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Six Years of Astrometric Monitoring of the OH maser in U Herculis

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Abstract. Using VLBI phase referencing, we have been registering the position of the most blue-shifted OH 1667 MHz maser spot with respect to nearby extragalactic reference sources for almost 7 years. The data for these 10 epochs allow us to determine the proper motion and parallax of U Her. It also yields the opportunity to compare the maser position to the position of the star, as measured by the Hipparcos satellite. Results support the theory that the compact bright spot is the amplified stellar image.

1. Introduction

Previously the distance to U Her has been determined to be 280 – 385 pc, using the empiric $P - L$ relation (Alvarez & Mennesier 1997, Chapman et al. 1994). If VLBI astrometry can be used to determine the parallax of maser bearing AGB stars, then fundamental distance measurements can become available for these objects with similar or better accuracy than possible for optically known Mira variables with Hipparcos. The Mira variable U Her is a very suitable candidate for a pilot project; besides the fact that it is relatively close, both its main line OH masers and water masers have been the target of a number of high resolution studies (e.g. Chapman et al. 1994, Yates & Cohen 1994). Moreover, it is optically bright enough to appear in the Hipparcos catalogue, with a well determined position and proper motion, although its parallax was not yet measured with any significant accuracy.

The main goal of this project was to verify that the most blue-shifted of the maser spots corresponds to a special condition; maser action in the shell initiated by the radio continuum radiation from the stellar "surface". In these circumstances the most blue-shifted spot should be a bright beacon, predicted to be fixed on the true stellar position. VLBI observations by Sivagnanam et al. (1990) provided strong evidence for this. It was shown that in U Her the dominant OH 1665 and 1667 MHz VLBI features at the most blue-shifted side of the spectrum are coincident, in accordance with such a model.

2. Observations

The observations to determine the position of U Her started on July 22 1994 on the NRAO[1] VLBA. Here we report on 10 epochs covering the period to to December 15 2000. The first 6 epochs have been presented in Van Langevelde et al., (2000; paper I) and the recent observations have been made using similar setups.

For all epochs the same extra-galactic continuum source (1636+2112) was used to calibrate phase, delay and phase rate. A second reference source was used to check the astrometry. This source, 1628+214, lies approximately 1.°6 to the east, while U Her is 2.°8 to the South of 1636+2112. In this context it could be important that, when observing with the VLBA at intermediate elevations, one generally expects the largest gradients in ionospheric path to be in the north-south direction. The data have been processed in AIPS without much special astrometric software. Although we have explored the possibilities of ionospheric corrections, we have not been able to achieve much improvement and the current results do not include any specific ionospheric calibration. In the early epochs the phase referencing always worked smoothly, in the more recent epochs we have seen the effects of the solar maximum, affecting the ionospheric stability. In fact, data from an 11th epoch was discarded, as it apparently suffered from poor ionospheric conditions.

3. Results

3.1. Relative Astrometry

In Figure 1 relative positions are displayed with respect to the quasar 1636+2112. It can be seen that the position of the other quasar is reproducible to $\Delta(\alpha,\delta) = -0.38\pm2.04, -0.98\pm0.61$ mas. This can be taken as an indication of the intrinsic accuracy of the relative astrometry. However, it can be argued, that because of the fact that the reference sources are closer to each other than to the target that this should be taken as a lower limit.

Also displayed is the measured position of the most blue-shifted maser spot. It clearly shows the proper motion and it is in fact best fitted with a model for the motion that includes a parallax. The best fit to this data is $\mu_{10} = -15.56 \pm 0.55,\ -9.65 \pm 0.61$ mas/yr, $\pi_{10} = 3.8 \pm 1.14$ mas, which is similar to the previously published result $\mu_6 = -17.05 \pm 0.85,\ -9.48 \pm 0.73$ mas/yr, $\pi_6 = 5.3 \pm 2.1$ mas. It should be mentioned that we consider the calibration of the last 4 epochs to be preliminary only.

[1]The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

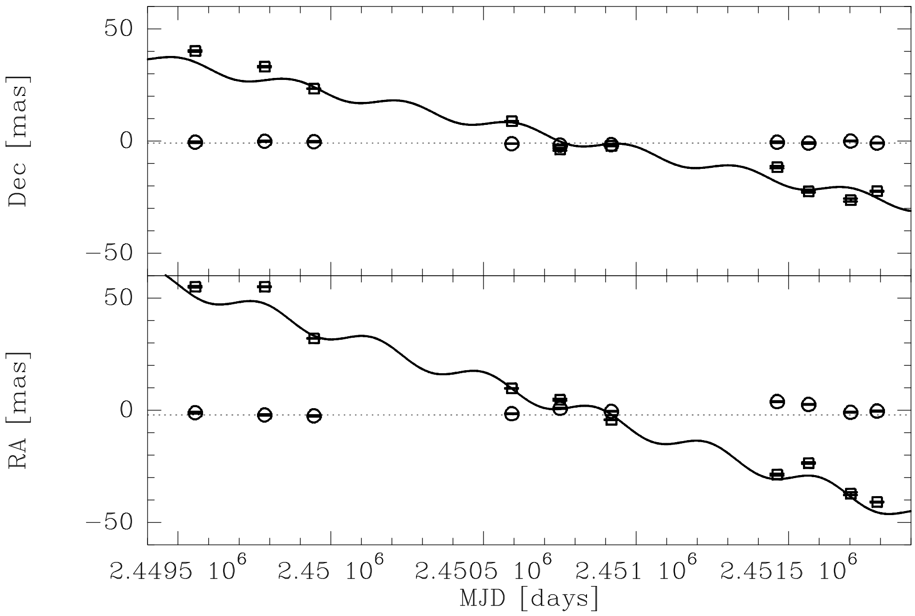

Figure 1. The residual separation between 1636+2112 and the most blue-shifted maser spot of U Her (squares) and the other calibrator (circles) and best fitting models

3.2. Absolute Astrometry

We have been able to tie the positions of the reference sources to the ICRS (paper I). This allows a direct comparison of the position of the maser spots, and in particular the most blue-shifted one, to an optical position. The Hipparcos database provides a position for U Her with unprecedented accuracy. However, the epoch of that position is 1991.25, well before our campaign. The comparison will therefore be dominated by extrapolating (backwards in time) using the measured proper motion. It is arguable how one defines the best proper motion, but here we limit ourselves to the new result determined from 10 epochs of radio data. In figure 2 we show the results of this fit. It can be seen that the optical and radio position of the most blue-shifted spot line up within the errors. The measured separation for the first epoch is now $\Delta(\alpha, \delta) = -6.0 \pm 7.9, -2.7 \pm 8.1$ mas.

3.3. Discussion

We have shown that it is possible to measure the stellar motion and the parallax by VLBI monitoring. However, it is not entirely clear whether the method is just limited by measurement errors. In other words, does the most blue-shifted maser peak directly measure the position of the star?

The fact that absolute astrometry lines up the blue spot with the optical position, is a strong confirmation that this spot is special, originating from the amplified stellar radio-sphere. However, some observational properties show the situation to be more complex. For instance, the maser characteristics of the most blue-shifted spot are not unique. In certain epochs another blue-shifted

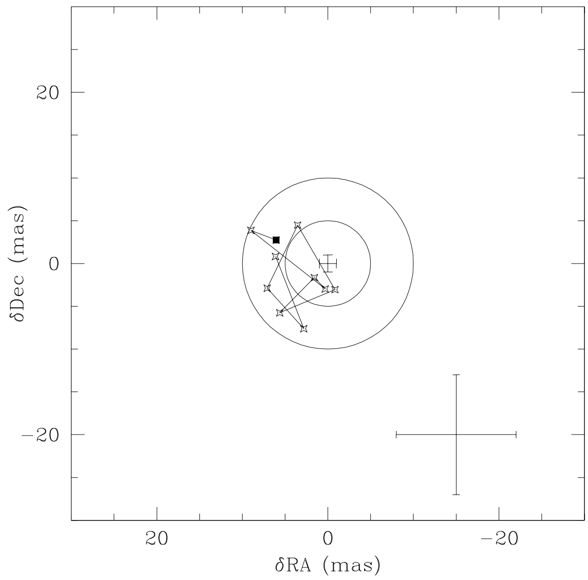

Figure 2. Residuals of the radio positions transfered to epoch 1991.25. Central is the optical position uncertainty and estimates of the optical and radio size. For the first epoch (filled square) the error bars are given in the bottom corner.

1667 MHz spot is brighter than the most-blue shifted spot. Also as much as 75% of the blue 1667 MHz spots have 1665 Mhz counterparts. Furthermore, all show the stellar motion, and it is noteworthy that the fit of the motion of the bluest spot is not perfect, possibly indicating additional motions of the maser with respect to the star. Alternatives could be that the phase referencing to U Her is substantially worse than the phase connection between the calibrator pairs or that U Her does not follow a simple trajectory, possibly because it is not a single star.

Balancing these arguments, we favour the amplified stellar image origin of the most blue-shifted spot. First, there is the coincidence of the optical and maser spot. Moreover, the candidate spot also seems to be persistent, and finally there is the absence of any red-shifted bright spots.

References

Alvarez, R., Mennesier, M.-O., 1997, A&A, 317, 761.

Chapman, J.M, Sivagnanam, P., Cohen, R.J., Le Squeren, A.M, 1994, MNRAS, 268, 475.

Sivagnanam, P., Diamond, P.J., Le Squeren, A.M., Biraud, F., 1990, A&A, 229, 171.

Van Langevelde, H.J., Spaans, M., 1993, MNRAS, 264, 597.

Van Langevelde, H.J., Vlemmings W., Diamond P.J., Baudry A., Beasley A.J., 2000 A&A357 945 (paper I)

Yates, J.A., Cohen, R.J., 1994, MNRAS, 270, 958.