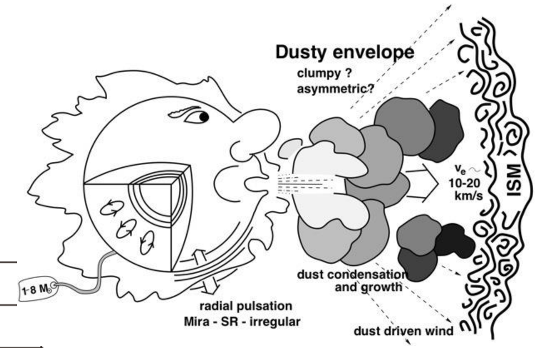
2016.10.03-04 VERA User's Meeting 2016, Mitaka

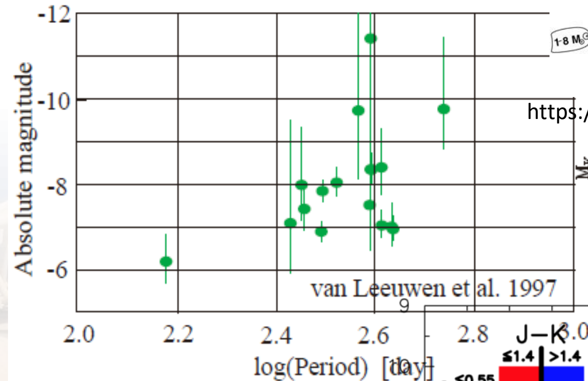
長周期変光星の位置天文観測
Astrometry of the Galactic Miras and LPVs with VERA

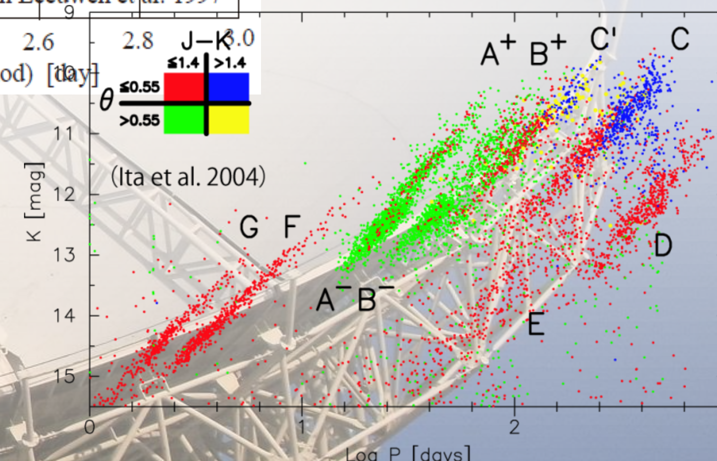
Akiharu Nakagawa, Tomoharu Kurayama, Madoka Ooyama, Gabor Orosz , VERA Project



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

- Mass 1〜8 M。（Mira:1〜2.5 M。?）
- 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



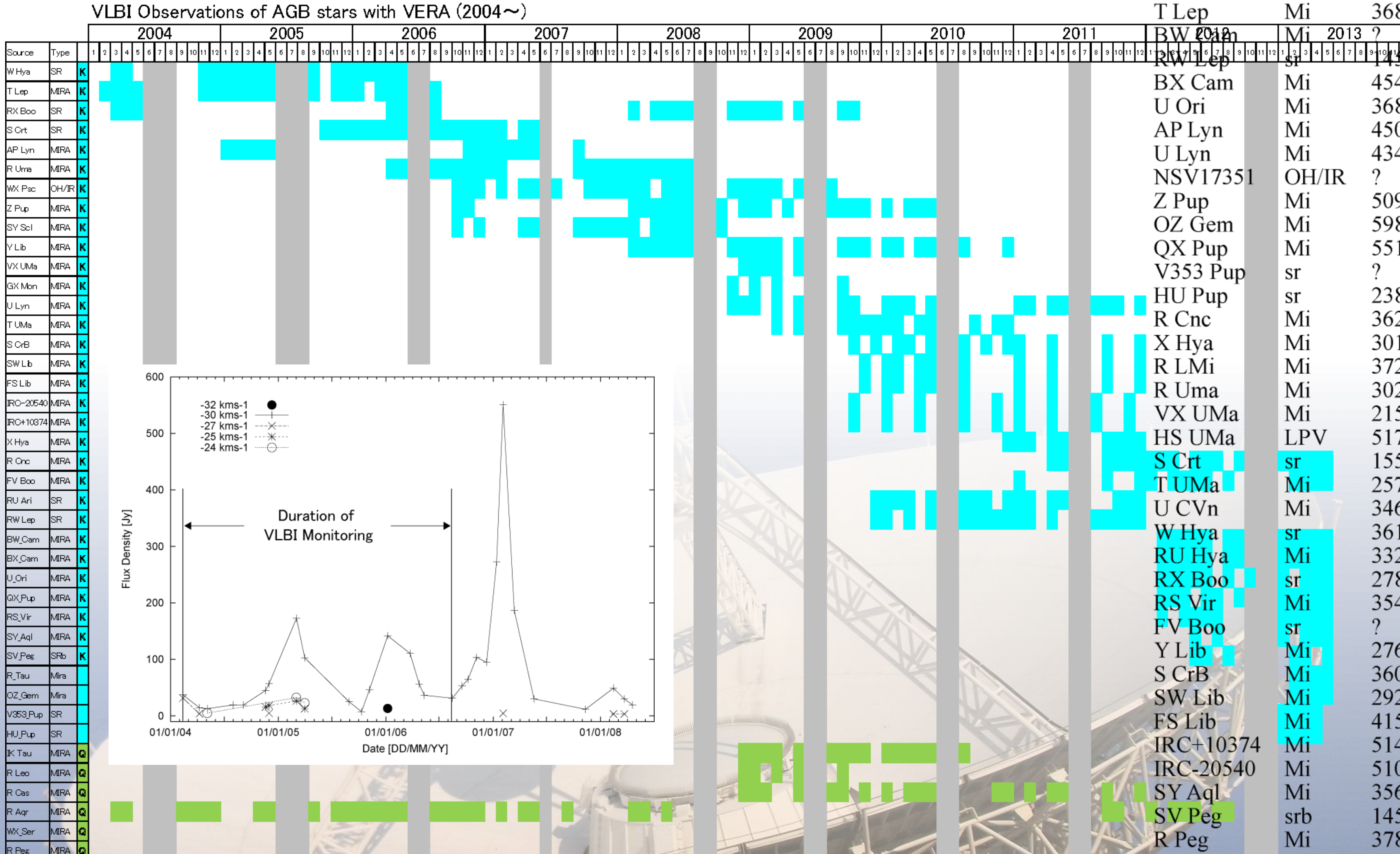


Two main topics
(1) Mira Period – M(K) relation
(2) OH/IR Period – M(mid-IR) relation

VLBI monitoring observations with VERA

VLBI monitoring with 1 month interval.

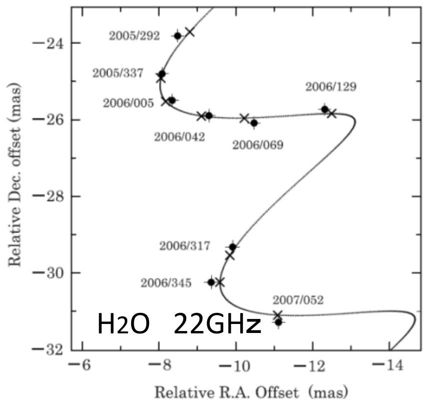
We need 1.5～2 yr to derive a parallax.



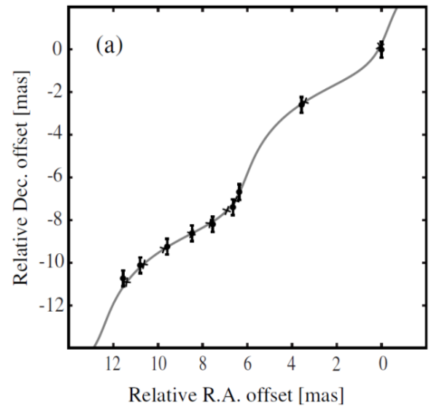
Source	Typ.	P[day]
SY Scl	Mi	413
WX Psc	Mi	660
RU Ari	sr	354
V637 Per	sr	?
R Tau	Mi	321
BX Eri	sr	165
T Lep	Mi	368
BW Cam	Mi	?
RW Lep	sr	145
BX Cam	Mi	454
U Ori	Mi	368
AP Lyn	Mi	450
U Lyn	Mi	434
NSV17351	OH/IR	?
Z Pup	Mi	509
OZ Gem	Mi	598
QX Pup	Mi	551
V353 Pup	sr	?
HU Pup	sr	238
R Cnc	Mi	362
X Hya	Mi	301
R LMi	Mi	372
R Uma	Mi	302
VX UMa	Mi	215
HS UMa	LPV	517
S Crt	sr	155
T UMa	Mi	257
U CVn	Mi	346
W Hya	sr	361
RU Hya	Mi	332
RX Boo	sr	278
RS Vir	Mi	354
FV Boo	sr	?
Y Lib	Mi	276
S CrB	Mi	360
SW Lib	Mi	292
FS Lib	Mi	415
IRC+10374	Mi	514
IRC-20540	Mi	510
SY Aql	Mi	356
SV Peg	srb	145
R Peg	Mi	378

Parallax measurements

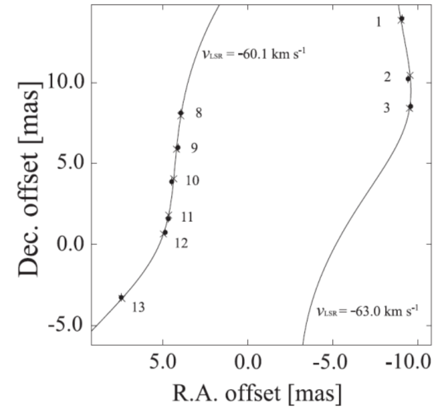
Motions on the sky plane



S Crt (SR) : Nakagawa et al. 2008

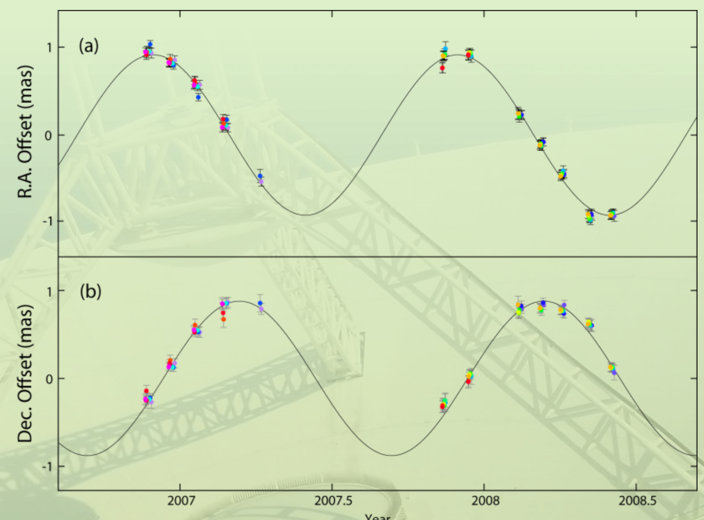


SY Scl (Mira) : Nyu et al. 2012



RW Lep (SR) : Kamezaki et al. 2014

Parallactic oscillation



R UMa (Mira) : (Nakagawa et al. 2016) H_2O 22GHz

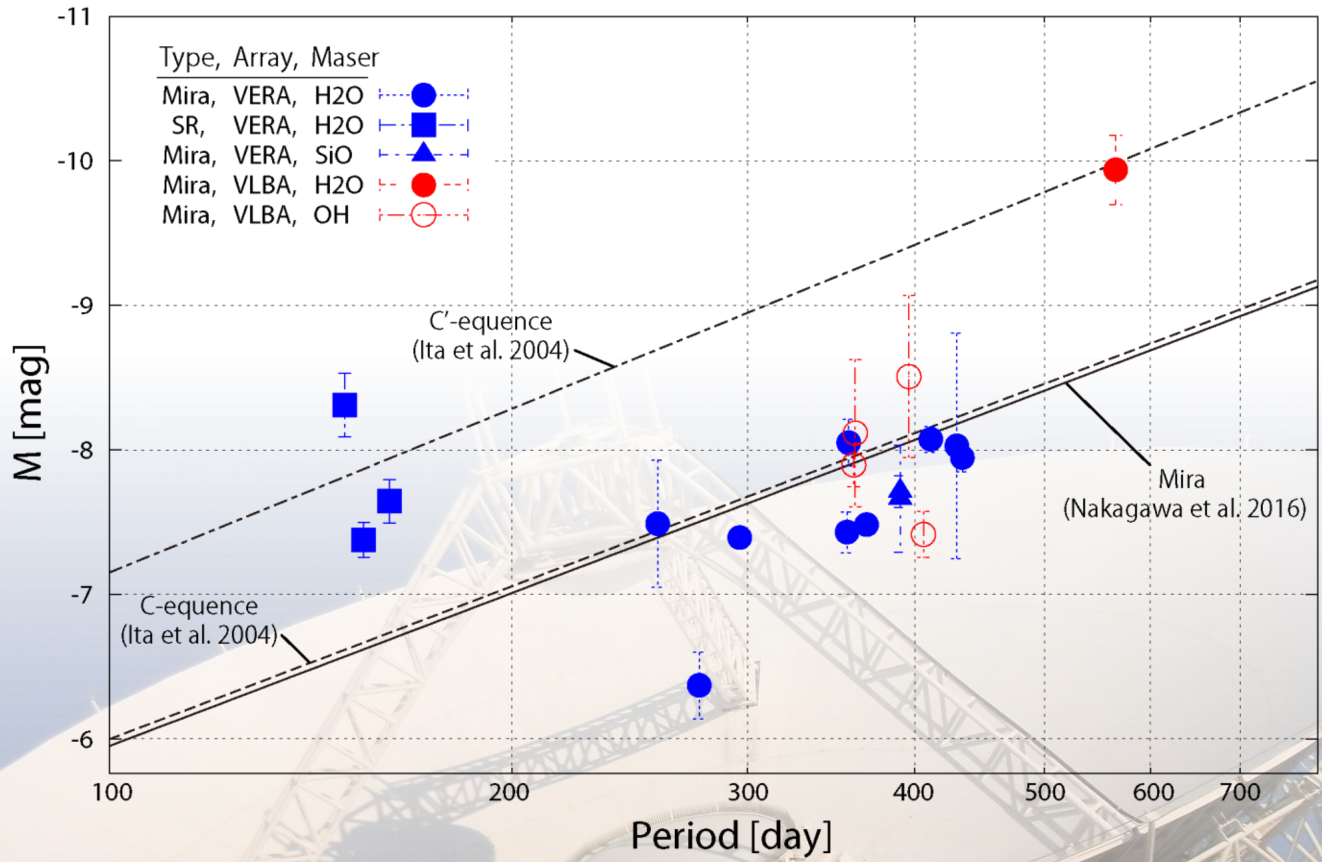
Latest results from VLBI astrometry

24 sources

Source	Type	Parallax [mas]	P [day]	LogP	mK [mag]	MK [mag]	Maser	Reference (Parallax,mK)
RW Lep	sra	1.62±0.16	150	2.176	0.639	-8.31±0.22	H2O	kam14, a
S Crt	srb	2.33±0.13	155	2.190	0.786	-7.38±0.12	H2O	nak08, a
RX Boo	srb	7.31±0.5	162	2.210	-1.96	-7.64±0.15	H2O	kam12, b
T UMa	Mi	0.96±0.15	257	2.410	2.60	-7.49±0.44	H2O	in prep., a
Y Lib	Mi	1.24±0.13	276	2.441	3.16	-6.37±0.23	H2O	in prep., a
R UMa	Mi	1.92±0.05	302	2.480	1.19	-7.39±0.06	H2O	nak16, d
FV Boo	Mi	0.97±0.06	340	2.531	3.836	-6.23±0.13	H2O	kam16, a
SY Aql	Mi	1.10±0.07	356	2.551	2.36	-7.43±0.14	H2O	in prep., a
R Cnc	Mi	3.84±0.29	357	2.553	-0.97	-8.05±0.16	H2O	in prep., a
W Hya	sra	10.18±2.36	361	2.558	-3.16	-8.12±0.51	OH	vle03, c
S CrB	Mi	2.39±0.17	360	2.556	0.21	-7.90±0.15	OH	vle07, c
T Lep	Mi	3.06±0.04	368	2.566	0.12	-7.45±0.03	H2O	nak14, c
R Aqr	Mi	4.7±0.8	390	2.591	-1.01	-7.65±0.37	SiO	kam10, c
R Aqr	Mi	4.59±0.24	390	2.591	-1.01	-7.70±0.11	SiO	min14, c
RR Aql	Mi	1.58±0.40	396	2.598	0.46	-8.55±0.56	OH	vle07, c
U Her	Mi	3.76±0.27	406	2.609	-0.27	-7.39±0.16	OH	vle07, c
SY Scl	Mi	0.75±0.03	411	2.614	2.55	-8.07±0.09	H2O	nyu11, b
R Cas	Mi	5.67±1.95	430	2.633	-1.80	-8.03±0.78	OH	vle03, c
U Lyn	Mi	1.27±0.06	434	2.637	1.533	-7.95±0.10	H2O	kam15, a
OH231.8+4.2	OH/IR	0.55±0.05	551	2.741	---	---	H2O	in prep.
UX Cyg	Mi	0.54±0.06	565	2.752	1.40	-9.94±0.24	H2O	kur05, a
S Per	src	0.413±0.017	822	2.915	1.33	-10.59±0.09	H2O	asa10, b
PZ Cas	src	0.356±0.026	925	2.966	1.00	-11.24±0.16	H2O	kus13, b
VY CMa	src	0.88±0.08	956	2.980	-0.72	-11.00±0.20	H2O	cho08, b
NML Cyg	---	0.62±0.047	1280	3.107	0.791	-10.25±0.16	H2O	zha12, a

Period- Mk relation of Mira and SR variables based on VLBI astrometry

$$Mk = -3.52\log P + (1.09 \pm 0.14)$$



More sources are needed to solve a zero-point with better accuracy.

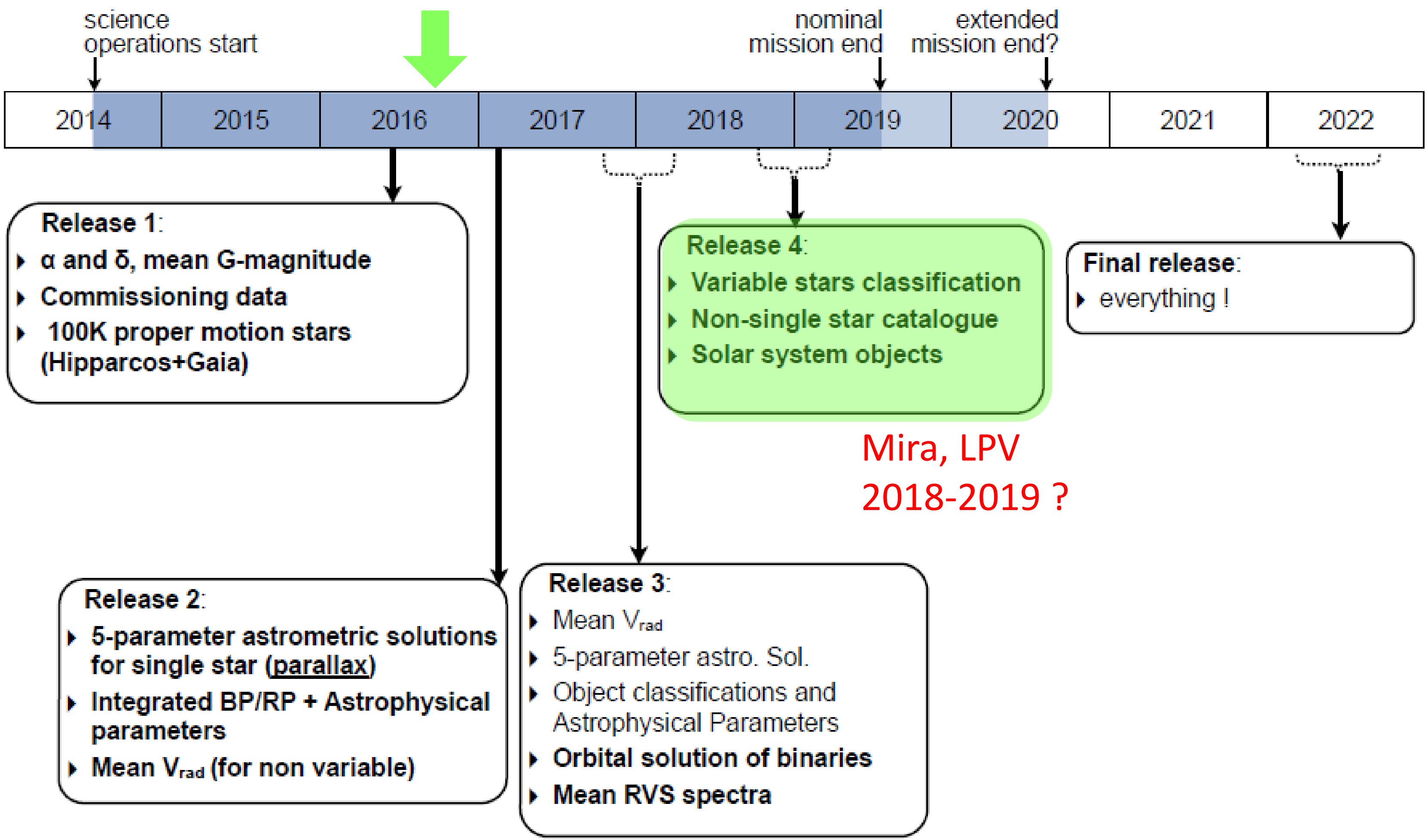
Name	HIP/TYC	$\Delta\alpha*$ [mas]	$\Delta\delta$ [mas]	$\Delta\varpi$ [mas]	$\Delta\mu_{\alpha*}$ [mas yr^{-1}]	$\Delta\mu_{\delta}$ [mas yr^{-1}]	Reference (VLBI)
S Persei	11093	+4.969 ± 8.474	−10.626 ± 8.497	−0.001 ± 0.720	−0.153 ± 0.242	−0.225 ± 0.211	Asaki et al. (2010)
LS I +61 303	12469	−28.882 ± 6.726	+22.324 ± 7.611	+0.188 ± 0.650	−1.322 ± 0.373	+1.133 ± 0.383	Lestrade et al. (1999)
HII 174	1803-0008-1			−0.024 ± 0.302	−0.130 ± 0.918	−0.395 ± 0.492	Melis et al. (2014)
HD 283447	19762	+8.447 ± 0.759	−36.971 ± 0.482	−0.460 ± 0.495	−8.998 ± 0.170	+0.011 ± 0.111	Torres et al. (2012)
T Tau	20390	+231.577 ± 1.280	+514.096 ± 0.545	+0.291 ± 0.309	+7.600 ± 0.169	−12.339 ± 0.095	Loinard et al. (2007)
T Lep	23636			−0.843 ± 0.759	−4.395 ± 0.502	+1.668 ± 0.791	Nakagawa et al. (2014)
3C273	60936	+0.912 ± 1.474	+0.819 ± 1.961	−0.140 ± 0.377	−0.384 ± 0.443	+0.111 ± 0.288	Ma et al. (2009)
σ^2 CrB	79607	−12.772 ± 1.142	−5.524 ± 1.491	+0.104 ± 0.913	−0.471 ± 0.065	−0.009 ± 0.086	Lestrade et al. (1999)
Cyg X-1	98298	−0.378 ± 0.444	−0.648 ± 0.732	−0.310 ± 0.250	+0.015 ± 0.086	+0.034 ± 0.139	Reid et al. (2011)
HD 199178	103144	−4.246 ± 8.859	+6.620 ± 9.330	+0.358 ± 0.474	−0.170 ± 0.409	+0.349 ± 0.431	Lestrade et al. (1999)
AR Lac	109303	−4.324 ± 2.945	−0.975 ± 4.398	−0.332 ± 0.510	−0.220 ± 0.127	−0.082 ± 0.191	Lestrade et al. (1999)
IM Peg	112997	+0.503 ± 1.029	−0.014 ± 1.046	−0.039 ± 0.372	+0.001 ± 0.093	−0.110 ± 0.096	Bartel et al. (2015)
PZ Cas	117078	−29.855 ± 3.349	−9.348 ± 4.012	+0.438 ± 0.558	−0.275 ± 0.205	−0.236 ± 0.303	Kusuno et al. (2013)

Lindegren et al. 2016

Gaia DR1

	VERA	Gaia
・HU Pup	---	-0.15±0.57（400%）
・T UMa	0.96±0.19（20%）	1.07±0.94（88%）

ポスター：大山まど薫

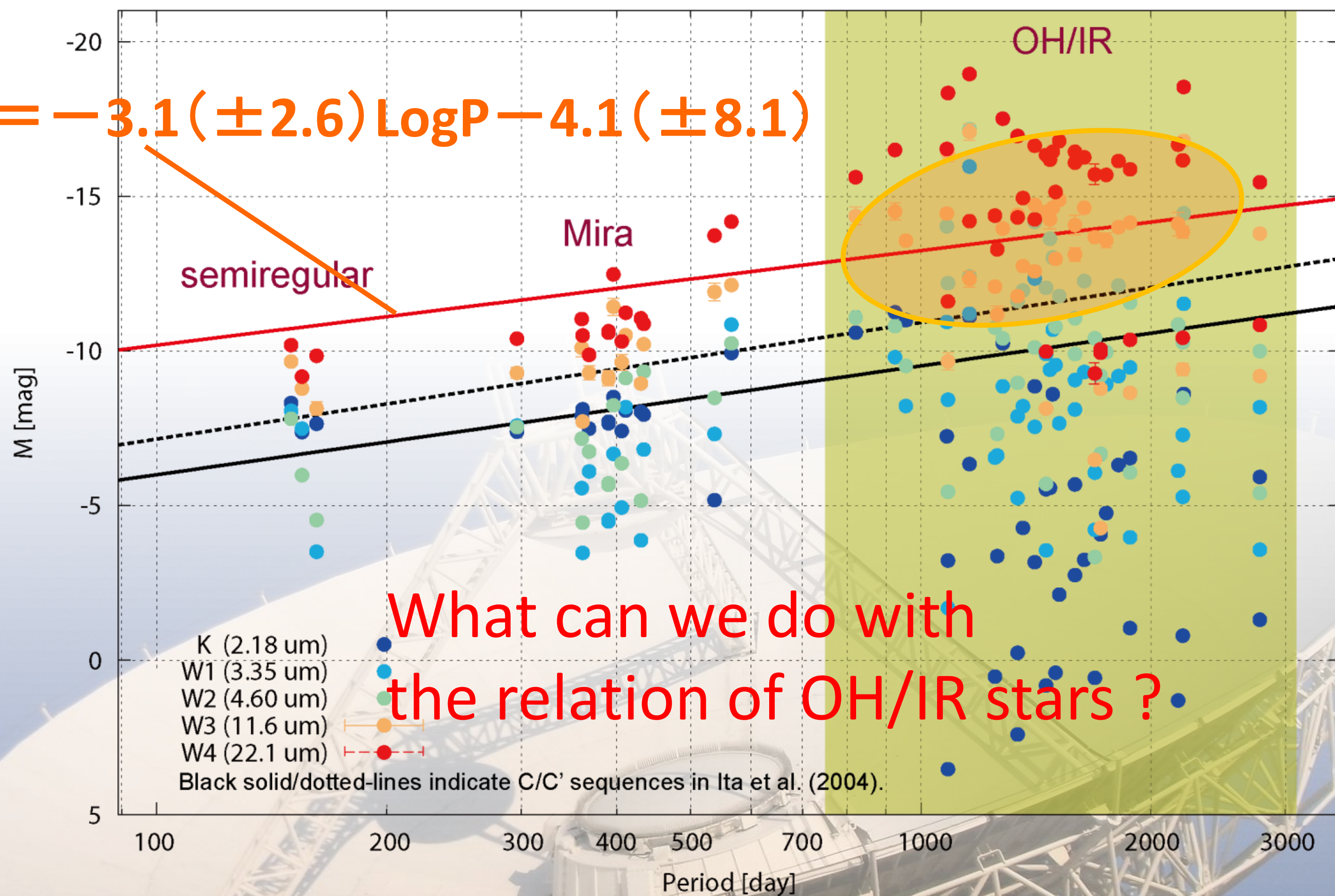

gaia
science operations start
nominal mission end
extended mission end?
2014
2015
2016
2017
2018
2019
2020
2021
2022
Release 1:
α and δ, mean G-magnitude
Commissioning data
100K proper motion stars (Hipparcos+Gaia)
Release 4:
Variable stars classification
Non-single star catalogue
Solar system objects
Final release:
everything !
Mira, LPV
2018-2019 ?
Release 2:
5-parameter astrometric solutions for single star (parallax)
Integrated BP/RP + Astrophysical parameters
Mean Vrad (for non variable)
Release 3:
Mean Vrad
5-parameter astro. Sol.
Object classifications and Astrophysical Parameters
Orbital solution of binaries
Mean RVS spectra

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

$M_{W3} = -3.1(\pm 2.6)\,\mathrm{Log}P - 4.1(\pm 8.1)$



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

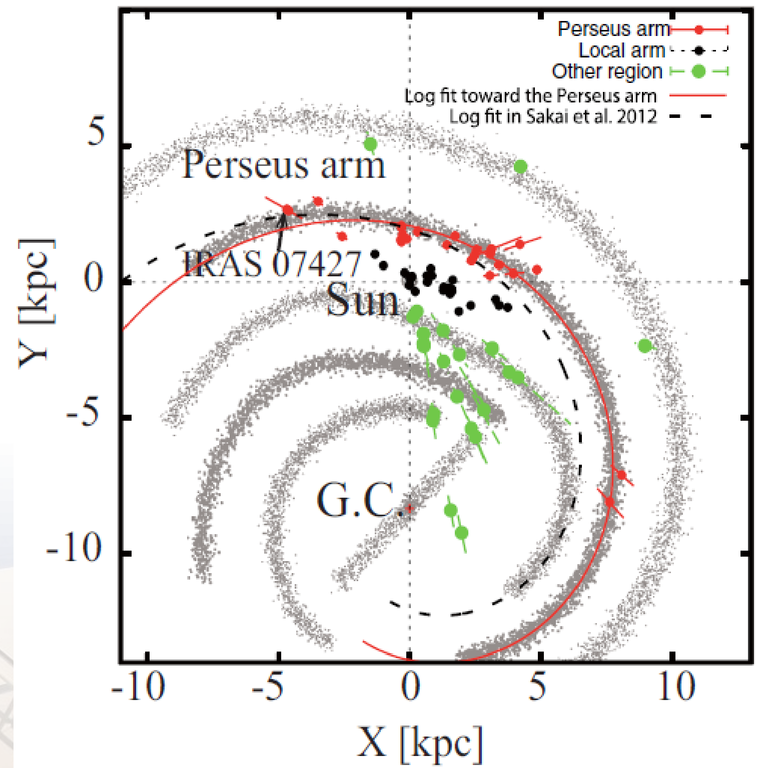
Study of the Galactic kinematics

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

・・・They are very young, ~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...

Sakai et al. 2015



OH/IR stars as a new tracers of the study of the Galactic kinematics

- Period=1000 days → M=~4Msun（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

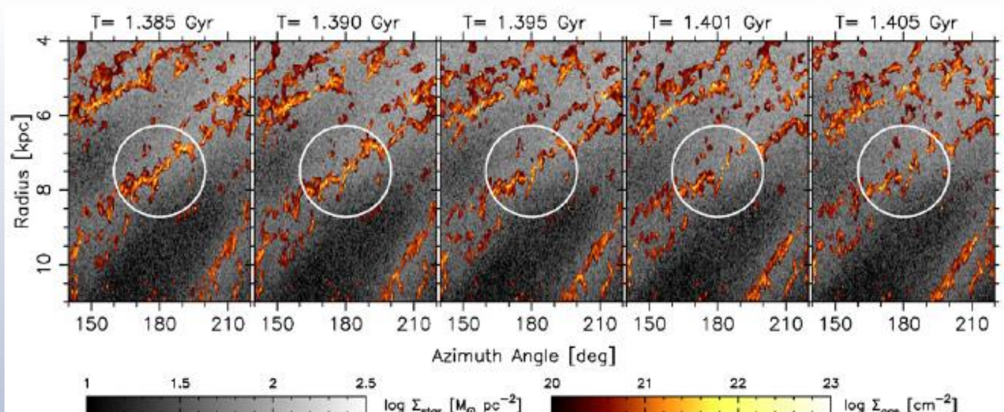
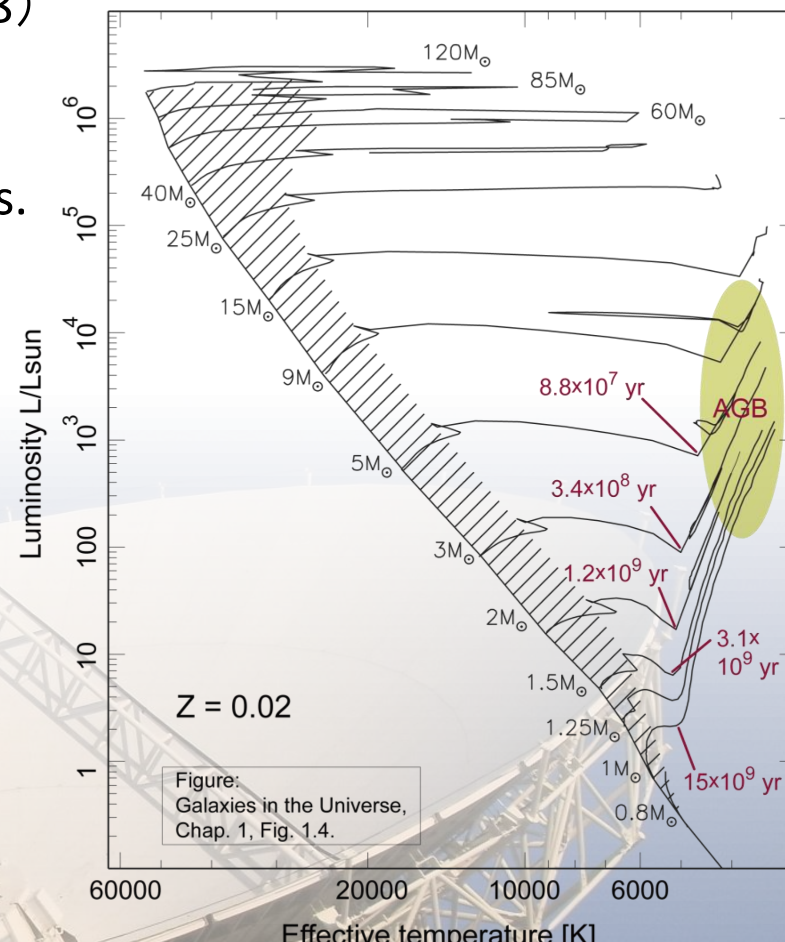


Figure 10. Same as Figure 8, but for snapshots every 5 Myr after $t = 1.385$ Gyr. (An animation of this figure is available in the online journal.)



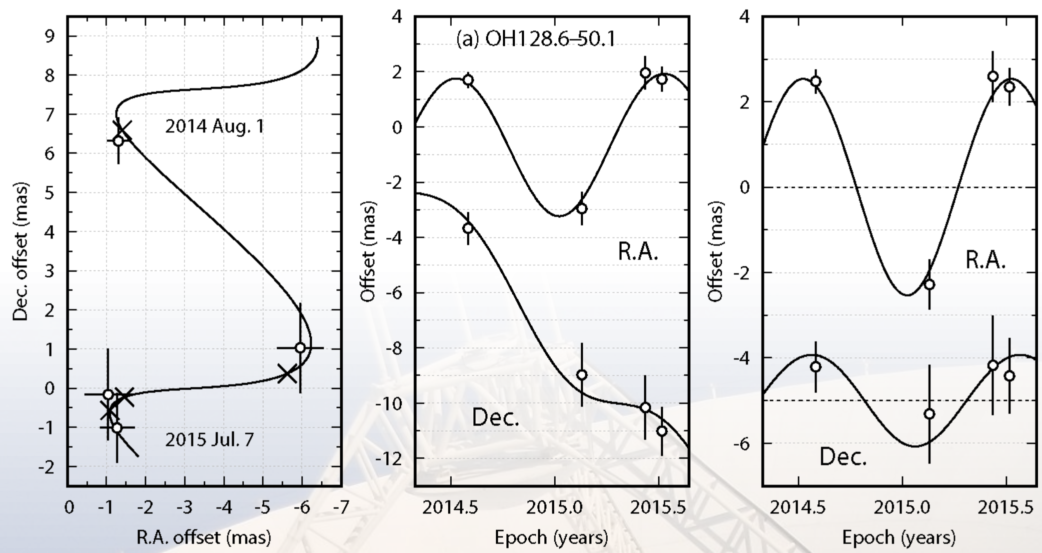
To construct Mid-IR PL-relation of OH/IR stars ,

VLBI astrometry of OH/IR stars

is important.

- VLBI : OH, H2O, SiO masers

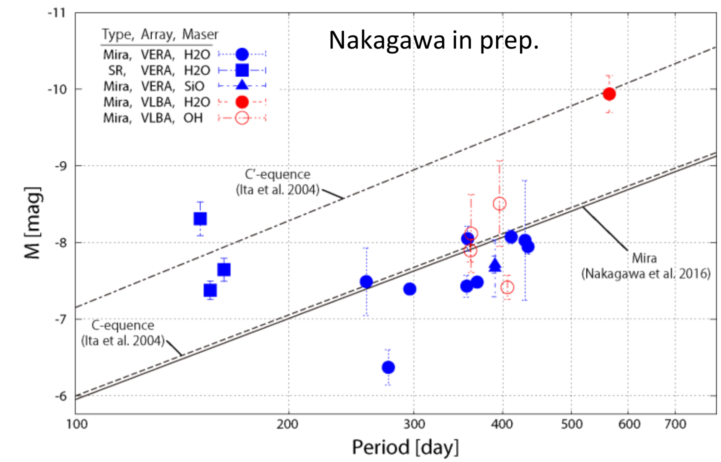
Gabor et al. in prep.



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

Summary

— Astrometric study of the Galactic LPVs —



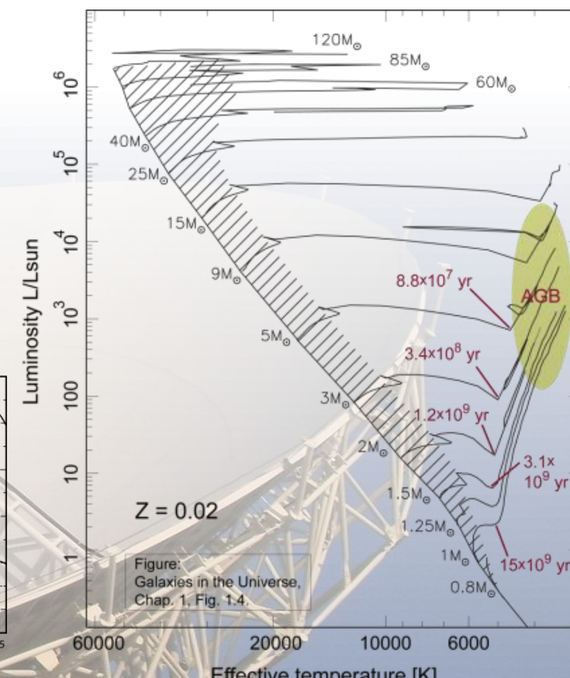
（1）Mira & Semiregular variables

- Phase-referencing VLBI at 22 GHz with VERA
- Parallaxes of ~15 Miras and SRs were determined
- Period-Mk relation ; Mk = -3.52logP + (1.09±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 ~10^8 years

  → They are unique sample for comparison with theoretical model
- VLBI astrometry using OH/H2O/SiO masers is important



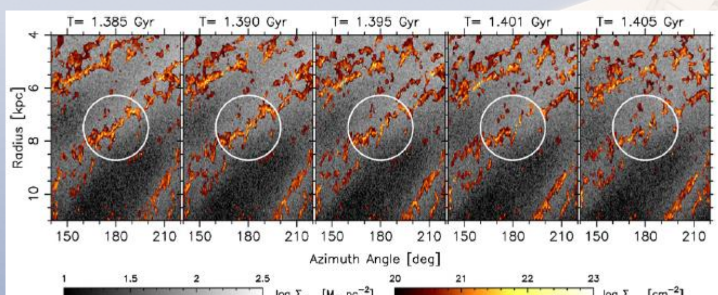


Figure 10. Same as Figure 8, but for snapshots every 5 Myr after $t = 1.385$ Gyr.
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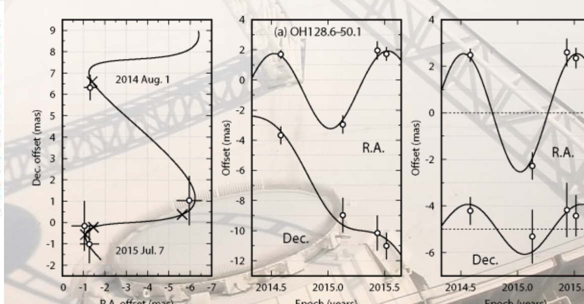
Wada et al. 2011



Gabor in prep.