The Visual Orbit of the Chromospherically-Active Binary Star HR 8170

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ABSTRACT

We present the visual orbit of the chromospherically-active spectroscopic binary star HR 8170. The orbit was determined by fitting visibility amplitude measurements made in the K (2.2 μm) photometric band using the Palomar Testbed Interferometer. Only a single instrument baseline was used, but adequate coverage in the (u, v) plane was provided by a combination of the binary's orbital motion and Earth rotation. The projected separation of the binary is found to be only ~ 2 milliarcsec, so the system is only marginally resolved compared to the 4 milliarcsec fringe spacing of the instrument. Nevertheless, the new data provide a useful and nearly-independent test of the previous spectroscopically-determined orbit.

1. Introduction

The chromospherically-active binary stars are a broad class of objects which frequently have orbital separations small enough that the stars' tidal interactions cause them to spin-lock, forcing their rotational periods to accelerate to match their orbital periods and producing strong stellar dynamos. Among these objects are the RS CVn and Algol binaries.

The angular separations of such binaries are typically of the order of milliarcseconds. Observational studies of such close binaries have largely been limited to spectroscopy and photometry of the components' combined light. These studies have produced an extensive literature of orbital parameters derived from radial velocity curves and photometric light curves. The Catalog of Chromospherically Active Binary Stars (CABS2; Strassmeier et al. 1993) summarizes the data for some 206 active binary systems.

The advent of practical long-baseline optical interferometry has made it possible to approach these close binary systems in a fundamentally new way, by measuring their visual orbits directly. Visibility data can serve as a basic "sanity check" on spectroscopically- and photometrically-derived models of these binaries, and point the way toward studies with future instruments capable of precisely measuring the full set of basic system parameters.

We observed the chromospherically-active binary HR 8170 (= CABS2 182) on 11 nights in 1999 with the Palomar Testbed Interferometer (PTI; Colavita 1999) as part of an ongoing effort to make nearly-independent tests of the orbital parameters of these systems. Although clear evidence was found for visibility evolution on the timescales expected from Earth rotation and from the 3.24 day orbital period, the data were found to be significantly inconsistent with a simple binary model consisting of stars with astrophysically plausible sizes. Below we discuss a possible explanation for this result in terms of the influence of an unseen third star.

2. Observations

The observations were conducted using standard single-beam techniques (Colavita 1998) between the nights of 21 August and 20 October 1999 (see Table 1). Briefly, the observations consisted of 35 "scans", during each of which the interferometric fringe was tracked and measured for 125-130 sec. A comparable number of scans on calibrator stars, which were chosen to have predicted angular diameters less than 1 mas, no known companions, and angular distances from the science targets of typically less than 10 deg, were interspersed with the science scans. The scans were taken over a series of nights in order to provide coverage of the orbital phase. The baseline D of the instrument was 110 m and the observing wavelength λ was 2.2 μm, producing a formal angular resolution $\lambda/D = 4.1$ mas.

3. Data Reduction and Model Fit

The raw visibility data were calibrated using the standard PTI techniques (Colavita 1998). For each scan, the measurements of the raw squared fringe visibility V^2_{raw} in 25-sec samples were averaged. The uncertainty in the V^2_{raw} value for each scan was estimated from the scatter between the 25-sec samples. A phase jitter correction was applied to compensate for the visibility loss caused by imperfect tracking of the fringe, and this was found to improve the quality of the fit.

The system visibility V^2_{sys}, which is the value of V^2_{raw} that would be measured for a pointlike source, was estimated by the weighted average of the V^2_{raw} in the calibrator scans, after correcting for the effects of the finite sizes of the calibrator stars. Dividing the V^2_{raw} measured for a science scan by the appropriate V^2_{sys} produced the final V^2 measurement for the each science scan.

The binary-star model was fit simultaneously to all 37 V^2 measurements. The chosen model treats the stars as uniform circular disks of angular diameters θ_1 and θ_2, moving in a circular orbit with angular semimajor axis a and period P. The pole of the orbit is inclined by angle i with respect to the line of sight, and the long axis of the projected orbit is oriented along position angle PA, measured east from north. The ratio of the brightness of the secondary to that of the primary is R. The parameters were adjusted to minimize the overall chi-squared using the POWELL multi-parameter minimization routine (Press et al. 1992). The sizes of the stars were chosen to be consistent with their brightness and spectral types; because the stars are small compared to the instrumental resolution, the results are insensitive to this choice. The best-fit model is plotted for comparison with the data in Figure 1. The value of χ^2 per degree of freedom is 5.9, indicating that the model does not fit the data well.

A clue to this discrepancy lies in the Hipparcos catalog, in which HR 8170 is flagged as having acceleration or higher-order terms in its astrometric solution. This is presumably the effect of a tertiary companion which had previously gone undetected because its orbital period is too long to have been seen the spectroscopic radial-velocity data. A star more than ~ 200 mas from the close binary would be beyond the fringe envelope of the interferometer, so that it would contribute incoherently to the flux and depress the measured fringe visibility from its nominal value V^2_{binary} to V^2_{triple}:

$$V^2_{triple} = \left(\frac{1+r_1}{1+r_1+r_2}\right)^2 V^2_{binary}$$

where r_1 and r_2 are the fluxes of the secondary and tertiary stars, measured in units of the flux of the primary.

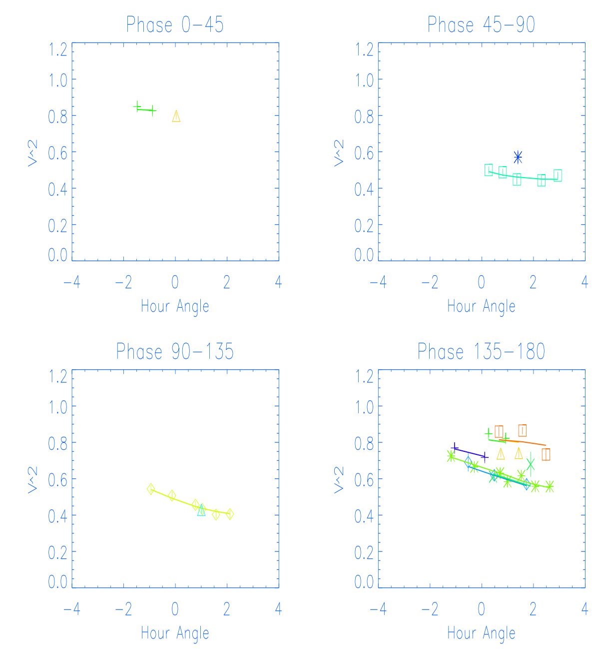

Fig. 1 Binary + Incoherent Light Model for HR 8170. Each point on the plot represents the squared visibility measured in one of the 37 scans of the fringe. Each of the plots contains data taken during a range of orbital phase, where the bins take into account the 180-deg ambiguity intrinsic in the measurement. The various plotting symbols indicate the nights on which the data were taken. The solid curves trace the model visibility.

Incorporating the third star into the model reduces the χ^2 per degree of freedom to 1.9, indicating that the modified model is doing a significantly better, but still not quite satisfactory, job of describing the data. This residual misfit could result if the tertiary were located within the outer regions of the fringe envelope, so that it contributed a small (and hour angle-dependent) term to the measured visibility.

The uncertainties on the model parameters were estimated by the range over which the total squared residuals were within 3.0 of their minimum. This procedure cannot be quite correct because the model is apparently not quite right, but the results should be good enough to allow comparison with the spectroscopic and photometric results. This comparison is presented in Table 1.

Table 1: Orbital Parameters for HR 8170

Source	a (mas)	Orb PA (deg)	i (deg)
PTI	1.5 ± 0.4	167 ± 6	81 ± 8
CABS2	1.8		77

Source	P (day)	r_1	r_2
PTI	3.2428 ± .0025	0.38 ± .22	0.35 ± .25
CABS2	3.243347		

4. Conclusions

The new PTI observations have clearly detected the orbital motion of the spectroscopic binary HR 8170. However, they also provide evidence for an additional source of light in the system. We have shown that treating this additional source as a star outside the fringe envelope of the instrument gives an improved fit to the data, and that the resulting orbital parameters are consistent with those expected from previous spectroscopic measurements. However, the large residuals in the fit suggest that even our two-plus-one model is not adequate to fully describe the system.