

HR 362: DOUBLE-LINE SPECTROSCOPIC BINARY

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Orbital elements are determined for the double-line spectroscopic binary HR 362. The elements for the primary component agree well with those determined by Christie (1933), with a revised period of 9.07530 ± 0.00001 days, and a small but significant eccentricity of 0.040 ± 0.007 . The spectral types of the two components, as indicated by the mass ratio of 1.41 ± 0.03 , are F7 V and G7 V. The system may also exhibit partial eclipses, indicating that the minimum masses of $1.16 \pm 0.04 M_{\odot}$ and $0.83 \pm 0.02 M_{\odot}$ are within a few percent of the true masses.

Key words: spectroscopic binary—orbital elements—radial velocities—stellar masses

I. Introduction

HR 362 (HD 7345, ζ Piscium B) is a sixth-magnitude star of spectral type F7 V. The stellar system in which HR 362 is a member is a very interesting one. Designated by Aitken as number 996 in the *New General Catalogue of Double Stars* (1932), this system is an optical triple whose two brighter components are both spectroscopic binaries.

ADS 996A (HR 361) is of spectral type A7 IV with $V = 5.24$. Its radial velocity varies by about 45 km s^{-1} , but no orbit has been determined. In addition, component A is an occultation double with $\Delta m = 0.1$ magnitude and a projected separation of $0''.05$ (Hoffleit and Jaschek 1982). Component B (HR 362) is located $23''$ from A at position angle 63° . Although the separation and position angle have not changed appreciably since 1832 (Aitken 1932; Jeffers, van den Bos, and Greeby 1963), their common proper motion is evidence that they are a physical pair. Component B has a visual magnitude of $V = 6.27$ and color indices $(B - V) = 0.50$ and $(U - B) = 0.05$ (Eggen 1963). About $1''$ from B is the third visual component, C. Various observers have given estimates of the visual magnitude of C of 10.3 to 12.2, the latter value being the most often quoted. Four available visual observations of BC (Aitken 1932; van den Bos 1960; Van Biesbroeck 1960, 1974) indicate an orbital period in the range of 150–200 years. B is also an occultation double with a projected separation of $0''.001$ and Δm of around 2 magnitudes. This occultation double is presumably the spectroscopic binary considered in this study. Therefore, ADS 996 contains a total of at least five stars.

Variability in the radial velocity of HR 362 was first noted by Plaskett (1919). Christie (1933) used 27 Mount Wilson Observatory radial-velocity observations along with four older observations from Dominion Astrophysical Observatory to compute a single-line spectroscopic

orbit (see Table II). In the discussion of his observations, Christie hints at seeing evidence of the secondary's spectrum. However, he was not able to obtain any spectrograms clearly showing both sets of lines.

II. Observations

The first observation of HR 362 with the Fick Observatory radial-velocity spectrometer (Beavers and Eitter 1977) in September 1980 revealed the presence of a secondary dip. The star was then scheduled to be observed regularly as part of a local program to obtain SB2 orbits for known SB1 systems. Twenty-four additional observations were obtained during the 1981 and 1982 observing seasons, all but a few of these observations showed two correlation dips. Each dip was assigned a quality A, B, or C when it was measured, based on the appearance of the dip. Previous studies with the Fick instrument have shown that the corresponding standard errors are $\sigma_A = 1.0 \text{ km s}^{-1}$, $\sigma_B = 1.8 \text{ km s}^{-1}$, and $\sigma_C = 3.5 \text{ km s}^{-1}$. The primary's (stronger) dip was most often B quality, which is typical for F-type stars when observed with the G mask usually employed at Fick. The secondary's dip was usually very weak, and all observations were assigned a C quality. The observations are listed in Table I.

III. Spectroscopic Orbit

The orbit of each component was computed separately to provide a check of the results. Each observation was weighted by $1/\sigma^2$, where for the Fick observation σ was taken to be the σ_A , σ_B , or σ_C given above. For the older observations, the assigned σ was the standard deviation of the residuals obtained in a preliminary orbit calculation. We determined that $\sigma_{\text{DAO}} = 2.0 \text{ km s}^{-1}$ and $\sigma_{\text{MTW}} = 3.6 \text{ km s}^{-1}$.

The orbit for the F7 primary was first computed with the 31 observations used by Christie (1933) together with the 25 Fick observations. This combined orbital solution for the primary is an improvement over that published by Christie. In particular, the period was determined

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very accurately to be 9.07530 ± 0.00001 days. However, the rms error of the residuals for the combined orbit was 1.83 km s^{-1} , while the Fick data taken separately had an rms error of less than 1 km s^{-1} . Thus, it was apparent that using only the Fick observations would provide a better orbital solution than that obtained using the combined data. A second orbital solution for the primary was made using only the 25 Fick observations and holding the period fixed at 9.07530 days. The resulting solution has an rms error of only 0.85 km s^{-1} with smaller standard errors for all of the elements than obtained in the combined solution. Hence, the Fick orbital solution was adopted as being final.

The orbit of the secondary was computed using 20 Fick observations. Again, the period determined in the combined solution was used and kept fixed throughout the calculations. The rms error of the secondary's orbital solution was 4.54 km s^{-1} , which is what would be expected with data of this quality.

The observations used in the orbital solution, together with their residuals, are given in Table I. One observation which falls very close to the systemic velocity, and is presumably affected by blending, was not used in the final solution. The final orbital elements are listed in Table II, where the errors listed are standard errors. In both tables, component (1) refers to the F7 V primary,

and component (2) refers to the (fainter) secondary. T refers to the time of periastron passage closest to the mean data of observation. Because of the superior quality of the data for component (1), we adopt the values of e , γ , T , and P given by its orbital solution. (The solution for the secondary orbit yielded $e = 0.10 \pm 0.20$, $\gamma = 7.44 \pm 1.04 \text{ km s}^{-1}$, $T = 2444938.4 \pm 0.3 \text{ JD}$, $\omega = 325^\circ \pm 11^\circ$). Also listed in Table II, for comparison, are the elements obtained by Christie (1933). Other than a small increase in the value of the semiamplitude (and of course $a \sin i$ and the mass function), the revised elements compare favorably with those of Christie. Although the orbital solution which we obtain by using Christie's data and our computer program has slightly different elements than those obtained by Christie, the agreement with the elements obtained by Lucy and Sweeney (1971) using the same data set is excellent. The final orbital solution and observations are plotted in Figure 1. The observations of Christie are also plotted, for comparison.

The new value for the orbital eccentricity of 0.040 ± 0.007 is particularly interesting. Lucy and Sweeney (1971) recomputed the orbit of HR 362 using the data of Christie, and found a value of $e = 0.046 \pm 0.019$. They determined that this value of e was not significant at the 5% level, and rejected the elliptical orbit in favor of a circular one. Our analysis with the Fick observations, using the same criteria set forth by Lucy and Sweeney, shows that the nonzero eccentricity is significant, and at a very high level ($p = 0.0003\%$).

IV. The HR 362 System

The new double-line spectroscopic orbit allows us to infer a great deal about this system. If the primary is of spectral type F7 V, the computed mass ratio of 1.41 ± 0.03 implies that the secondary should have a spectral type of G7 V ($\pm$ one subclass) and a Δm of around 1.6 magnitudes (Allen 1976, p. 206). This Δm is not entirely

TABLE I

FICK OBSERVATORY

RADIAL VELOCITY OBSERVATIONS OF HR 362

JD 2400000+	Phase ^a	Radial Velocity (km/s)		O-C (km/s)		Dip Quality	
		1	2	1	2	1	2
44488.8319	-51.505	42.5	-40.1	-0.4	3.4	A	C
4880.8161	-8.698	61.2	-58.2	-0.0	2.4	B	C
4884.7828	-7.135	-43.5	90.2	0.6	1.4	B	C
4885.7009	-7.236	-33.8	70.6	-0.3	2.2	A	C
4888.7127	-7.568	55.6	-53.0	0.1	-1.1	B	C
44893.7238	-6.120	-44.6	86.7	-0.9	-1.9	B	C
4896.7078	-6.449	28.1	-15.5	0.4	2.6	B	C
4897.6973	-6.558	55.8	-49.4	2.0	0.5	B	C
4899.7508	-6.784	47.3		0.0		B	
4903.7458	-5.224	-33.7	76.3	2.0	4.0	B	C
44904.7597	-5.336	-7.0	33.5	0.2	5.5	B	C
4905.6652	-5.436	22.6	-11.9	-1.2	1.4	C	C
4914.6954	-4.431	21.4	-20.0	-0.9	-8.6	B	C
4918.6890	-4.871	20.6	-18.2	-0.7	-6.0	C	C
4919.6855	-4.981	-18.4	48.8	-1.4	3.4	B	C
44919.6966	-4.982	-17.1	45.3	0.3	-0.7	B	C
4930.6508	-2.189	-41.7		-0.7		C	
4930.6647	-2.190	-41.6		-0.8		B	
4930.6793	-2.192	-40.1	72.6	0.6	-8.6	C	C
4930.6918	-2.193	-41.2		-0.7		C	
44958.5652	1.265	-26.9	58.4	0.2	0.6	B	C
5231.8214	31.375	8.6		3.8		C	*
5288.6783	37.640	63.3	-55.7	0.8	5.3	B	C
5288.8172	37.655	62.3	-63.3	-0.4	-1.7	A	C
5291.6233	37.964	-11.1	39.4	0.5	2.6	A	C

*Asterisk denotes blended observation not used in the orbital solution.

^aThe decimal portion of the tabulated value is the phase in the cycle numbered by the integer portion.

Table II

Orbital Elements of HR 362

Christie (1933)	Present Study
$P = 9.07504 \text{ days}$	$P = 9.07530 \pm 0.00001 \text{ days}$
$e = 0.033 \pm 0.018$	$e = 0.040 \pm 0.007$
$\gamma = 10.35 \text{ km/s}$	$\gamma = 10.66 \pm 0.18 \text{ km/s}$
$K = 51.07 \pm 0.90 \text{ km/s}$	$K_1 = 53.43 \pm 0.26 \text{ km/s}$
	$K_2 = 75.28 \pm 1.61 \text{ km/s}$
$T = \text{JD } 2439999.162 \pm 0.253$	$T = \text{JD } 2444947.09 \pm 0.14$
$\omega = 122^\circ \pm 7^\circ$	$\omega = 127^\circ \pm 6^\circ$
$a \sin i = 6.34 \cdot 10^6 \text{ km}$	$a_1 \sin i = (6.66 \pm 0.03) \cdot 10^6 \text{ km}$
	$a_2 \sin i = (9.35 \pm 0.20) \cdot 10^6 \text{ km}$
	$M_1 \sin^3 i = 1.16 \pm 0.04 M_\odot$
	$M_2 \sin^3 i = 0.83 \pm 0.02 M_\odot$
$f(m) = 0.124 M_\odot$	$K_2/K_1 = 1.41 \pm 0.03 = M_1/M_2$

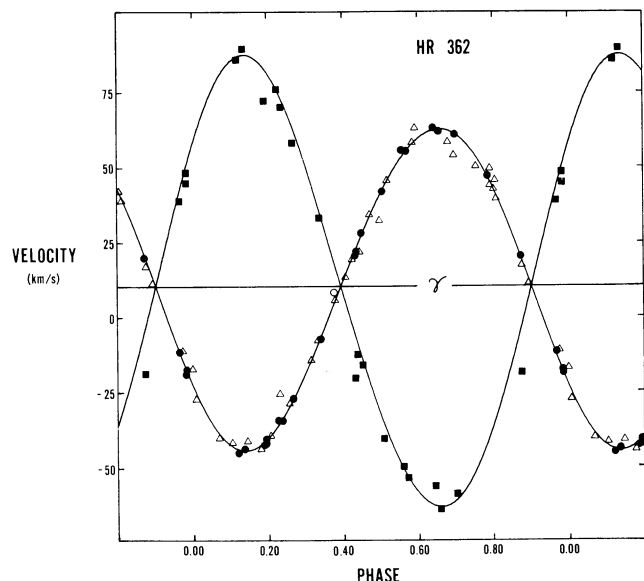


FIG. 1—Observed radial velocities and orbital solution for HR 362. Filled circles refer to component (1), filled squares refer to component (2). One blended observation is plotted as an open circle. The data of Christie (1933) are plotted for comparison using open triangles.

inconsistent with the value found from the occultation observation, and leads to values for the visual magnitudes of $V_1 = 6.5$ and $V_2 = 8.1$. The implied spectroscopic parallax is $0''.029$, nearly the same as the value of $0''.026$ from the most recent trigonometric parallax measurement of this star (Hoffleit and Jaschek 1982). Since the spectral types are not the same in this case we are at present unable to use the difference in strengths of the dip to estimate Δm for the pair.

The minimum masses given for the two components in Table II are approximately equal to the expected masses for stars of these spectral types. Allen (1976, p. 209) lists $1.21 M_\odot$ and $0.86 M_\odot$ for the masses of an F7 V and a G7 V, respectively. These masses in turn imply a value for the inclination angle i of around 80° . Since the separation of the components is only $0.11/\sin i$ AU (or about $11/\sin i$ times the sum of the expected radii), there is an appreciable probability that eclipses will occur. In fact, HR 362 is listed in the *New Catalogue of Suspected Variable Stars* (Kukarkin, et al. 1982) as being variable, with the V magnitude ranging between 6.24–6.32. If this variability is due to partial eclipses in this system, we obtain $i > 86^\circ$ and $M_1 = 1.16 M_\odot$, $M_2 = 0.83 M_\odot$ by assuming appropriate radii for these dwarfs.

V. Conclusions

It is apparent that further study of HR 362 is warranted. A careful search for eclipses in the spectroscopic binary should be undertaken. The present orbit provides the necessary parameters to calculate an ephemeris for possible eclipses, which should occur at times given by

$$JD = 2444950.69 + nP/2, \quad (n \text{ is any integer})$$

where n is odd for primary eclipses and even for secondary eclipses. The determination of the spectroscopic orbit of the A component (HR 361) would be both useful and interesting. Since the occultation observation indicates that Δm is small, it may be possible to observe both components. Finally, a careful long-term visual/interferometric study of the BC pair to determine the apparent orbit might yield a value for the mass of component C, which from its estimated Δm is probably a late-K or early-M dwarf.

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