# Improving the parallaxes of OH bearing Miras


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## Background

- High mass loss at the **A**symptotic **G**iant **B**ranch (*AGB*) produces **C**ircum**s**tellar **E**nvelopes (*CSEs*) around late type stars.
- Different maser species (*OH, $H_2O$, SiO*) are important probes to the kinematics and dynamics of CSEs.
- OH masers are found at a few hundred to a thousand AU from the central star.

### *Maser Astrometry*

*Goals:*

- Proper identification of the location of the different maser species
  - Most CSE results assume the location of star
- Parallax distances to obscured stars
  - At 8kpc: π=0.125 mas
- Galaxy dynamics
  - 10 km/s at 8 kpc: μ=0.250 mas/yr
- Stellar astrophysics, binaries, planets
- Reference frame ties

*Needs:*

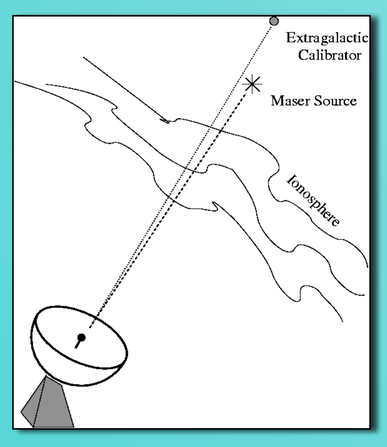
- Good understanding of how the masers move w.r.t. the star
  - positional tie < 1 AU
- Persistent masers for long term monitoring
  - careful for effects of stellar pulsations

### *Amplified Stellar Image*

- Describes the amplification of the stellar radio-sphere by the maser screen in front of the star. (Norris et al., 1984; Vlemmings et al., 2001)
  - results in compact, bright maser spot at most blue shifted side of the maser spectrum
  - coincides in different maser transitions
- Ties the most blue-shifted maser spot directly to the star
  - astrometry accuracy < 1 AU
- Confirmed in van Langevelde et al. (2001) by a direct comparison between the Hipparcos and the maser positions of U Her.
- But: not all stars show bright blue shifted spot

## VLBI Astrometry

### *Phase Referencing*




- Determine maser positions with respect to extra-galactic calibrators
- Key requirements are to calibrate phase of the system and to remove ionospheric phase fluctuations:
  - **Nodding calibrator:** Strong, compact source used to calibrate system and remove gross ionospheric phase fluctuations
  - **In-Beam calibrator:** Within the same primary beam and observed simultaneously with the maser, used to calibrate differential ionospheric phase fluctuations between the nodding calibrator and the maser line of sight.


## *Abstract*

We have carried out observations with the VLBA to measure the parallaxes of Mira variables. Recently we have improved our technique by making use of nearby, in-beam calibrators. Additionally, the observing conditions have improved during solar minimum. We are able to improve the distance estimates significantly for a fraction of our sample (U Her, S CrB and RR Aql). The distances of these stars are of fundamental importance for studying the physical properties of AGB with high mass loss.


## Motion fitting results

U Her:

$\Pi_{vlbi}$ = 3.76 ± 0.27 mas, $\mu_{vlbi}$ = -16.99 ± 0.77, -11.88 ± 0.50 mas/yr

$\Pi_{vlbi}$ = 3.61 ± 1.04 mas, $\mu_{vlbi}$ = -14.94 ± 0.38, -9.17 ± 0.42 mas/yr

$\Pi_{vlbi}$ = 3.74 ± 0.61 mas, $\mu_{vlbi}$ = -14.98 ± 0.29, -9.23 ± 0.31 mas/yr

$\Pi_{hip}$ = 1.88 ± 1.31 mas, $\mu_{hip}$ = -16.84 ± 0.82, -9.83 ± 0.92 mas/yr

S CrB:

$\Pi_{vlbi}$ = 2.39 ± 0.17 mas, $\mu_{vlbi}$ = -8.58 ± 0.38, -13.21 ± 0.61 mas/yr

$\Pi_{vlbi}$ = 2.31 ± 0.33 mas, $\mu_{vlbi}$ = -9.08 ± 0.38, -12.49 ± 0.33 mas/yr

$\Pi_{vlbi}$ = 2.36 ± 0.23 mas, $\mu_{vlbi}$ = -9.06 ± 0.23, -12.52 ± 0.29 mas/yr

$\Pi_{hip}$ = 2.40 ± 1.17 mas, $\mu_{hip}$ = -8.33 ± 0.93, -11.55 ± 0.62 mas/yr

RR Aql:

$\Pi_{vlbi}$ = 1.58 ± 0.40 mas, $\mu_{vlbi}$ = -25.11 ± 0.74, -49.82 ± 0.54 mas/yr

$\Pi_{hip}$ = 2.48 ± 2.57 mas, $\mu_{hip}$ = -24.01 ± 4.18, -47.66 ± 2.80 mas/yr

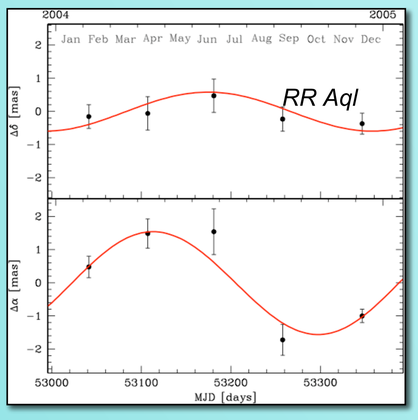
*Colour coding:* New; Vlemmings et al. 2003; Combined total fit; Hipparcos (Perryman et al. 1997; Knapp et al. 2003)

## *New and Improved distances*

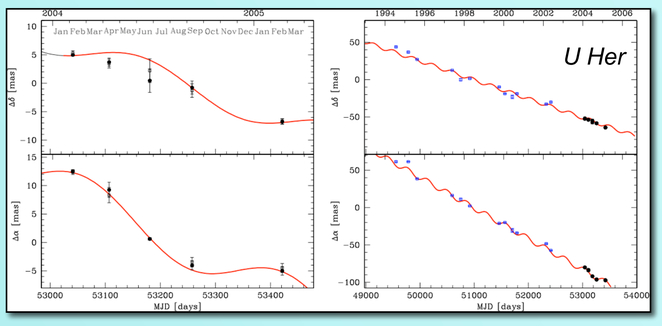
**U Her at $266^{+21}_{-18}$ pc**

**S CrB at $418^{+32}_{-28}$ pc**

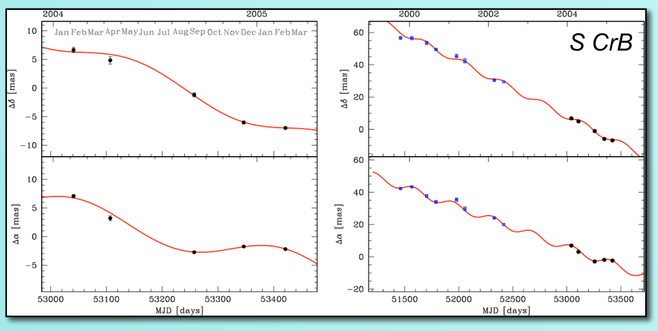
**RR Aql at $633^{+214}_{-128}$ pc**

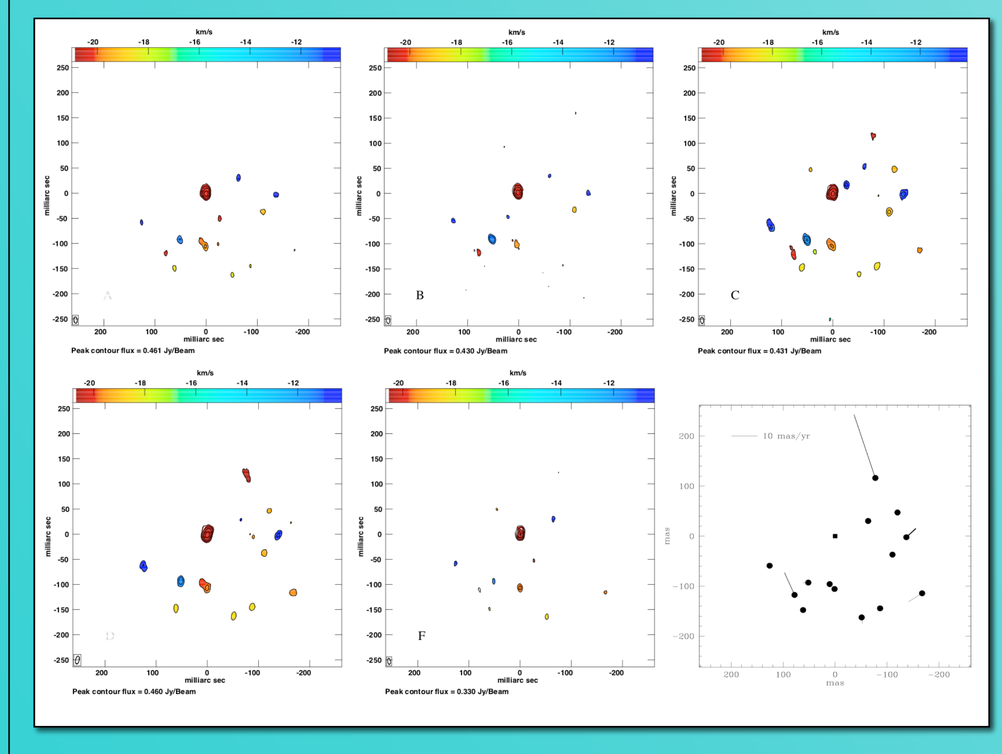



*The motion of the most blue-shifted 1665 MHz OH maser spot of RR Aql for the recent 5 epochs of observation (scale 150x150 mas)*

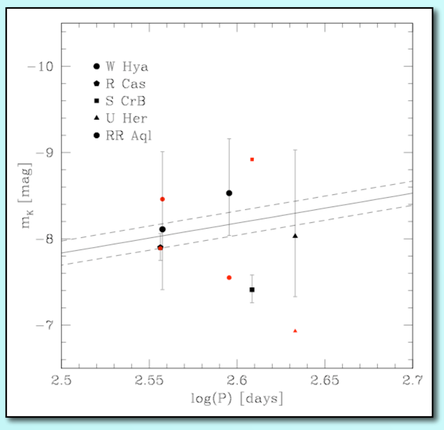



*The position of the brightest maser spots for our 3 sources with respect to their extragalactic calibrator. The red line indicates the fitted proper motion and parallax. For U Her and S CrB the right panel displays the combined data (blue data points are the previously observed epochs). For RR Aql the proper motion subtracted fit is shown.*




U Her internal motions: The colour panels are 5 new epochs of the 1667 MHz OH masers of U Her referenced to the most blue-shifted maser, *the amplified stellar image*. The 6th panel indicated the spots detected in at least 3 of the epochs. No significant internal motions were detected. The vectors indicate 2σ motions. Positional scatter is consistent with the astrometric position fitting errors and a ~1-2 km/s *turbulent* motion.




## P-L Relation

- The VLBI distances are compared with the P-L relation from Whitelock & Feast (2000)

$$M_k = 0.84 - 3.47 \log P$$

- VLBI OH results (black symbols) show less scatter than the Hipparcos results (red symbols)

| *Source* | *P-L* | *Hipparcos* | *VLBI distance* |
|---|---|---|---|
| U Her | 380 pc | 532 pc | 266 pc |
| S CrB | 470 pc | 417 pc | 418 pc |
| RR Aql | 540 pc | 403 pc | 633 pc |
| R Cas | 200 pc | 106 pc | 176 pc |
| W Hya | 90 pc | 115 pc | 98 pc |

## Results

- Fitted proper motions and parallaxes to 3 AGB stars
- Obtained improved distances to U Her and S CrB and new proper motion and parallax for RR Aql
- In-beam calibration significantly improves maser astrometry
  - Though no useful calibrator for U Her
- Better conditions due to solar minimum also help
- Only U Her shows (still) the *amplified stellar image*
- No significant internal motions detection in 1667 MHz OH maser shell of U Her
  - Positional scatter is consistent with estimated astrometric errors *plus* ~ 1-2 km/s turbulent motion
- Phase referencing of the OH masers yields accuracy of:
  - ~1 mas using in-beam calibration (an angular separation of less than 20' between calibrator and target source)
  - increases to few mas when separation increases

## *References*


- Knapp et al., 2003, A&A, 403, 994
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- Perryman et al., 1997, A&A, 329L, 49
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- Vlemmings & van Langevelde, 2000, Proceedings of the 5th EVN Symposium; Gothenburg, Sweden; p. 189
- Whitelock & Feast, 2000, MNRAS, 319, 759