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Astrometry of the OH Masers of 4 Mira Stars

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Abstract. The OH main line masers in circumstellar shells were observed with astrometric VLBI in order to accurately determine the position of the star, as well as its motion, including the parallax. Results are presented on 4 Mira stars monitored for 2 - 8 years with the VLBA. The data show that in some stars the VLBI detection is dominated by blue-shifted emission that is associated with the stellar image amplified by the maser shell in front of the star. In other cases the maser is not directly tied to the stellar position, but still persistent enough to measure proper motion and parallax.

1. Introduction

Accurate distances of astronomical objects are the starting point for most astrophysical interpretations. For the optically visible Mira variables, accurate distances have become available from the Hipparcos astrometric mission. But a large fraction of AGB stars have so much circumstellar material that they are too obscured to reliably measure their motion. In addition they are Long Period Variables with large optical amplitudes. However, some of these stars exhibit circumstellar masers, which principle allow very accurate astrometry using VLBI. Although H_2O and SiO masers yield intrinsically higher resolution, we have concentrated on OH first. Firstly, the OH masers lie at large distances from the star and are expected to be persistent over many years. Furthermore, it has been proposed (Norris et al. 1984; Sivagnanam et al. 1990) that in OH shells we can detect the amplified stellar image, which would serve as a fixed point with respect to the star. Finally, astrometry at 18cm can done on the VLBA relatively straightforwardly at the accuracy that is permitted by the OH maser brightness (≈ 1 mas).

Below we describe the results of 8 year monitoring of U Her and 2.5 years of W Hya, S CrB and R Cas. Two of these stars have their VLBI spectra dominated by blue-shifted emission, which is shown to be consistent with the amplified stellar image. But even for the two stars with only compact red-shifted emission it is possible to follow the motion of the star. It is thus demonstrated that accurate distances for enshrouded AGB stars can be obtained by VLBI. A

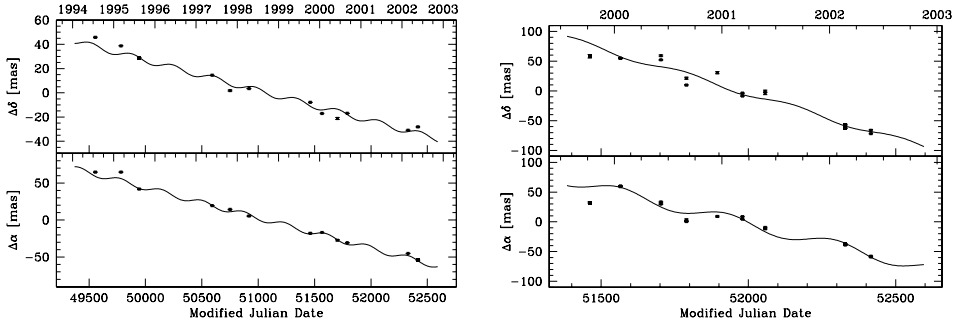

Figure 1. The position of the most blue-shifted 1667 MHz maser spot of U Her (left) with respect to the reference source, spanning approximately 8 years. For W Hya (right) both 1665 and 1667 blue-shifted spots are used. Note that the observations only span 2.5 years. The drawn line represents the best fit for proper motion and parallax.

more detailed discussion of the results can be found in Vlemmings et al. (2003), early results on U Her were published in van Langevelde et al. (2000).

2. Observations & Results

The 4 Mira variables were selected to have bright (> 1 Jy) 1665 or 1667 (main line) maser emission and to be presumably nearby (< 500 pc). Also, two bright nearby phase reference sources needed to be available. Most of the calibrators were between $1^\circ - 2^\circ$ from the target; for S CrB one calibrator was within 1°, for U Her both were at $\approx 3^\circ$. Cycle times of 5 minutes were used, often with 2 calibrators per target in one cycle, which allows an estimate of the accuracy.

The astrometry was obtained directly from the correlator model without any special software, with the exception of a home grown AIPS task to transfer calibration results from wide band data (on the reference sources) to the 500 kHz bands on the maser. Assuming a constant separation between pairs of extragalactic reference sources, the precision of the relative astrometry is estimated to be $\approx 1 - 2$ mas. Significant degradation of this accuracy was detected during the solar maximum, as well as its dependence on "throw" and elevation. In Fig. 1 & 2 we show only the formal errors derived from the fitted position, the residuals originate in most cases from the accuracy of the astrometry.

3. Discussion

The relative astrometry yields both proper motions as well as significant determinations of the parallax of each source. As these sources are all 4 optically visible Mira stars, the proper motions can be compared directly with results from the Hipparcos mission. In most cases they agree within the uncertainties.

The Hipparcos catalogue entries for the 4 target sources are flagged as being rather unreliable, but still optical parallaxes are available, albeit with rather large uncertainties. For S CrB and U Her the VLBI results seem more precise, while the R Cas value is significantly different from the Hipparcos value. The

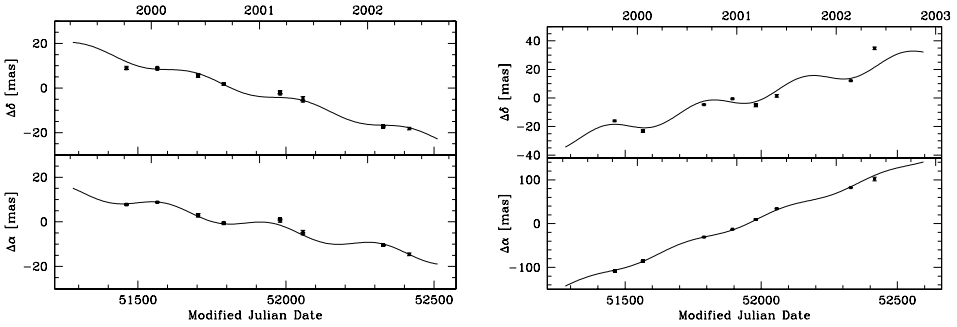

Figure 2. For S CrB (1667 & 1665; left) and R Cas (1665; right) only spots in the receding part of the shell could be found. Still, satisfying fits of proper motion and parallax could be made, especially for S CrB which has the closest reference source.

VLBI value puts this star closer to the $P-L$ relation established by (Whitelock & Feast 2000) For W Hya the VLBI results seems less accurate than the Hipparcos value; this star is very close and the residuals are larger than can be explained from the astrometry and seem to correlate with its variability. Maybe we are witnessing structural changes in the maser tied to the stellar cycle.

Absolute astrometry can be done as well, because most of the reference sources have a position determined with respect to the celestial reference frame. For all 4 targets this yields absolute astrometry to about ≈ 2 mas accuracy. This allows a direct comparison between the maser position and the Hipparcos optical position, where the main limitation is set by the extrapolation of the proper motion to a common epoch. In the cases of the blue-shifted masers these positions agree within the errors to lie within the expected radio-sphere of the stars. For the red-shifted masers, the separation can be substantial. From this we conclude that the brightest maser spots are not exclusively produced by amplified stellar emission, but that when there is a significant maser screen in front of the star, the line of sight to the star is favored.

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