# Astrometric observation of 'very' long period variables

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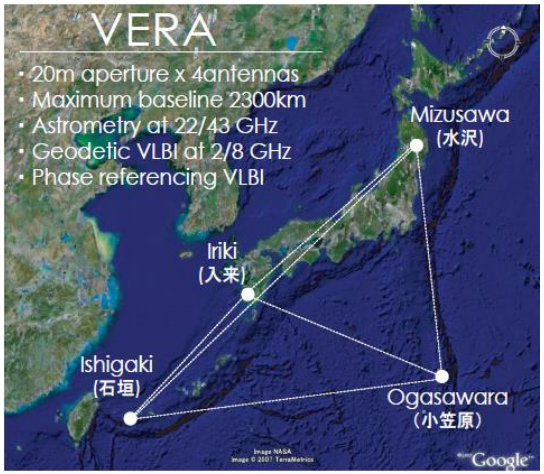
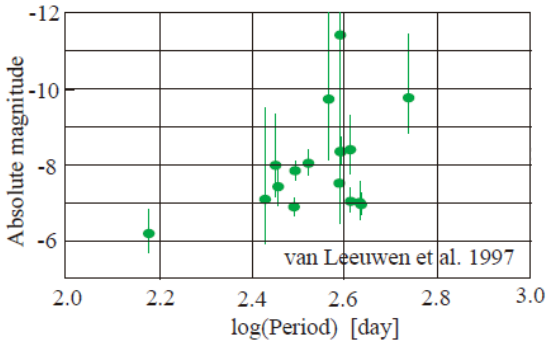
Long period variables shows high mass-ross and plays an important role in chemical enrichment of the universe. They are also used as a standard candles in distance estimation of celestial objects.

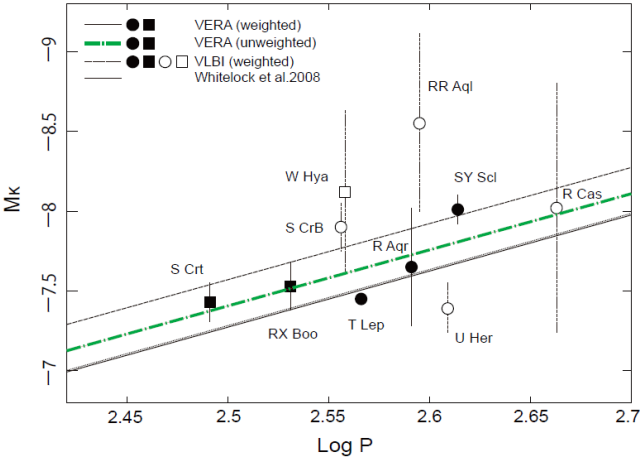
Though astrometric observations of long period variables revealed their period-luminosity relation especially for Mira type variables (van Leeuwen et al.1997, Whitelock et al. 2008, Nakagawa et al. 2014), the relation for stars with period longer than ~1000 days are not studied in the Milky Way Galaxy. Astrometric observations of these kind of sources are little or nothing. We started water maser survey toward potential sources of 'very' long period variables. Optical monitoring are also considered using 1m telescope at Kagoshima.

Current purpose: # Determination of Period-Luminosity Relation (PLR) of Mira type variables

位置天文に基づいたミラ型変光星の周期光度関係の確立




Current result from VERA

Nakagawa et al. 2014 PASJ

**VLBI Astrometry**

Distance : D

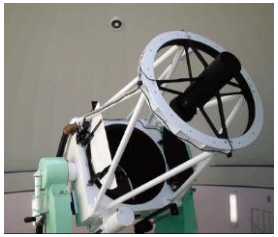
Apparent mag: mk

Abs. mag. : Mk

Period : LogP

Determination of PLR（Mk-LogP）

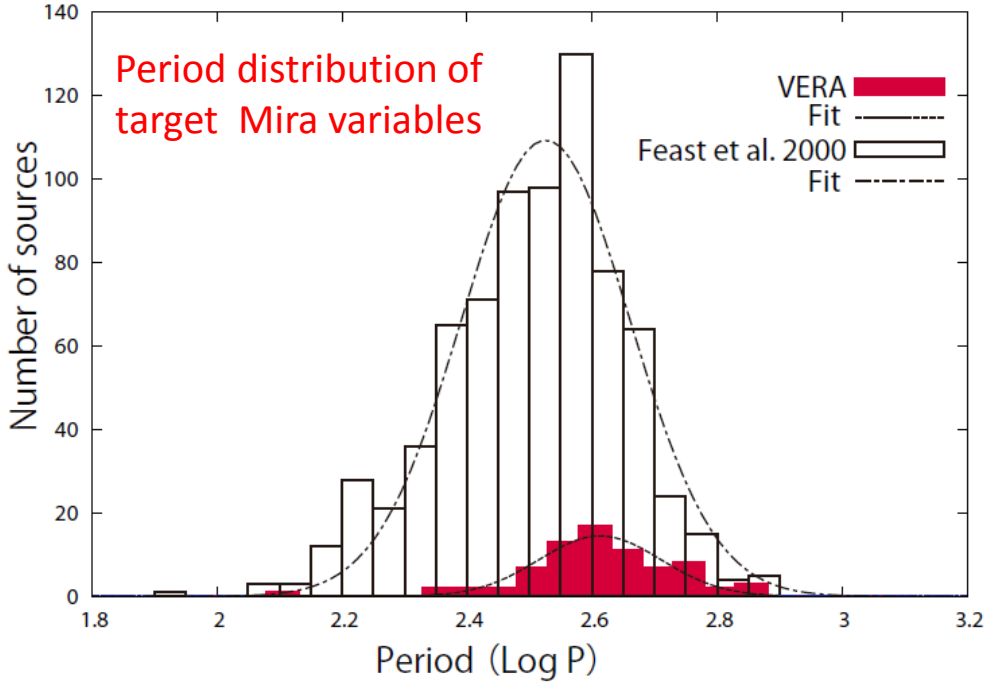
**IR Photometry**



# VLBI astrometry with VERA

Measurement of annual parallax using water maser emission.


- Single-dish monitoring and surveys at IRIKI.
- VLBI monitoring using with VERA.




| 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 |

# Current results of astrometric VLBI observations toward variable stars with VERA.

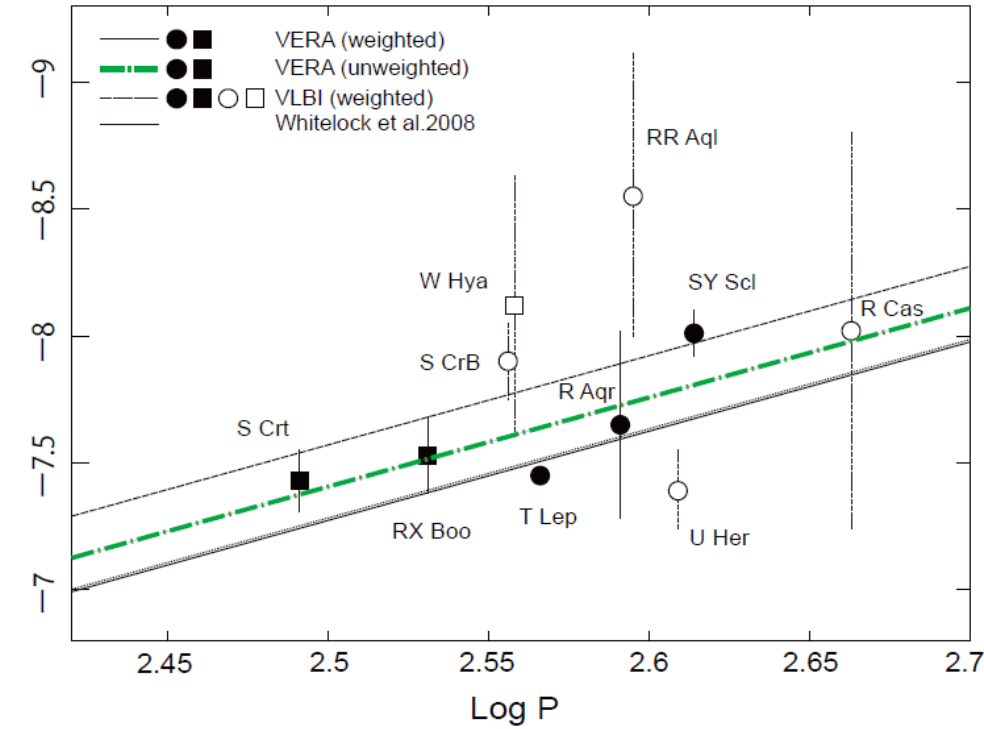
## Parallax of variable stars with VLBI astroemtry

Table2: Results from VLBI astrometry

| | Source | Type | Parallax† [mas] | P [day] | LogP | $m_K$‡ [mag] | $M_K$ [mag] |
|---|---|---|---|---|---|---|---|
| VERA | T Lep | Mira | 3.06±0.04(a) | 368 | 2.566 | 0.12 (h) | -7.45±0.03 |
| | S Crt | SR | 2.33±0.13(b) | 310* | 2.190 | 0.73 (i) | -7.43±0.12 |
| | R Aqr | Mira | 4.7 ±0.8 (c) | 390 | 2.591 | -1.01(h) | -7.65±0.37 |
| | SY Scl | Mira | 0.75±0.03(d) | 411 | 2.614 | 2.61 (j) | -8.01±0.09 |
| | RX Boo | SR | 7.31±0.5 (e) | 340 | 2.531 | -1.85(k) | -7.53±0.15 |
| VLBA | S CrB | Mira | 2.39±0.17(f) | 360 | 2.556 | 0.21(h) | -7.90±0.15 |
| | U Her | Mira | 3.76±0.27(f) | 406 | 2.609 | -0.27(h) | -7.39±0.16 |
| | RR Aql | Mira | 1.58±0.40(f) | 394 | 2.595 | 0.46(h) | -8.55±0.56 |
| | W Hya | SR | 10.18±2.36(g) | 361 | 2.558 | -3.16(h) | -8.12±0.51 |
| | R Cas | Mira | 5.67±1.95(g) | 460 | 2.663 | -1.79 (l) | -8.02±0.78 |

[†] Reference of the parallax; (a)Nakagawa et al 2014, (b)Nakagawa et al 2008, (c)Kamohara et al 2010, (d)Nyu et la 2011, (e)Kamezaki et al 2012, (f)Vlemmings & van Langevelde 2007, and (g)Vlemmings et al. 2003.
[‡] Reference of the m_K; (h)Whitelock et al. 2000 (Fourier mean magnitude), (i)Jura & Kleinmann 1992, (j)Whitelock et al. 1994, (k)Glass & van Leeuwen 2007, and (l)Feast & Whitelock 2000.
[*] For the period of S~Crt, we use 310~days, which is the double of its first overtone period of 155~day.

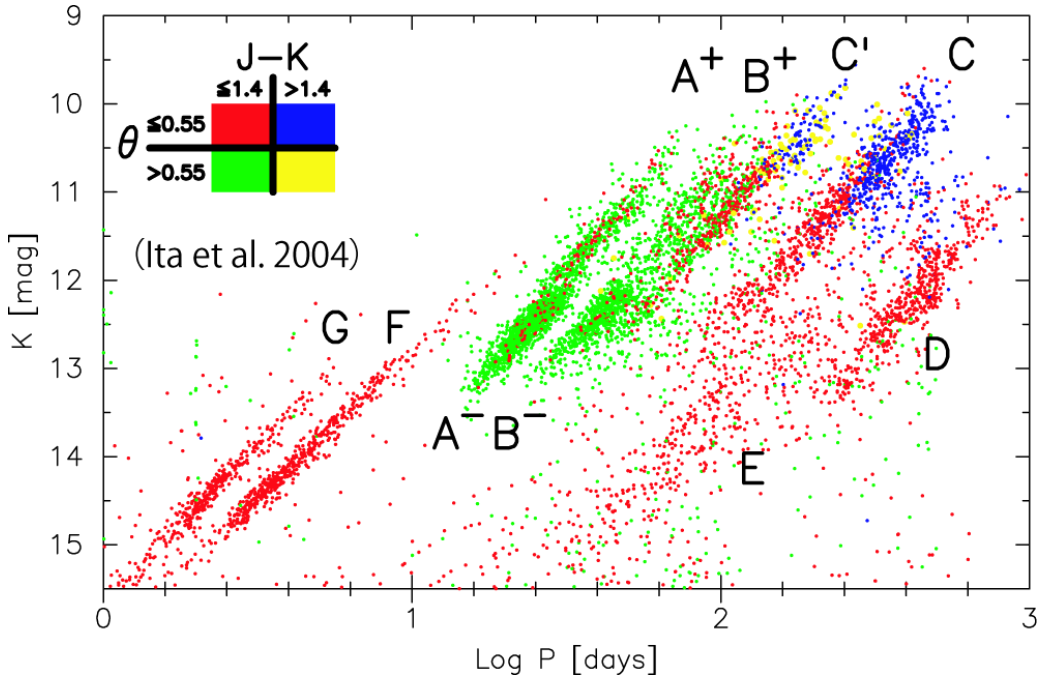
## Period-luminosity relation of the Galactic Mira variables obtained from VLBI astroemtry.




Nakagawa et al. 2014 PASJ

# Sequences of long period variables

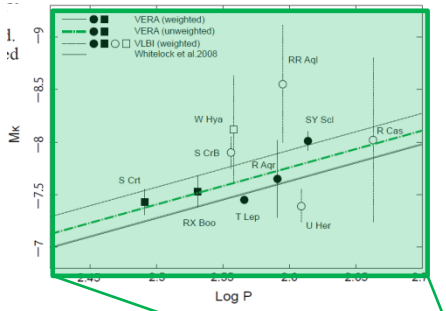
- Ita et al. 2004 shows several sequences of variable stars in LMC.



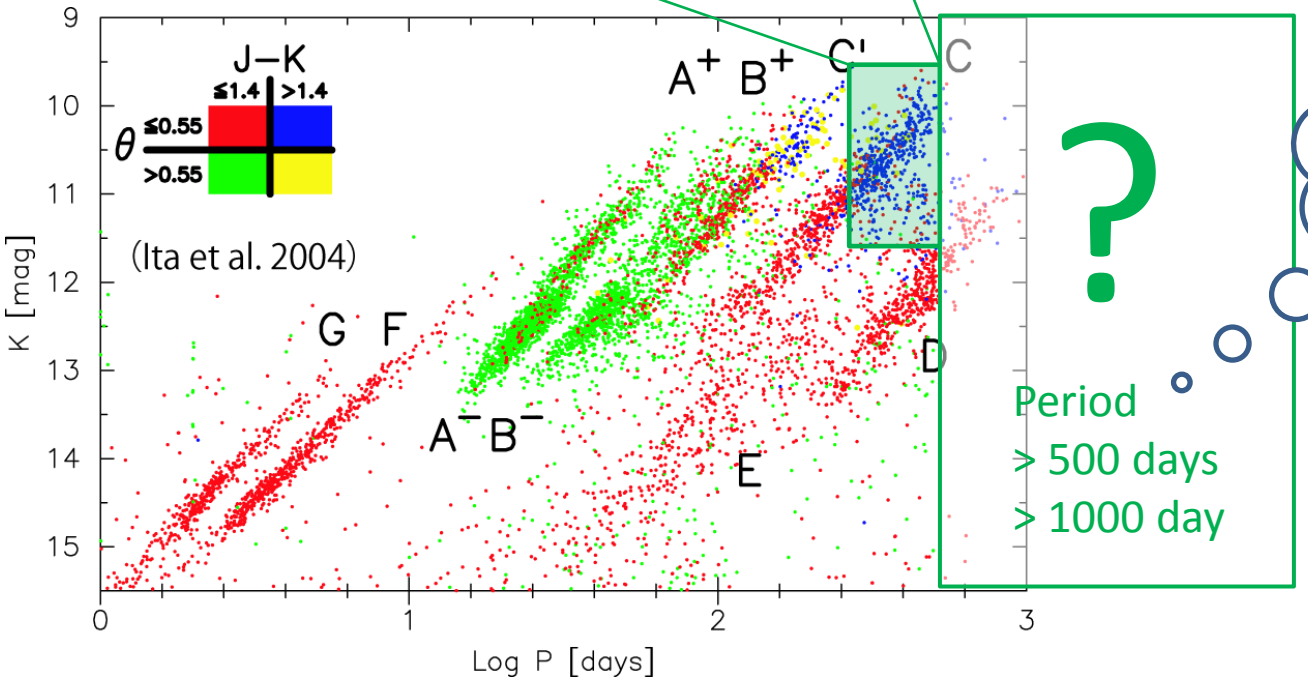

| | | |
|---|---|---|
| *A+* | Cyan | RGB variables and metal-poor and old AGB variables |
| *A-* | Yellow | Less regularly pulsating AGB variables |
| *B-* | Orange | RGB variables and metal-poor and old AGB variables |
| *B+* | Green | Less regularly pulsating AGB variables |
| *C'* | Blue | Mira variables 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 |

# Sequences of long period variables

- Ita et al. 2004 shows several sequences of variable stars in LMC.
- Almost NO observation for variable stars with pulsation periods > 500 days.




*C*
Mira variables pulsating in the fundamental mode




?

Period
> 500 days
> 1000 day

- OH/IR stars ?
- LSP ?
- Miras ?

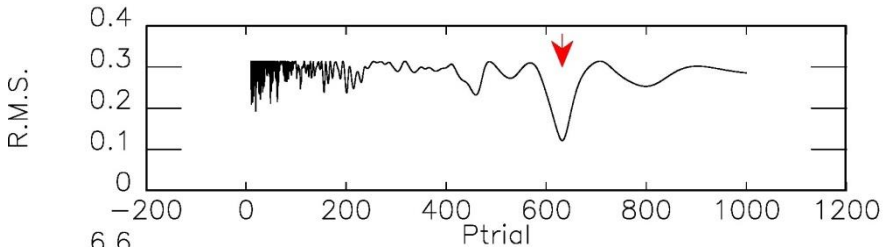
# Long period variables NOT on the known sequences ?

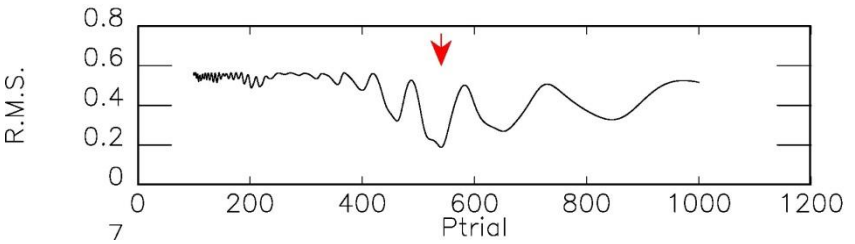
- OH/IR stars show very long period. There are many OH/IR stars whose pulsation period are not determined.
- Parallax measurements of OH/IR stars is not so many.
- Do they show period-luminosity relation ?
- Is there a pulsation mechanism with period of >1000 days ?
- Long secondary period (LSP) in variable stars.
  - Reason of the periodicity
    - Pulsation ? ・・・What kind of pulsation mode, mechanism ?
    - Binary system ? (Red giant with a low-mass companion, interaction with circum stellar matters. )
    - Spotted star ? (Dark spot on their photosphere.)

⇨ Parallax measurements of the stars give distances, free from any assumption of their properties, and it helps to deduce accurate physical parameters.

# Detection of 'very' long period variables from K-band monitoring using Kagoshima university 1m telescope

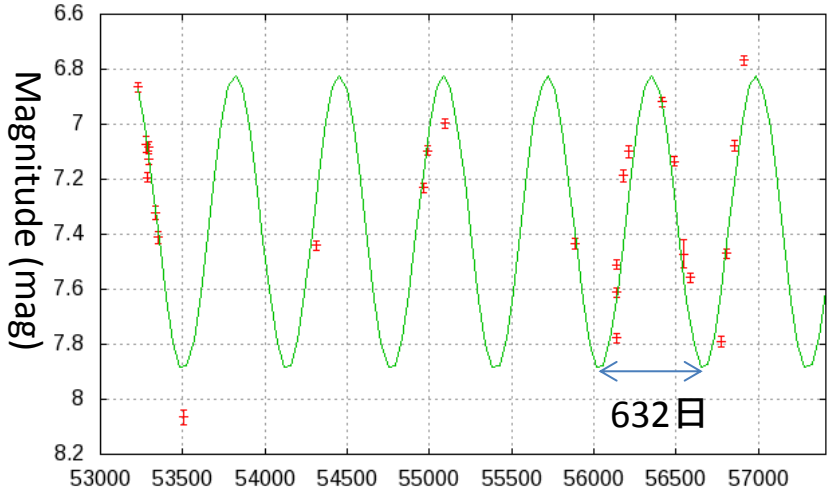
Results of Fourier analysis of light curve in K-band.

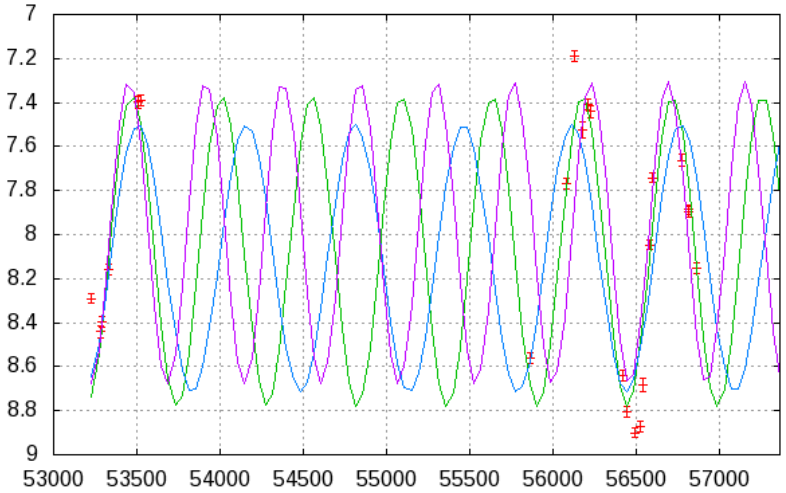



19303+1553_K.dat
Period = 632.85 day
RMS = 0.127182
Mean mag = 7.35731 mag

19235+1034_K.dat
Period = 540.95 , 651.66 , 462.3 day
RMS = 0.188412 , 0.269204 , 0.321513
Mean mag = 8.07561 , 8.10754 , 7.99176 mag



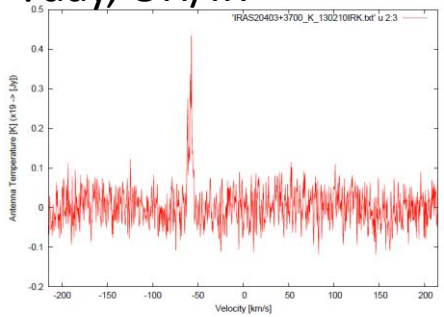
MJD (day)

IRAS 19303+1553, Data and best-fit model.

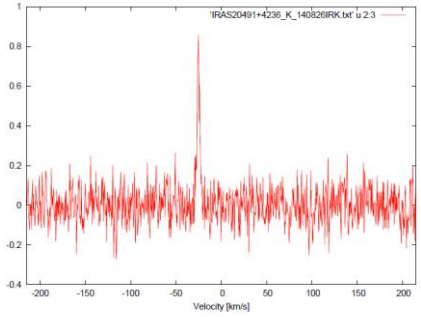
IRAS 19235+1034, Data and best-fit models.
It shows three possible periods of 540, 651, and 462 days.

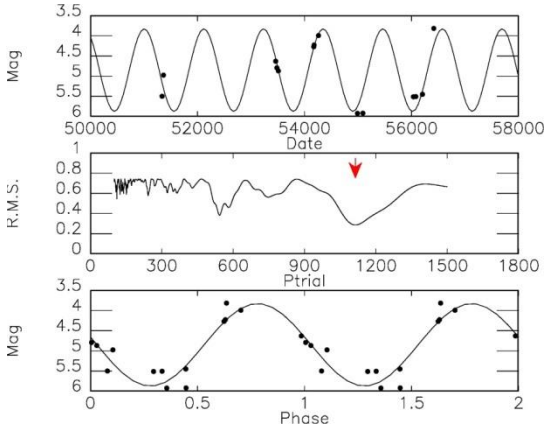
# $H_2O$ maser detection from 'very' long period variables

P=?day, OH/IR



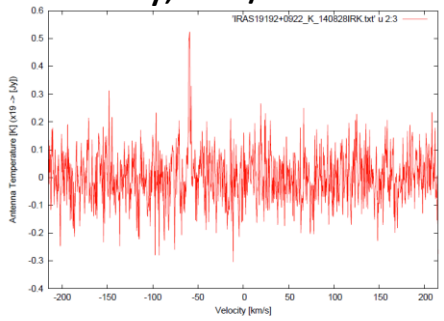

P=1500day, C-star



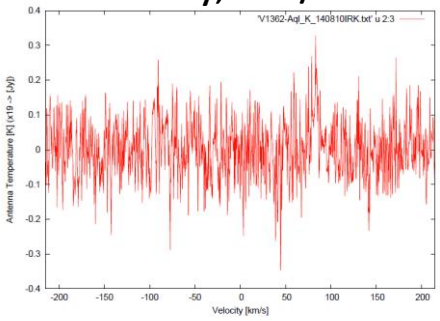




IRAS 18176-1848
Fourier analysis in infrared photometry gives a period of 1114 day.

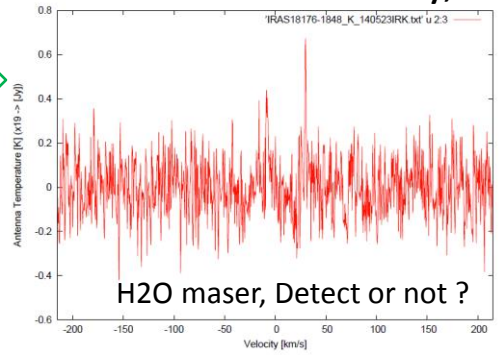
P=537day, OH/IR



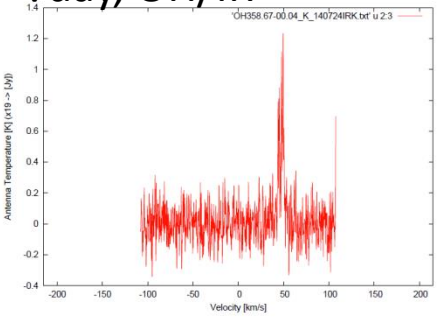

P=2000day, OH/IR



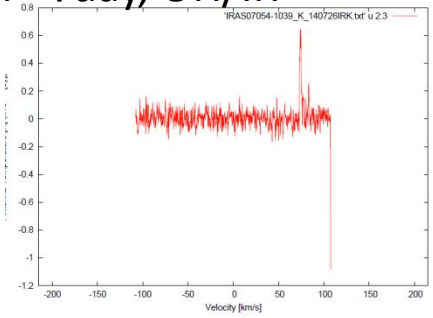

P=1114day, ? star



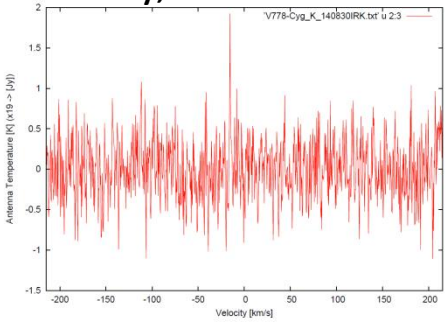

P=?day, OH/IR




P=?day, OH/IR




P=?day, C-star




Vertical axis shows an antenna temperature. Flux density in [Jy] can be obtained by multiplying 19 to the values.

# $H_2O$ maser survey for 'very' long period variables at VERA IRIKI station.

- ~280 candidate sources. (OH/IR, Carbon star, Mira, SR, LSP, IR source, ... )
- K-band variable star with period of ~1500 day found from 1m Kagoshima telescope.
- $H_2O$ maser survey at 22 GHz.
- Detection criterion : ~3 Jy
- Vlsr range : -200 < Vlsr < +200 km/s

| ID | Name | Coordinate (RA Dec) | Name2, Comment | Period (day) | Intensity | Catalog |
|---|---|---|---|---|---|---|
| 99 | AW_Tau | 05 47 30.22 +27 08 12.4 | SR, IRAS 05443+2707 | 564 | 6Jy△ | www.hs.uni-hamburg.de |
| 26 | NSV 17351 | 07 07 49.38 -10 44 05.9 | IRAS07054-1039, 弱いけど検出@2011年, OH/IR | | 11Jy | www.hs.uni-hamburg.de |
| 100 | AH_Sco | 17 11 17.02114 -32 19 30.7132 | IRAS 17080-3215, IRC-30282 | 714 | 20Jy | www.hs.uni-hamburg.de |
| 27 | OH 358.667-0.044 | 17 42 35.02 -30 05 41.9 | 入来単一鏡データなし、エントリーはある。(OH358.67-00.04.src) | | 13Jy | Kim et al 2010 |
| 166 | OH 12.3-0.2 | 18 13 08.8 -18 27 51 | MSX5C G012.2118-00.2307 , Mas,~ | | 26Jy | Kim et al 2010 |
| 50 | IRAS18176-1848 | 18 20 36.7 -18 47 09 | 18 20 36.7 -18 47 09 | 1114 | 15Jy | Kim et al 2013 |
| 9 | OH 30.1-0.7 | 18 48 41.91 -02 50 28.3 | V1362 Aql, IRAS 18460-0254, Mira(SIMBAD), NonDetectOVO@2013 | 2000 | 12Jy△ | 山下 |
| 13 | OH 44.8-2.3 | 19 21 36.52 +09 27 56.5 | IRAS 19192+0922, Maser(SIMBAD), NonDetectOVO@2006 | 537 | 38Jy? | Ohnaka 2013 |
| 251 | OH 57.5+1.8B | 19 31 45.8 +22 33 43 | OH 57.5+1.8B , Mas, | | | Ohnaka 2013 |
| 96 | V778_Cyg | 20 36 07.402 +60 05 26.15 | C* 20 36 07.402 +60 05 26.15 C4,5J 108 1 | | | Cho 2010 |
| 49 | IRAS 20403+3700 | 20 42 18.49 +37 11 41.0 | 20 42 18.49 +37 11 41.0 ~ 12 0 検出@2013年2月、9Jy | | 136Jy | Cho 2010 |
| 256 | OH 80.8-1.9 | 20 46 25.54 +40 06 59.4 | NML_Cyg, V1489 Cyg, IRC+40448, V* , M7-8 | | 9Jy | CatalinaSurvey (CSDR2) |
| 17 | OH 83.4-0.9 | 20 50 57.7 +42 48 04 | IRAS 20491+4236, Carbon Star(SIMBAD), OVOエントリー無し | 1500 | 36Jy▲ | www.hs.uni-hamburg.de |
| 134 | CSS_J213104.1+110912 | 21 31 04.10 +11 09 12.3 | V=11.57 P=455.00 Amp=2.43 , UU_Peg | | 14Jy | www.hs.uni-hamburg.de |
| 98 | EU_And | 23 19 58.880 +47 14 34.54 | C* 23 19 58.880 +47 14 34.54 R 83 0 | | 380Jy | www.hs.uni-hamburg.de |

△ Marginal detection.
▲ Detected as absorption line

⇨ 15 detection