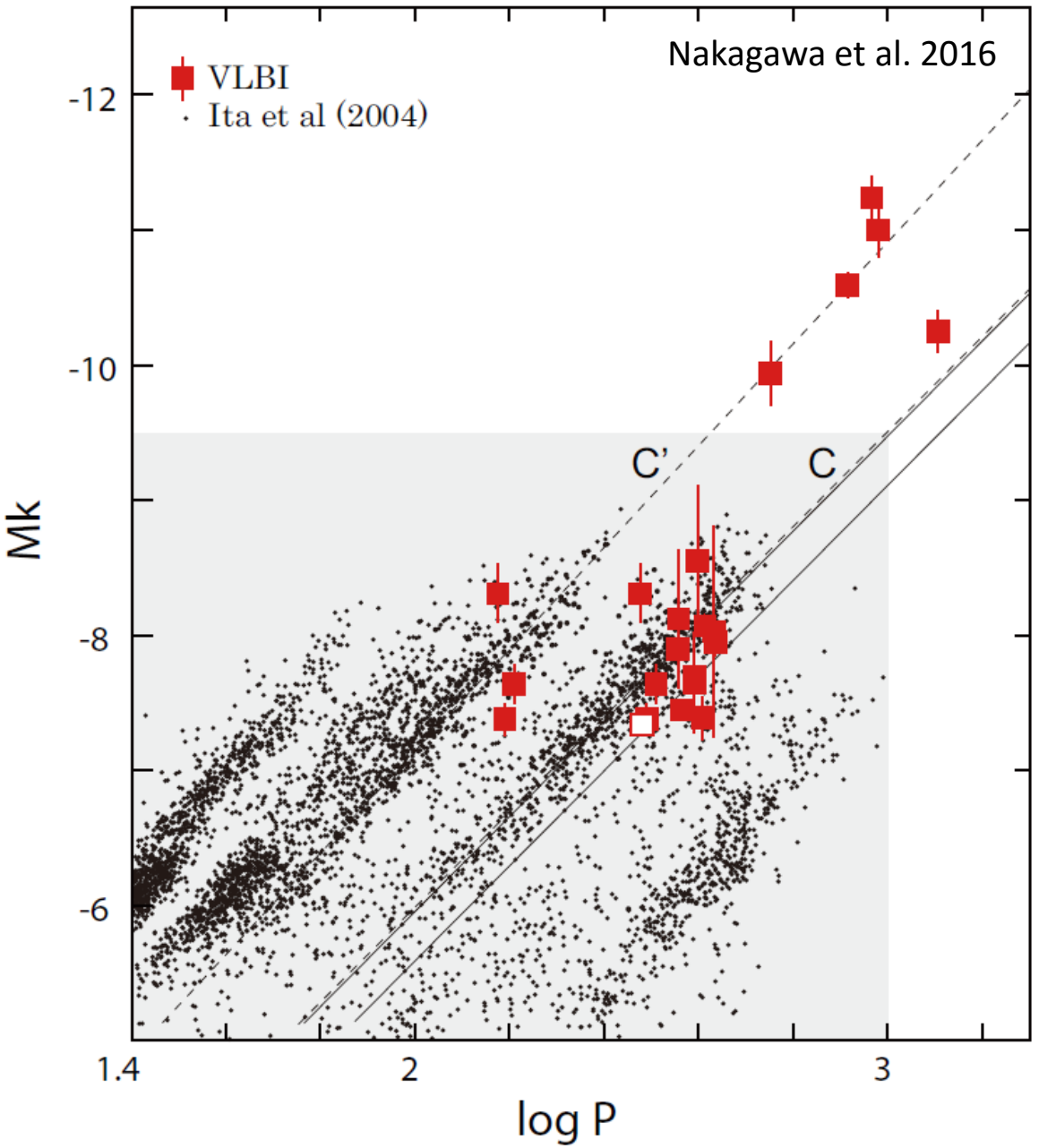
Nakagawa et al. 2016

Latest results :
PLR of the Galactic LPVs based on VLBI

<Solid lines> (*Preliminally : Submitted to PASJ*)
- Unweighted fitting
  MK = −3.52 LogP + (1.09 ± 0.14)
- Weighted fitting
  MK = −3.52 LogP + (1.45 ± 0.07)

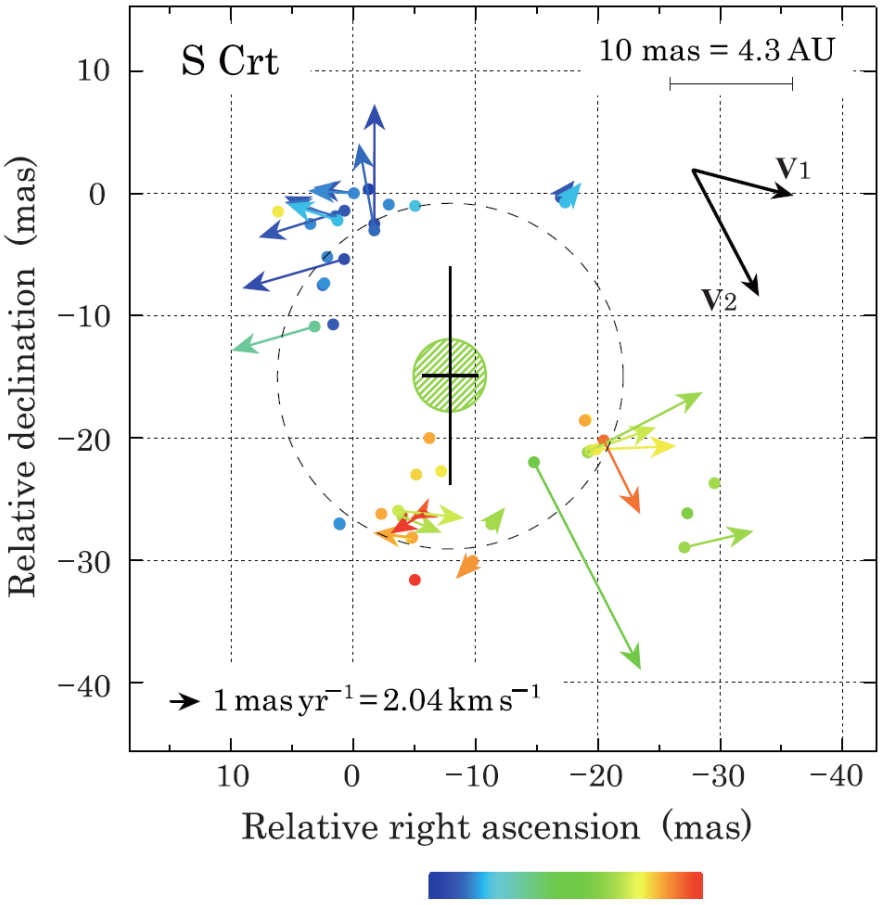
<Dashed lines> (*Ita et al 2004 PASJ*)
- Sequence C
  MK = −3.52 LogP + 1.05
- Sequence C'
  MK = −3.77 LogP + 0.40

<Assumption>
Distance modulus
= 18.49 (van Leeuwen 2007)



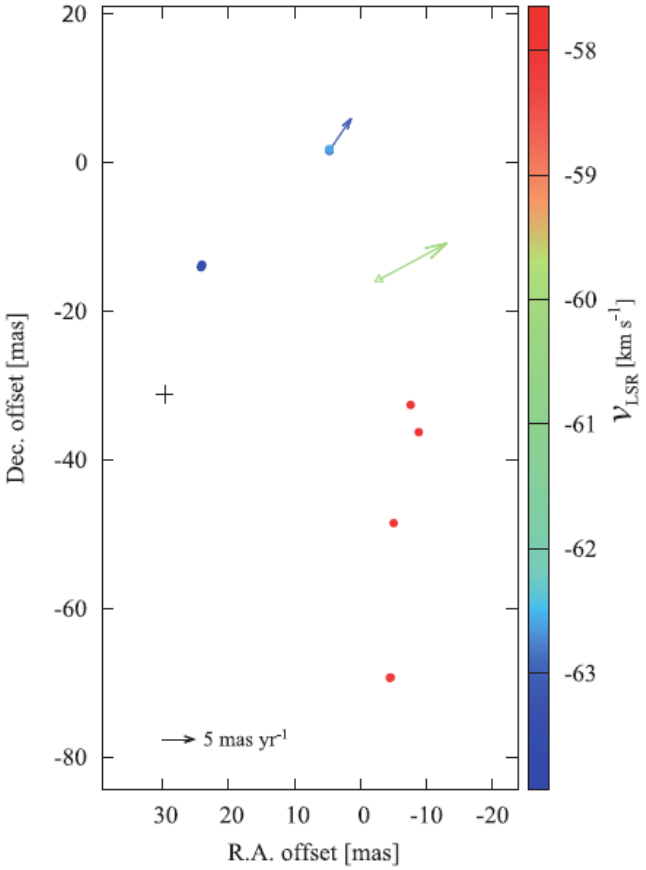
Maser distribution and Circumstellar kinematics

対称性の高い分布と運動



V_{LS} S Crt (SR variable)
Nakagawa et al. 2008

対称性の低い分布と運動



RW Lep （SR variable）
Kamezaki et al. 2014

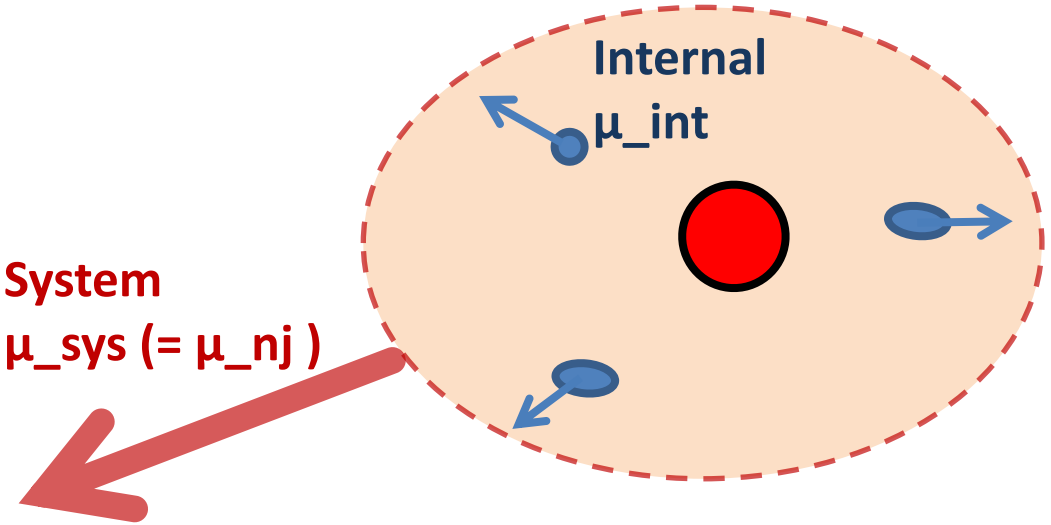
位置天文衛星データの活用

Kinematics of circumstellar matter based on proper motion

- Kinematics of circumstellar matter obtained with VLBI imaging based on pattern matching.
- High accuracy of proper motion of each maser spot
- Difference between NJ/GAIA and VERA indicate circumstellar (internal) motion of masers

Circumstellar motion of masers μ_int

μ_vera	= μ_sys + μ_int
—) μ_nj	= μ_sys
μ_vera - μ_nj	= μ_int



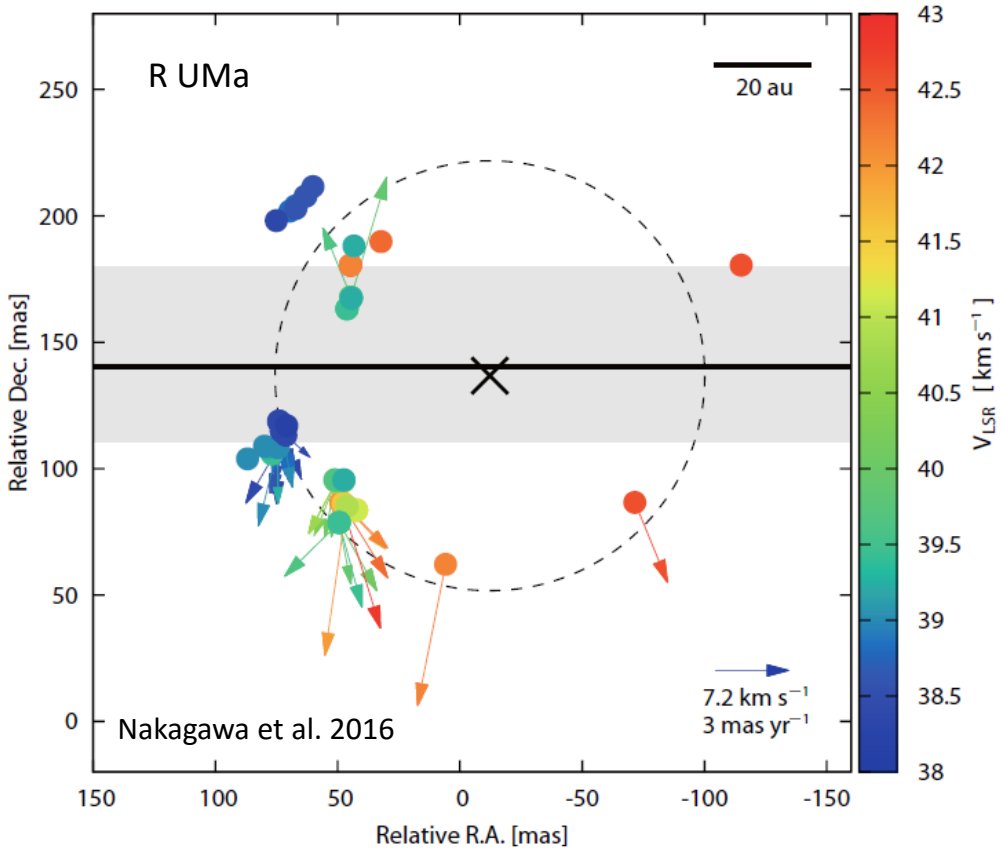
Typical velocity of circumstellar maser
7 km/sec → Angular velocity mas/yr
3.0 mas/yr@ 500pc
1.5 mas/yr @ 1kpc
1.0 mas/yr @ 1.5kpc

Circumstellar motion derived from two independent astrometry, VERA and HIPPARCOS

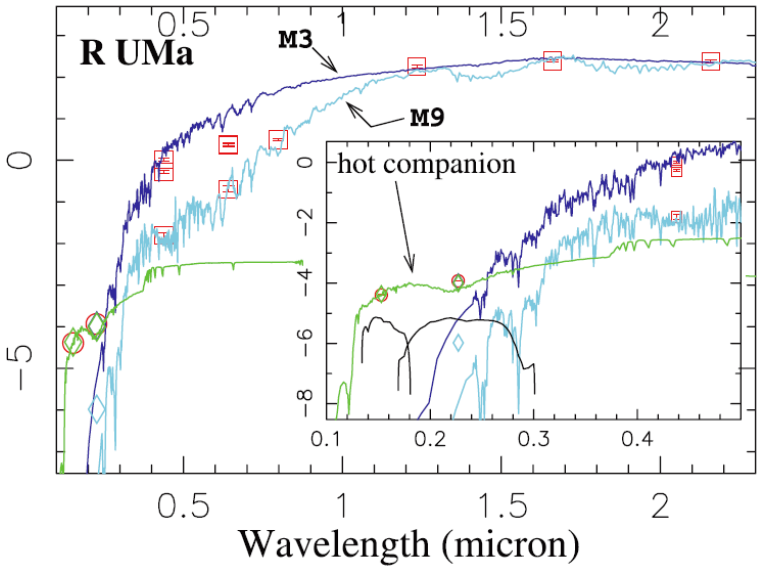
― 準備的な研究: R UMa ―

- No assumption of symmetry for distribution and kinematics of masers.
- Preliminary study using Hipparcos data.　→ R UMa の星周運動（Nakagawa et al. 2016）

$V_{circumstellar} = V_{VERA} - V_{HIPPARCOS}$



Existence of binary companion of R UMa

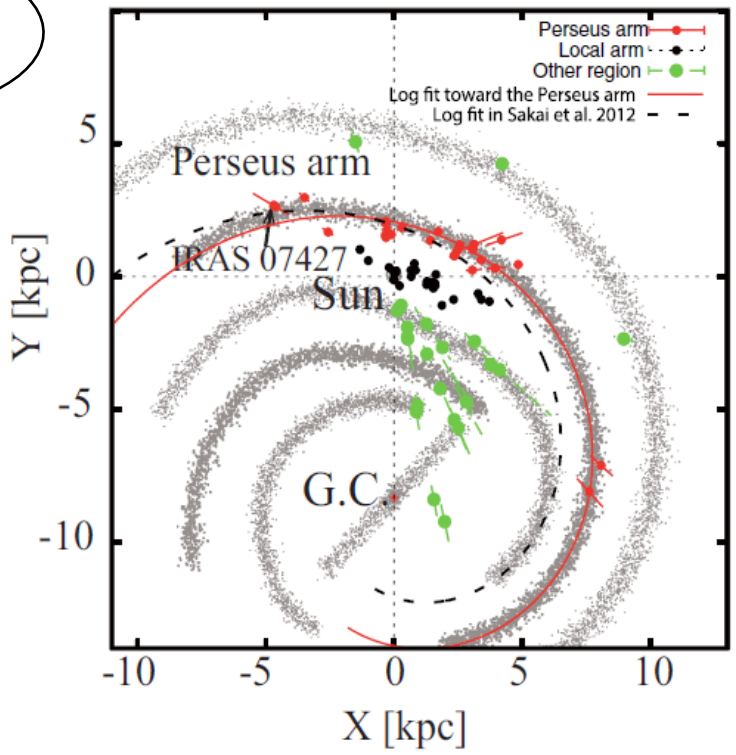


Sahai et al. 2008
NUV, FUV, optical and near-IR . Red symbols : R UMa
blue: cool AGB star; green: hot companion.

Contribution to study of the Galactic kinematics

In VLBI astrometry, SFRs are used as probes to study Galactic kinematics. But the number of samples is still small. We want to add more samples as a new plobes.

Sakai et al. 2015



OH/IR stars can be expected to have larger mass. If we can establish PLR of OH/IR with P>1000 days, they can be a new disk tracer.

<u>To determine distribution and motion of OH/IR stars, ...</u>

1、Annual parallax measurement

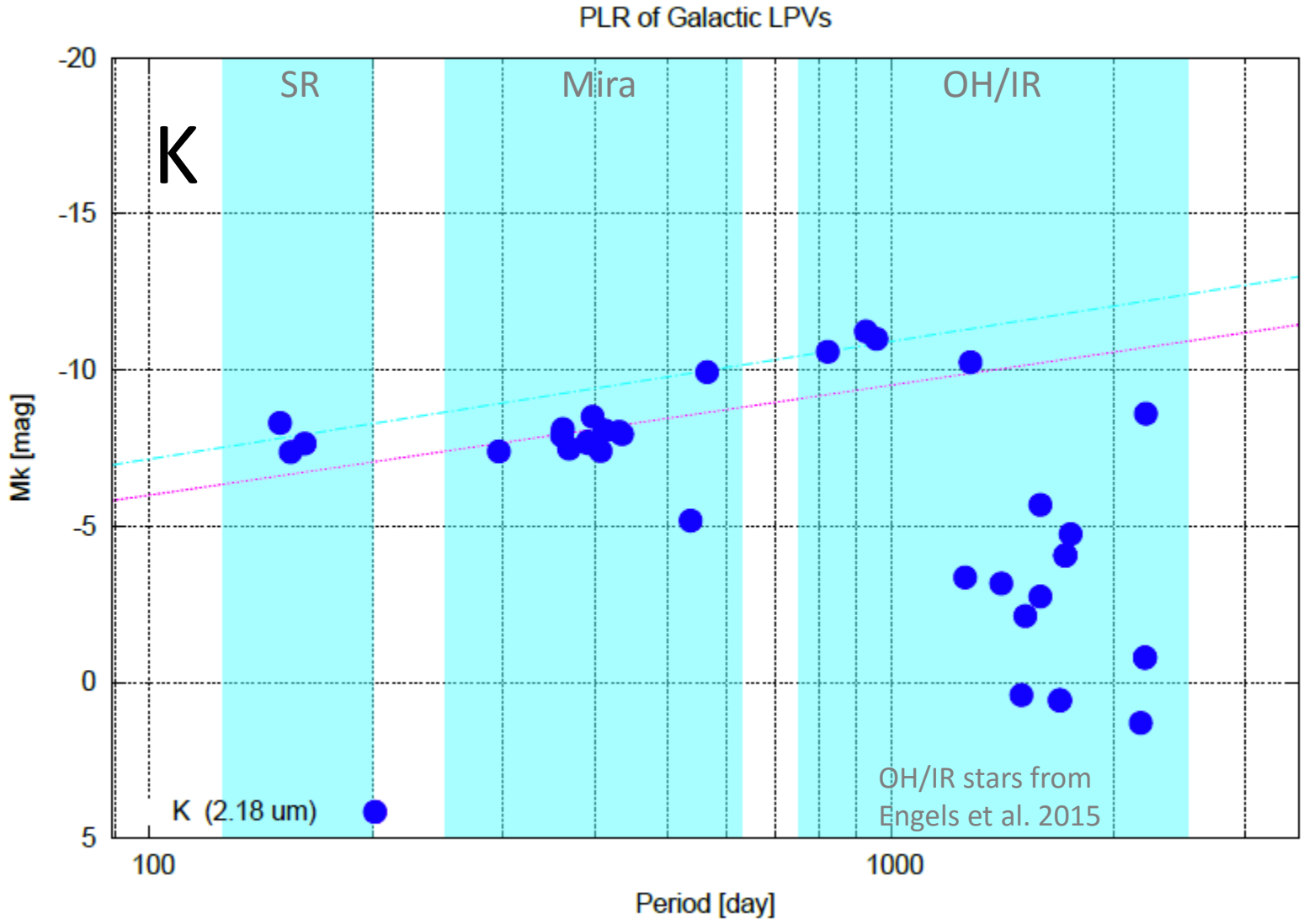
2、Distance indicator

→ PLR of the Galactic OH/IR stars

OH/IR stars with P > 1000d

⇒ Absolute magnitudes of Galactic OH/IR stars with known distances

Engels et al.（2015）
Phase lag method
17 OH maser source



OH/IR stars with P > 1000d

⇒ Absolute magnitudes of Galactic OH/IR stars with known distances

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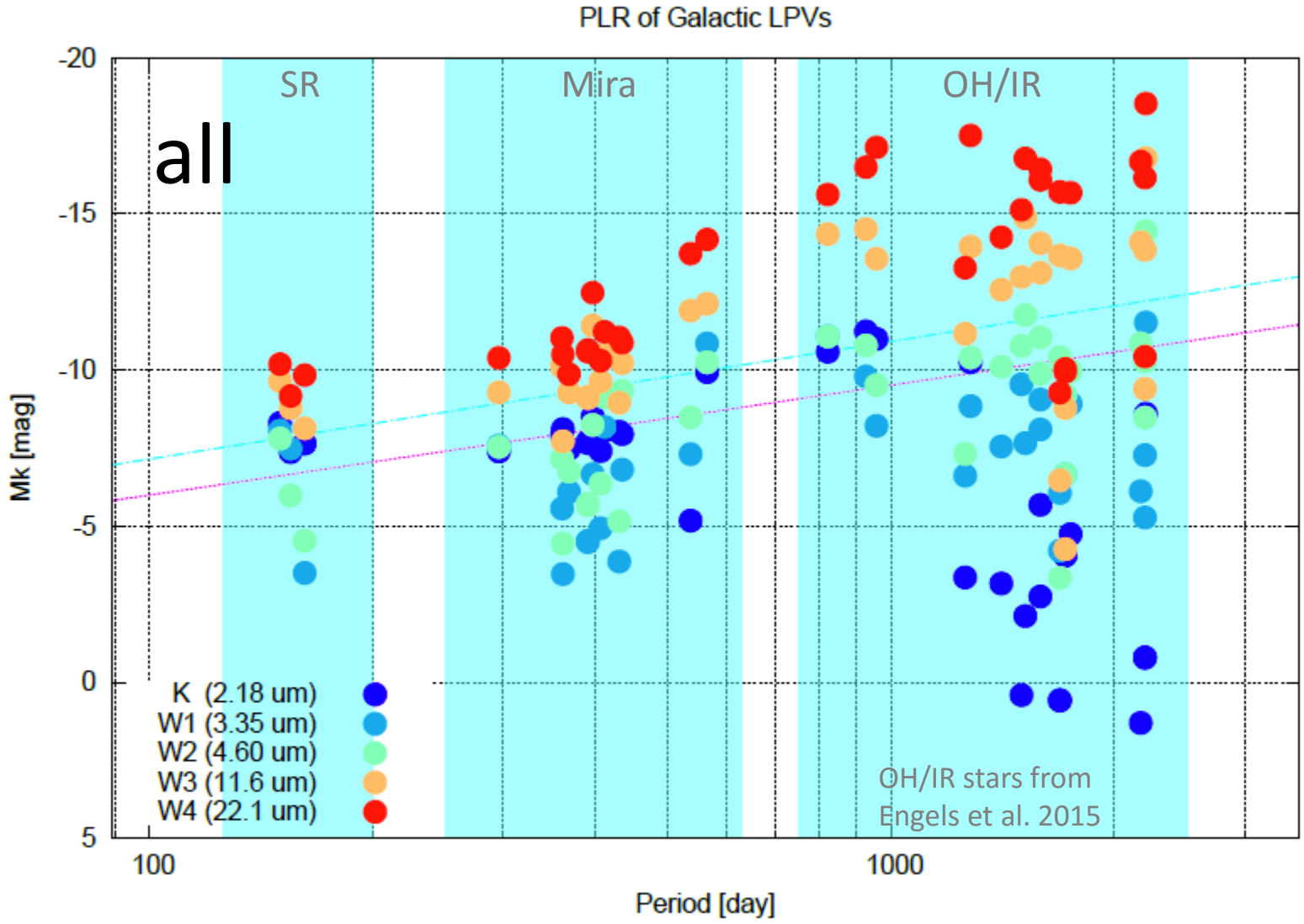

OH/IR stars with P > 1000d

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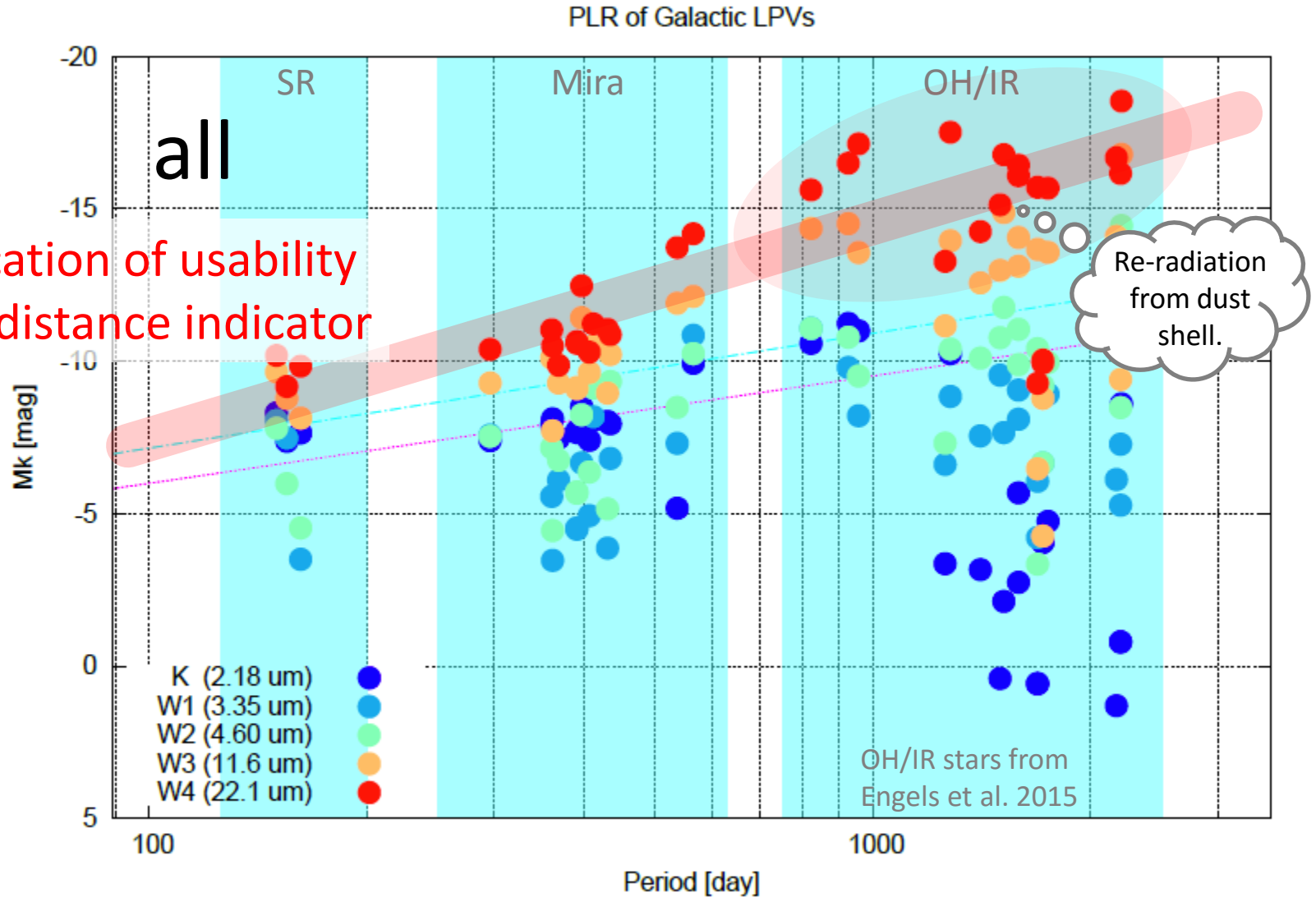
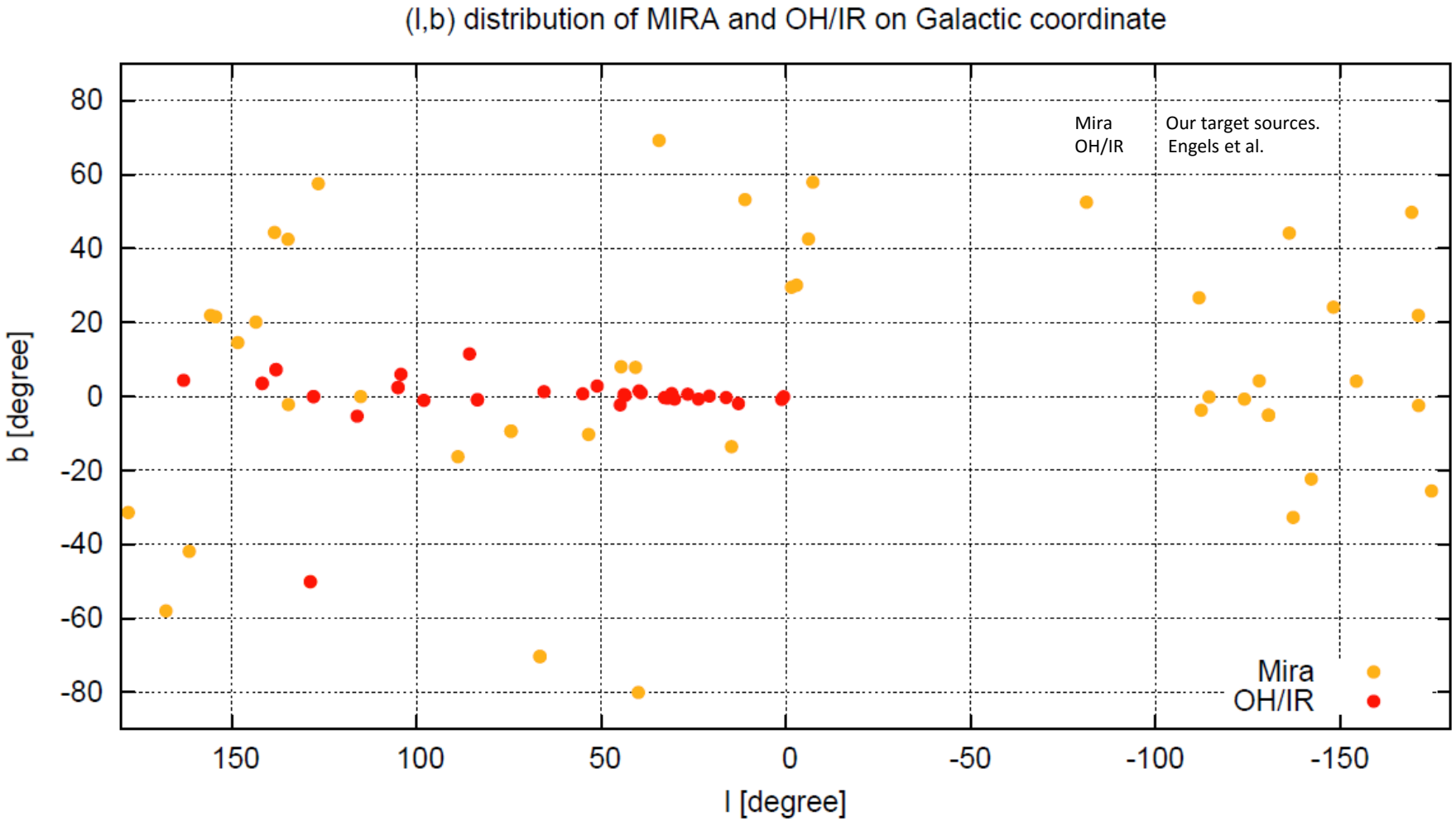


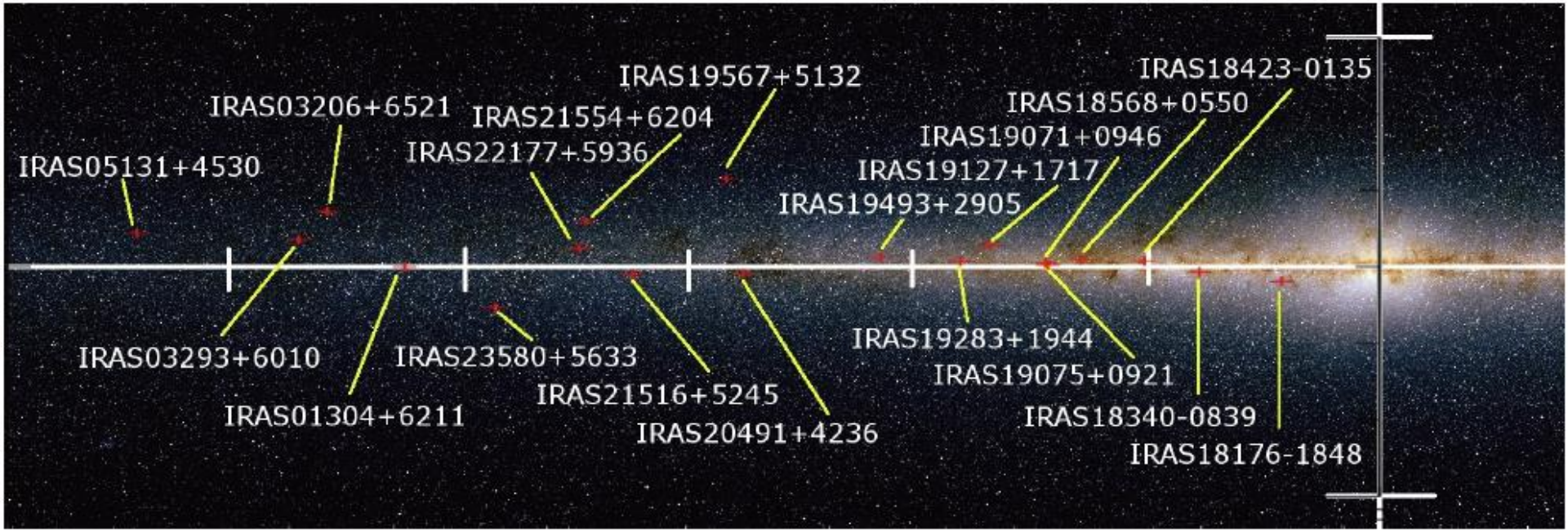
Indication of usability as a distance indicator

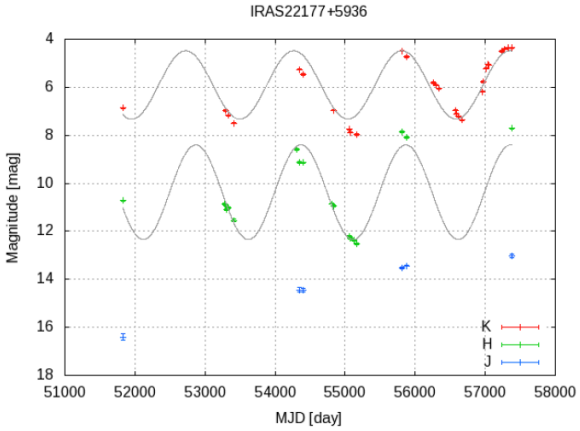
Distribution of Mira and OH/IR （l,b）coordinate

- Mira● → Wide distribution
- OH/IR● → Concentration to Galactic plane → High Mass → Disk tracer



OH/IR stars with P > 1000d





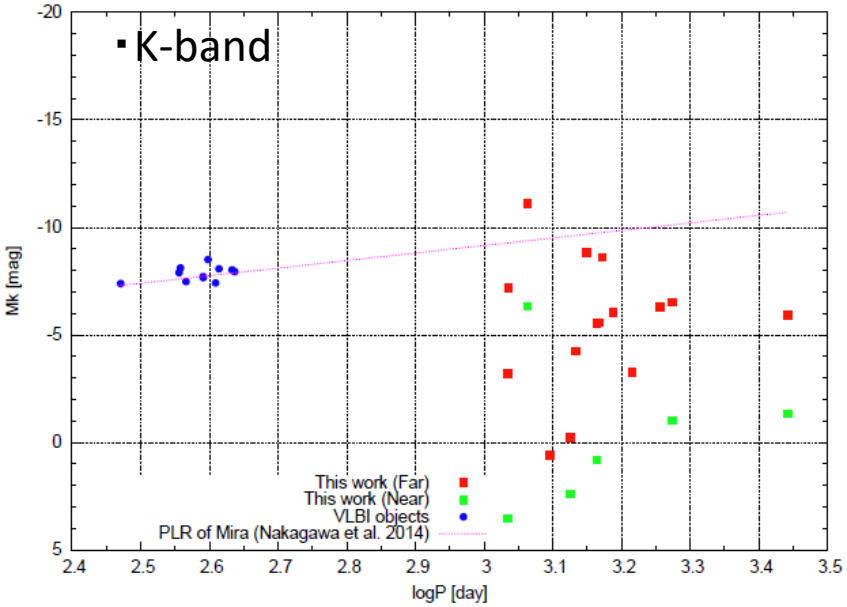
Yamashita (Thesis 2016)

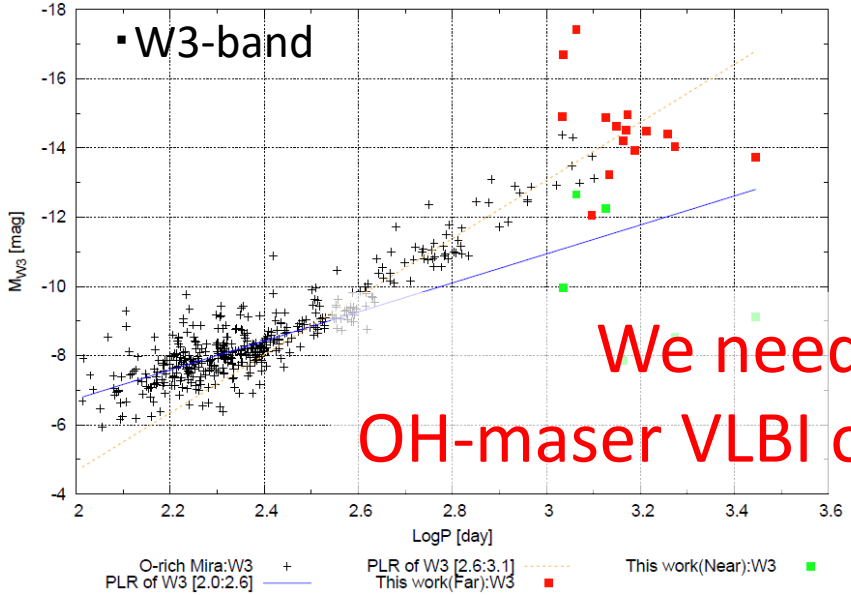
LPVs with P > 1000 day

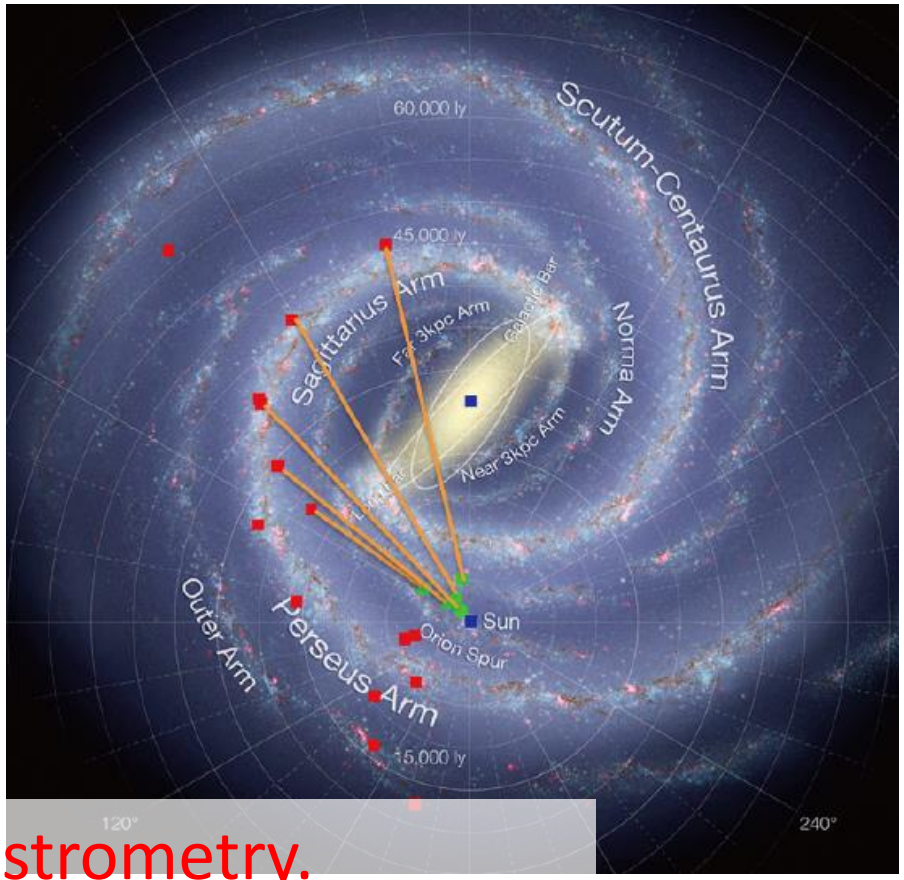
K-band monitoring with
Kagoshima university 1m IR telescope.

OH/IR stars with P > 1000d

Yamashita (Thesis 2016)







We need astrometry.

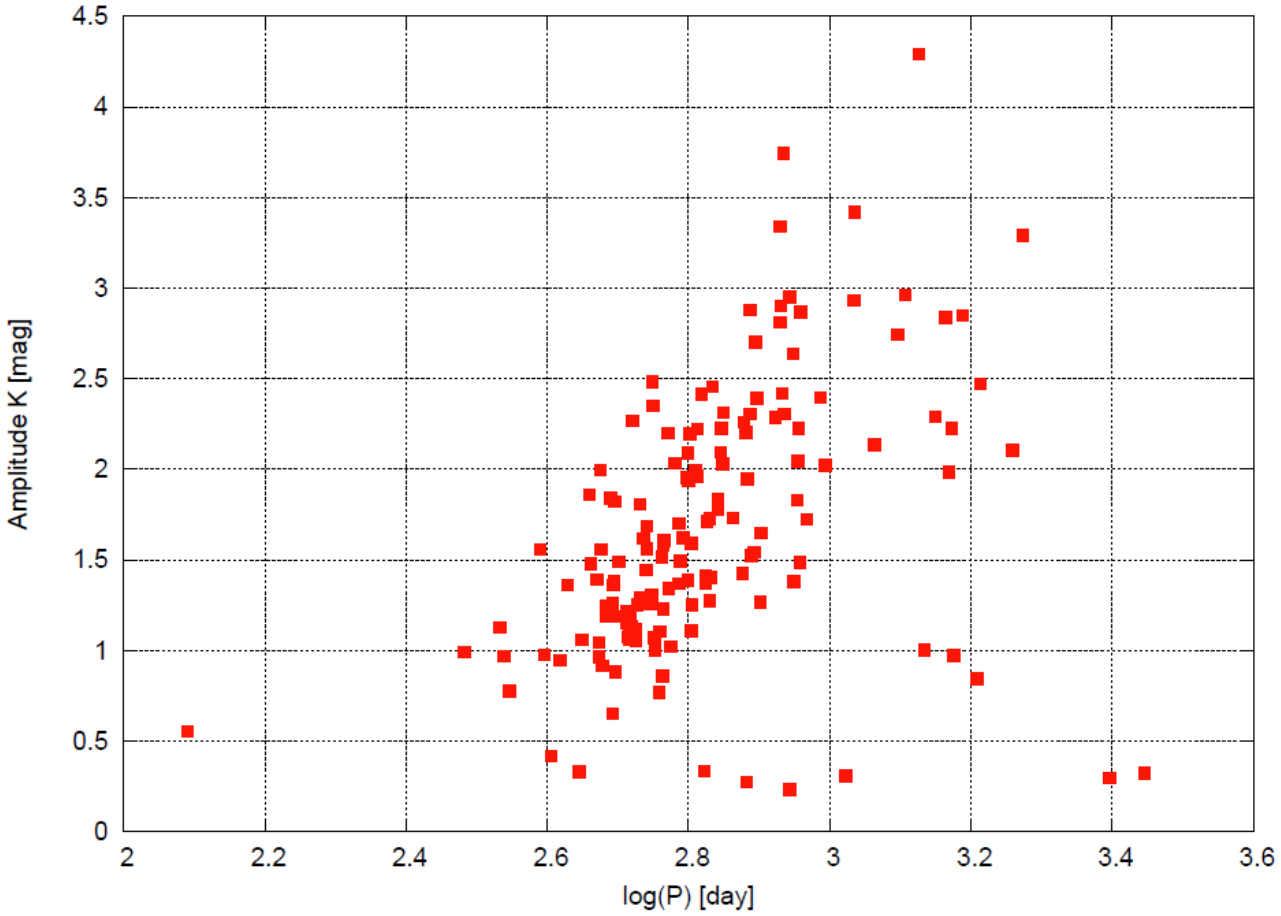
OH-maser VLBI or IR with X-JASMINE.

▪Kinematic distances

鹿大1m鏡でモニターしたLPV

- Period vs K-magnitude

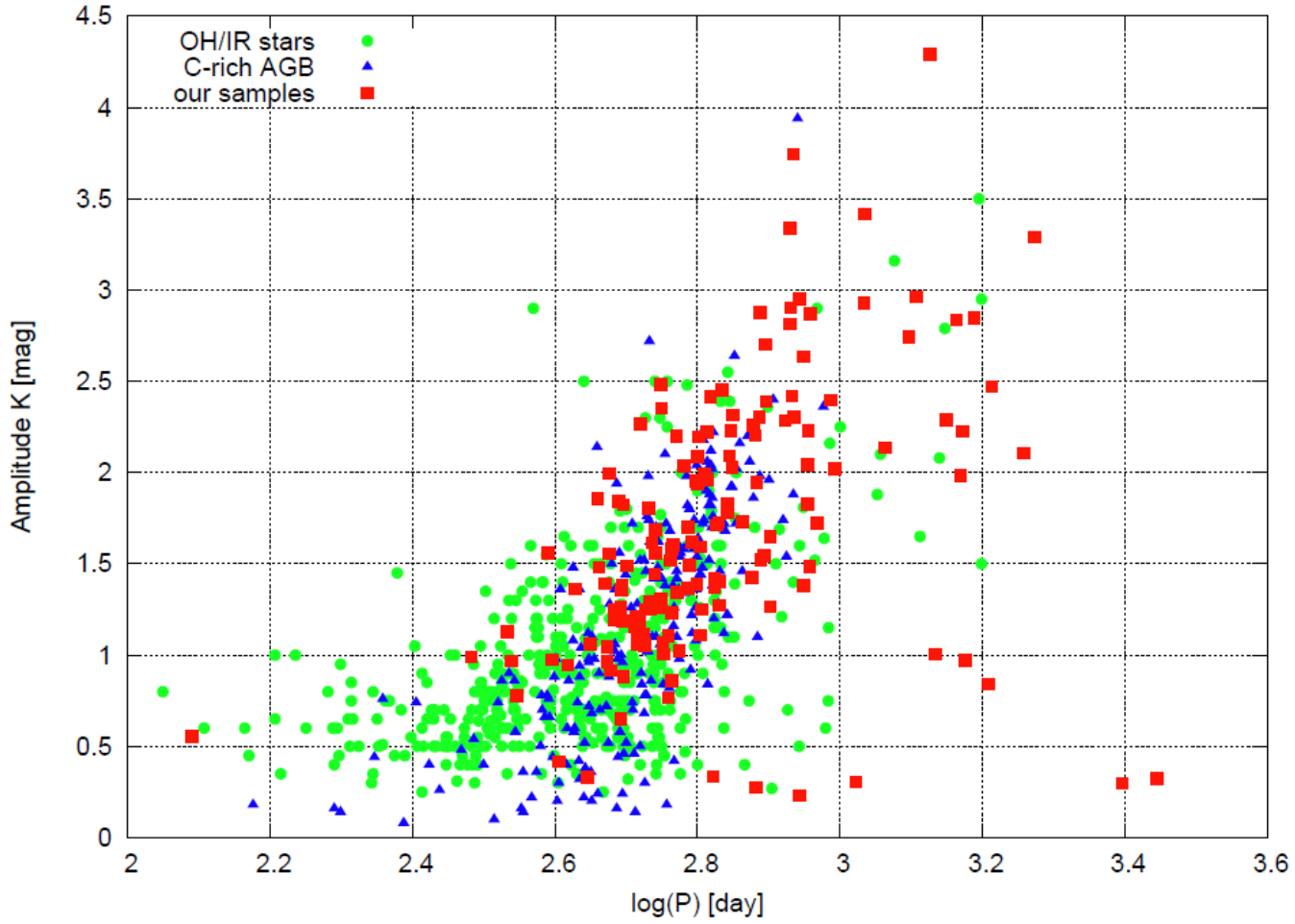
Yamashita (Thesis 2016)



鹿大1m鏡でモニターしたLPV

- Period vs K-amplitude

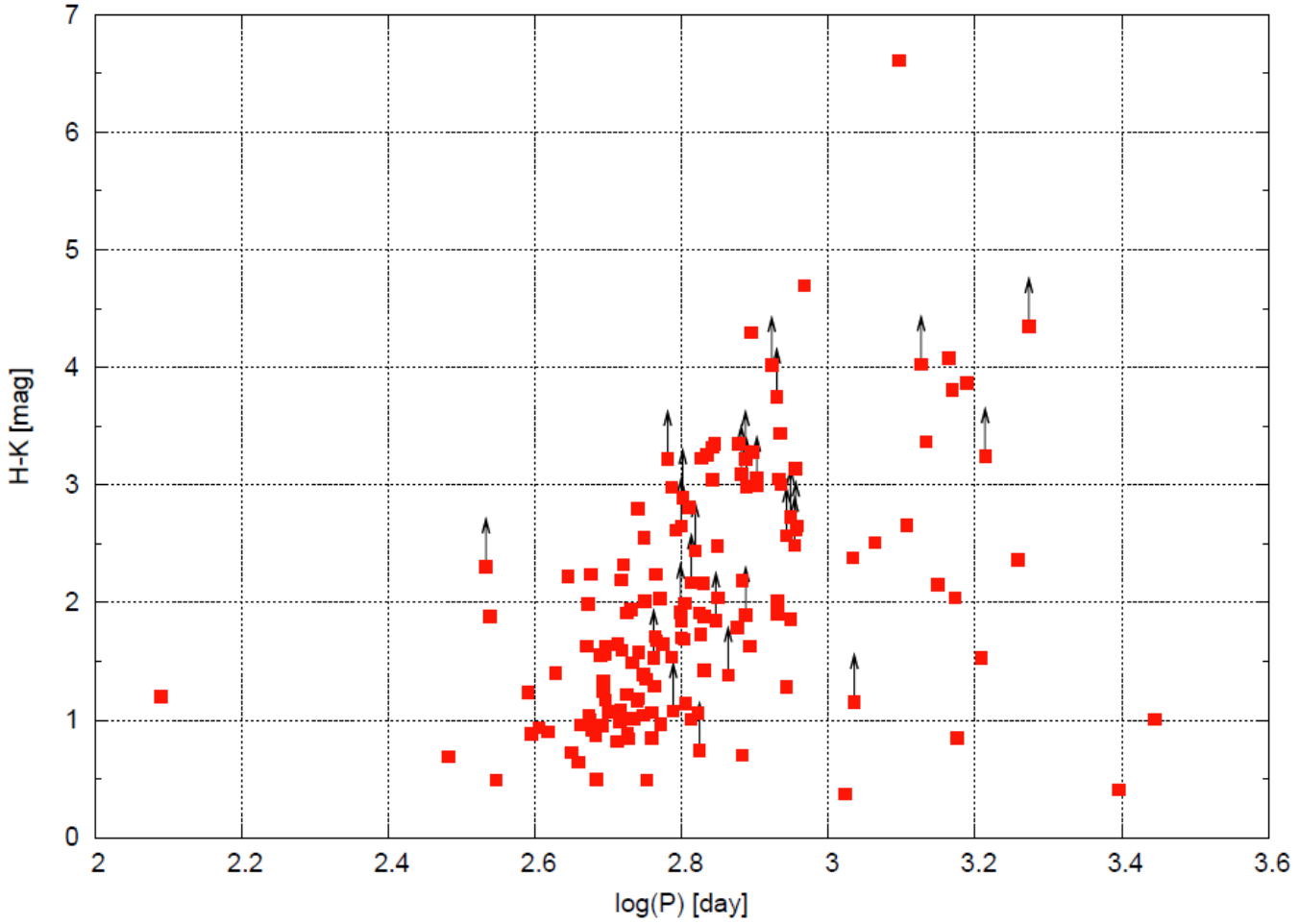
Yamashita (Thesis 2016)



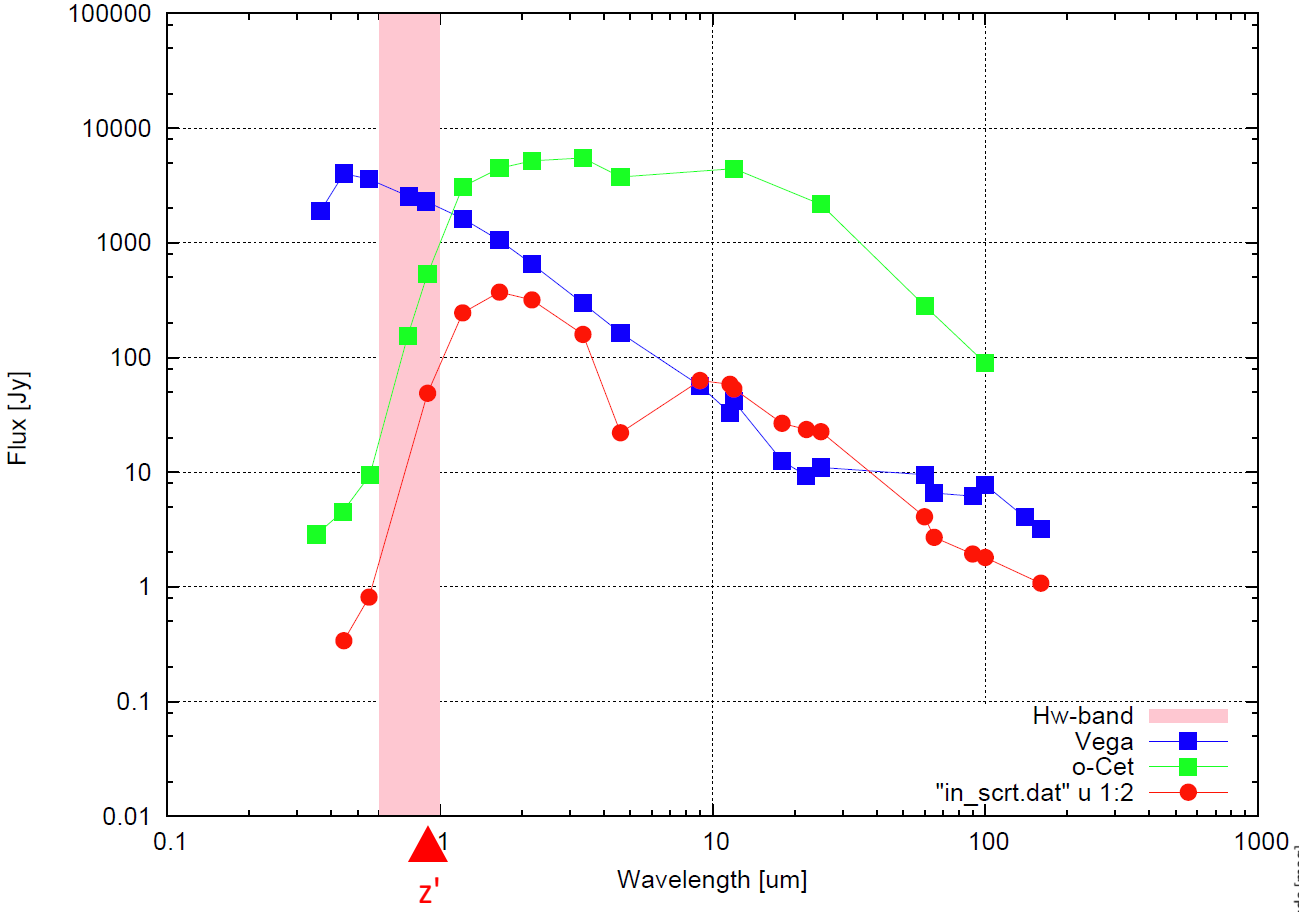
鹿大1m鏡でモニターしたLPV

- Period vs Color (H-K)

Yamashita (Thesis 2016)

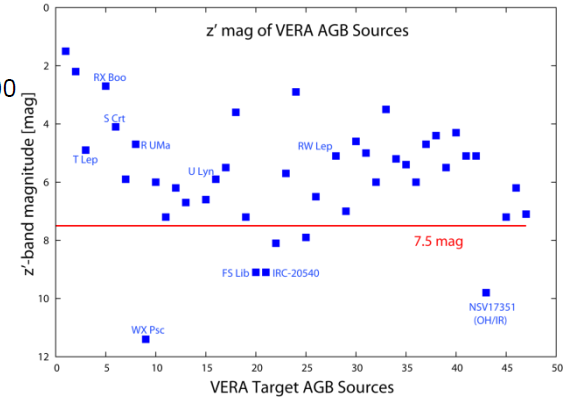


SED of Mira and SR（S Crt）



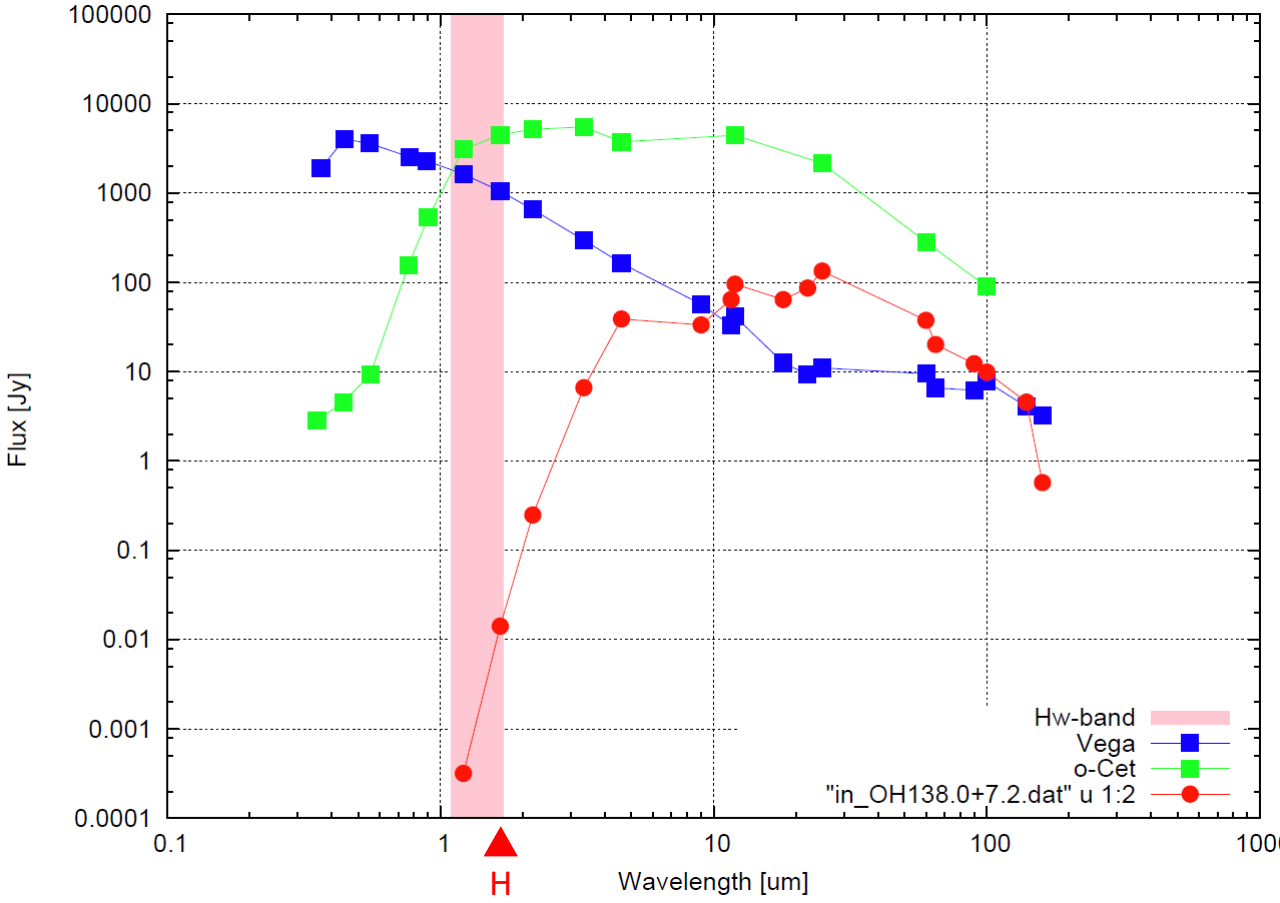
zw バンド帯で
急激なFluxの低下

検出は可能か。



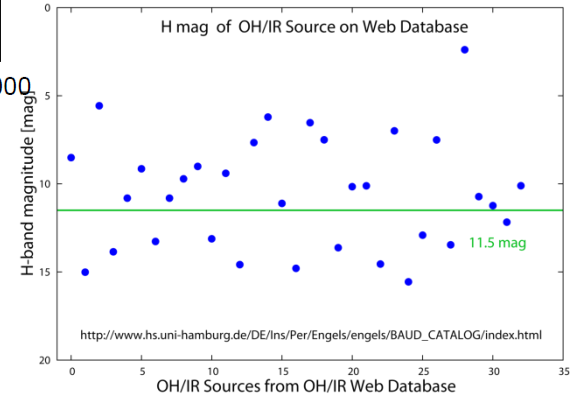
・NJによる固有運動の検出に期待。
・VERAによる各メーザー固有運動の決定を進める。
・バイナリーがメーザーに与える影響の評価

SED of OH/IR star（OH138.0+7.2）



Hw バンド帯で
急激なFluxの低下

zwバンドと同様なFlux低下が、OH/IR星はHwバンドで見られる。



・明るいものはSJによる検出が期待できるか
・SJの観測領域に存在することが条件

今後の活動

- Galactic MiraのPLRの高精度化
  - LMCとの金属量差異の効果

- Low-frequency Astrometry (1.6GHz)
  - OH/IR stars : OH maser astrometry (Gabor-san)
  - Single Dish　(臼田64mの利用)
- Near-IR, Mid-IR のモニター観測
  - 鹿児島1m鏡
  - TAO　中間赤外モニター

- JASMINE（赤外領域）によるParallax計測

鹿児島1ｍ鏡のメリット
IR長期間モニター