ABSTRACT

We present the first orbital elements for the massive close binary HD 115071, a double-lined spectroscopic binary in a circular orbit with a period of $2.73135 \pm 0.00003$ days. The orbital semiamplitudes indicate a mass ratio of $M_2/M_1 = 0.58 \pm 0.02$, and yet the stars have similar luminosities. We used a Doppler tomography algorithm to reconstruct the individual component optical spectra, and we applied well-known criteria to arrive at classifications of O9.5 V and B0.2 III for the primary and secondary, respectively. We present models of the Hipparcos light curve of the ellipsoidal variations caused by the tidal distortion of the secondary, and the best-fit model for a Roche-filling secondary occurs for an inclination of $i = 48.7 \pm 2.1$. The resulting masses are $11.6 \pm 1.1$ and $6.7 \pm 0.7 \, M_\odot$ for the primary and secondary, respectively, so both stars are very overluminous for their mass. The system is one of only a few known semidetached, Algol-type binaries that contain O stars. We suggest that the binary has recently emerged from extensive mass transfer (possibly through a delayed contact and common-envelope process).

Subject headings: binaries: spectroscopic — stars: early-type — stars: evolution — stars: individual (HD 115071)

1. INTRODUCTION

The hot, massive star HD 115071 (V961 Cen, LS 2998, HIP 64737) is found in the sky close to the open cluster Stock 16 (Turner 1985) and is classified as O9.5 V by Houk & Cowley (1975) and B0.5 Vn by Garrison, Hiltner, & Schild (1977). The star is not a known visual binary (Mason et al. 1998), but early measurements by spectroscopists indicated it is radial velocity variable and a probable spectroscopic binary (Cruz-González et al. 1974; Conti, Leep, & Lorre 1977). The proof of its binary nature came relatively recently in studies by Penny (1996) and Howarth et al. (1997). Both papers presented a cross-correlation analysis of a single, high-dispersion, UV spectrum made with the International Ultraviolet Explorer Satellite (IUE) that demonstrated that the system is in fact a double-lined binary. Stickland & Lloyd (2001) measured the radial velocities of the components in this spectrum and proposed an orbital period of $2.73126$ days based upon a light curve constructed from Hipparcos photometry. Lloyd & Stickland (2001) present a model of the light curve, and they argue that the system has evolved through Case A mass transfer (commencing during core H burning of the donor star).

The details and outcomes of Roche lobe overflow (RLOF) in massive binaries are still subjects of considerable debate (Wellstein, Langer, & Braun 2001), and thus the orbital and physical parameters of a system such as HD 115071 are of great interest. Here we present the first double-lined orbital solution for the binary (§ 3) based upon new high-quality optical spectra. We apply a version of the Doppler tomography algorithm (which we have used to good effect with UV spectra in prior papers in this series) to reconstruct the individual spectra of both components, from which we determine the spectral classifications, projected rotational velocities, and flux ratio (§ 4). We also present a light-curve analysis constrained by the spectroscopic results that allows us to estimate the stellar masses (§ 5). These masses are much lower than expected, and we discuss the evolutionary implications in § 6.

2. OBSERVATIONS AND REDUCTIONS

Our spectra were obtained in two observing runs at different sites. The first set was obtained with the 2.15 m telescope of the Complejo Astronomico El Leoncito (CASLEO) and REOSC echelle spectrograph (on loan from the Institut d’Astrophysique, Universite de Liege, Belgium) during the period 1997 March 19–28. The REOSC spectrograph uses an echelle grating with 70 grooves mm$^{-1}$ and blazed at 226434 Å with a cross-disperser grating of 400 grooves
made the fit of the composite profiles using spectral tem-

IUE 

through one cross-correlation measurement. Second, we 

feature separately rather than fitting the entire spectrum 

our techniques accordingly. First, we fitted each absorption 

IUE 

cal spectra we consider here have many fewer stellar lines 

spectrum with a narrow-lined reference spectrum. The opti-

spectra (Penny, Gies, & Bagnuolo 1997) involves fitting 

This arrangement produced single-order spectra that cov-

bling the target spectrum by a correction spectrum formed 

amplitude irregularities related to the fitting of the echelle 

linked together with the task SCOMBINE. Small-

task CONTINUUM). Finally, the individual orders were 

wavelength-calibrated using the task DOECSLIT, and the 

masses of 660 s duration that were later co-added in software 

bias, flat-field, dark, and Th-Ar comparison images were 

the better-exposed portions of the spectrum). Numerous 

features, flat-field, dark, and Th-Ar comparison images were 

the particular night's 

night. The correction spectrum was a smoothed version of 

average representation of this star's stellar spectrum. The 

ing the target spectrum by a correction spectrum formed 

were evident in the continuum, and the same 

pattern was seen in all spectra made on a given 

were able to remove most of the pattern by divid-

the target spectrum by a correction spectrum formed 

from spectra of B star τ Sco, which was also observed each 

The correction spectrum was a smoothed version of the 

particular night's τ Sco spectrum divided by a global 

average representation of this star's stellar spectrum. The 

spectra from each run were then collected and transformed 

onto their respective heliocentric wavelength grids.

3. RADIAL VELOCITIES AND ORBITAL ELEMENTS

Our procedure for measuring radial velocities in IUE 

effects (Penny, Gies, & Bagnuolo 1997) involves fitting 

Gaussionians to the cross-correlation functions of the target 

spectrum with a narrow-lined reference spectrum. The opti-

cal spectra we consider here have many fewer stellar lines 

and much better S/N than the IUE spectra, so we revised 

our techniques accordingly. First, we fitted each absorption 

feature separately rather than fitting the entire spectrum 

through one cross-correlation measurement. Second, we 

made the fit of the composite profiles using spectral tem-

plates rather than Gaussian functions (since the lines have 

shapes dominated by linear Stark broadening or rotational 

broadening and since some lines may contain weak blends). 

The templates were formed from spectra we obtained dur-

ing each run of the star, HD 57682 (O9 IV; Walborn 1972).

This star is a reasonable match in classification to both 

components in HD 115071 (§ 4) but has narrower lines 

(υ sin i = 33 km s⁻¹; Penny 1996). The radial velocity of this 

star was measured by parabolic fitting of the line cores for 

lines in the list of Bolton & Rogers (1978), and we found an 

average radial velocity of 25.0 ± 0.5 and 26.0 ± 1.1 km s⁻¹ 

from the CASLEO and MSO spectra, respectively. The 

averaged template spectra from each run were shifted by 

these values to place them in the rest frame. Next, we artifi-

cially broadened each template spectrum by convolution 

with a rotational broadening function to produce profiles 

that matched the spectral components of HD 115071 in the 

best-separated quadrature spectra. We also used these re-

solved profiles to estimate the line depth ratio between the 

components. Once these fitting parameters were set, we 

determined the radial velocities of each component for a 

given line by a least-squares fit of the observed profile with 

the co-addition of the two template profiles shifted in wave-

length to obtain the best match. This approach provided 

good fits of the observed profiles for all but two cases (HJD 

2,450,529.792 and HJD 2,450,531.755) where the line depth 

ratio appeared to be reversed.

We used this technique to measure radial velocities for the 

strongest lines in the spectrum, specifically H i λλ3835, 

3889, 3970, 4101, 4340, and 4861; He i λλ3819, 4009, 4026, 

4121, 4143, 4387, 4471, 4921, and 5015; He ii λλ4686; and 

Si iv λλ4089. There was no evidence of systematic line-to-line 

differences in the radial velocity measurements, and so no 

line-specific corrections were applied. The radial velocities 

from all the available lines were averaged together after 

deletion of any very discrepant measurements. Finally, we 

made small adjustments to these averages based on 

measurements of the strong interstellar Ca ii λλ3933 and 

3968 lines. An interstellar spectrum was formed by extract-

ing the mean spectrum in the immediate vicinity of each 

interstellar absorption line. (We made Gaussian fits of the 

interstellar Ca ii profiles in the extracted spectra, and we 

found that the radial velocity was −17.0 ± 0.2 and 

−16.0 ± 0.2 km s⁻¹ for the mean CASLEO and MSO spec-

a, respectively.) We then cross-correlated this spectrum 

with each individual spectrum to measure any small devia-

tions in our wavelength calibration (generally less than 3 km 

s⁻¹), and these small corrections were applied to the mean 

velocities. Table 1 lists the heliocentric dates of mid-obser-

vation, orbital phase, and, for each component, the mean 

radial velocity, the standard deviation of the mean, the 

observed minus calculated residual from the orbital fit, and 

the number of lines used in the mean. Table 1 also gives the 

radial velocities from the single IUE spectrum measured by 

Stickland & Lloyd (2001) (adjusted for the interstellar 

medium velocity on the MSO system).

Stickland & Lloyd (2001) and Lloyd & Stickland (2001) 

found that the Hipparcos light curve was best-fitted with a 

double sine, ellipsoidal variation for an orbital period 
P = 2.73126 ± 0.00009 days. We found that this period also 

agreed reasonably well with our radial velocity data. We 

used the nonlinear, least-squares fitting program of Morbey 

& Brosterhus (1974) to solve for the period and other orbital 

elements for the primary (the more luminous and massive

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4 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
star) and secondary components separately, and this yielded period estimates of 2.73149 ± 0.00007 and 2.73138 ± 0.00015 days, respectively. We made one additional calculation of the period by dividing the difference between the best-fit time of the Hipparcos photometry maximum and our spectroscopically determined time of quadrature by the closest integral number of cycles; this led to a period of 2.73130 ± 0.00004 days. We adopted the error-weighted mean of these three estimates for our working value of the period, $P = 2.73135 ± 0.00003$ days.

We fixed this period and then fitted for the remaining orbital elements independently for both components. The fitted epoch of primary maximum velocity, $T_0$, was the same within errors for both solutions, and so we applied the mean value to fits of both components. Eccentric solutions produced estimates of eccentricity consistent with a value of zero, and our final solutions in Table 2 assume circular motion. The observed and calculated radial velocity curves appear in Figure 1. The only major discrepancies occur in the IUE measurements (not used in the solution), both of which are ≈38 km s$^{-1}$ above the predicted curve. Note that in the case of the primary, the IUE velocity falls well above the maximum for the entire curve, so the mismatch cannot be due to an incorrect orbital phase, for example. The systematic difference may be related to line formation at different heights in an expanding atmosphere or orbital motion about a distant, unseen, tertiary star.

### 4. TOMOGRAPHIC RECONSTRUCTION

We used the Doppler tomography algorithm described by Bagnuolo et al. (1994) to reconstruct the individual primary

![Image of radial velocity measurements](image-url)
and secondary spectra independently from the CASLEO and MSO spectra. We took the radial velocity shifts for each component from the orbital solutions in Table 2, then the reconstruction was run for 50 iterations with a gain of 0.8 (the results are insensitive to both parameters). The reconstructed spectra are plotted in Figure 2 in a format similar to that used in the spectral atlas of Walborn & Fitzpatrick (1990). The reconstructions from the MSO spectra are shown just above those from the CASLEO spectra (in the short-wavelength portion of Fig. 2), and there is good agreement between these two sets of spectra.

We compared the reconstructed spectra with the spectrum standards in the atlas of Walborn & Fitzpatrick (1990) to determine the spectral classifications of the components. The strengths of the He I λ4026, 4143, and 4387 lines relative to those of He II λ4200 and 4541 are all consistent with a spectral type of O9.5 for the primary. The ratio of the Si IV λ4088 and 4116 lines to the nearby He I λ4121 and 4143 features indicates a main-sequence class, as does the relatively strong He II λ4686 to He I λ4713 ratio. Thus, we classify the primary as type O9.5 V, and we compare its spectrum in Figure 2 to that of HD 93027, which is given as the standard of this class in Walborn & Fitzpatrick (1990).

The secondary, on the other hand, has features indicating a cooler temperature and later type. The ratio of Si III λ4552 to Si IV λ4088 has a good match in the interpolated type B0.2 introduced by Walborn & Fitzpatrick (1990). The relative strength of the Si IV λ4088 and 4116 lines compared to the neighboring He I λ4121 and 4143 features clearly leads to a luminosity class III. Figure 2 illustrates the good agreement between the spectrum of the secondary and that of HD 108639, which Walborn & Fitzpatrick (1990) use as a standard for type B0.2 III. The C III λ4070 and 4650 blends appear to be somewhat weaker in the secondary’s spectrum than in the standard spectrum (evidence, perhaps, of CNO-processed gas in the secondary’s photosphere).

The two spectral standards, HD 93027 and HD 108639, provided us with the means to estimate the visual flux ratio, \( r = F_2/F_1 \), by matching the line depths in the reconstructed spectra with those in the standards. This was done by aligning the reconstructed and standard spectra, adjusting for differences in the placement of the continuum, Gaussian smoothing of the spectra to eliminate differences in projected rotational velocity and instrumental broadening, and then finding a best-fit line ratio that allocates a proportion of flux to each component to best match the line depths. We found \( r = 1.04 \pm 0.06 \) and \( 1.08 \pm 0.08 \) for the MSO and CASLEO reconstructions, respectively. Finally, we used the profiles in the reconstructed spectra to estimate the projected rotational velocities of the components. We focused on the Si IV λ4088 profile for this purpose since it represents the strongest metallic line (intrinsically narrow) in the range covered by the MSO spectra. Our procedure involved calculating a grid of rotational broadening functions for a linear limb-darkening law (Wade & Rucinski 1985; Gray 1992) and then convolving an observed narrow-lined spectrum with these broadening functions. We compared the spectral reconstructions from the MSO spectra with broadened versions of MSO spectra of the narrow-lined stars HD 53682 (O9 IV) and \( \tau \) Sco (B0.2 V). The best-

![Fig. 2.—Comparison of the reconstructed MSO spectra (above) and CASLEO spectra (below) of the primary and the secondary with spectra of the same classifications as Walborn & Fitzpatrick (1990). All the spectra were Gaussian smoothed to a nominal resolution of 1.2 Å FWHM for consistent line broadening.](image)
fitting profile matches were made with \( V \sin i = 101 \pm 10 \) and \( 132 \pm 15 \text{ km s}^{-1} \) for the primary and secondary, respectively. These agree within errors with estimates from the IUE observation (Penny 1996; Howarth et al. 1997; Lloyd & Stickland 2001).

5. LIGHT-CURVE ANALYSIS AND MASSES

Lloyd & Stickland (2001) presented an analysis of the Hipparcos light curve (Perryman 1997), and here we update their work by restricting a number of the fitting parameters based upon the new spectroscopic results. We used the light-curve synthesis code GENSYN (Mochnacki & Doughty 1972) to produce model \( V \)-band differential light curves (almost identical to differential Hipparcos Hp magnitudes for hot stars). The orbital parameters were taken from the spectroscopic solution, and the physical parameters were estimated from the spectral classifications of the stars. We first estimated the stellar temperature and gravity according to the spectral classification calibration of Howarth & Prinja (1989) for the primary (\( T_{\text{eff}} = 32 \text{ kK}, \log g_1 = 3.9 \)), and for the secondary we used data for comparable stars in the compilation of Underhill & Doazan (1982) (\( T_{\text{eff}} = 29 \text{ kK}, \log g_2 = 3.6 \)). We then determined the physical fluxes and limb-darkening coefficients from tables in Kurucz (1994) and Wade & Rucinski (1985), respectively. We also used the Kurucz flux models to transform our observed flux ratio based upon the relative line depths into a \( V \)-band flux ratio (Penny et al. 1997). The MSO spectra are centered at 4009 A, and the transformation yields a \( V \)-band flux ratio, \( F_2/F_1 = 1.05 \pm 0.06 \). The comparison of line depths in the CASLEO spectra was made over the available range in the standard spectrum from Walborn & Fitzpatrick (1990) (centered at 4350 A), and the resulting \( V \)-band flux ratio is \( F_2/F_1 = 1.09 \pm 0.06 \). We used the average value, \( F_2/F_1 = 1.07 \pm 0.06 \), in the light-curve analysis. The theoretical and observed flux ratios together yield an approximate estimate of the ratio of stellar radii, \( R_2/R_1 = 1.12 \pm 0.03 \). Each trial run of GENSYN was set by two independent parameters: the system inclination \( i \), and the secondary’s radius relative to the critical Roche-filling case (with the primary radius set so that the orbital average flux ratio matched the observed flux ratio).

The observed light curve (Fig. 3) is a double sine wave caused by tidal distortion in the stars. Since the stars have similar radii but the secondary has a much lower mass (\( \geq 3 \)), the secondary must be much closer to filling its critical Roche radius so that the tidal generation of the light curve is due mainly to the distortion of the secondary. The amplitude of the photometric variation is proportional to the degree of tidal distortion (how close the secondary comes to filling its Roche volume) and to the sine of the inclination (maximal effect for \( i = 90^\circ \)). Our first fit of the light curve assumed that the secondary completely fills its Roche volume, so this solution corresponds to the case of minimum inclination (and maximum masses). The best fit for this semidetached configuration is made with an inclination \( i = 48.7 \pm 2.1 \), and this fit is shown as the solid line in Figure 3. The error in the inclination results from two sources: the variation in the \( \chi^2 \) residuals of the fit with parameter \( i \), and the change in the solution introduced by the uncertainty in the flux ratio. The rms of the residuals from the best fit is 0.019 mag, which is approximately 1.7 times larger than the errors quoted in the Hipparcos catalog, and so some other kind of photometric variation may exist that is unrelated to orbital phase.

Note that it is possible to obtain fits with a lower inclination if the flux ratio constraint is abandoned. For example, we found that if we assumed a contact configuration in which both stars fill their Roche volumes, then we could make a satisfactory fit of the light curve with \( i = 38^\circ \). However, we rule out this model because it predicts a flux ratio, \( F_2/F_1 = 0.52 \), that is far below the limits established from the spectra of the components.

Models with a smaller secondary and less tidal distortion require a higher inclination to match the observations (yielding lower masses), but these solutions are less satisfactory for two reasons. First, higher inclination solutions generally yield light curves with less ellipsoidal variation but some evidence of eclipses. We show one example in Figure 3 for an inclination \( i = 60^\circ \) and a secondary volume radius of \( R_2/R_1 = 5.6 \) (\( \approx 90\% \) of the critical Roche radius). Eclipses as subtle as those shown in Figure 3 are probably not ruled out by the Hipparcos photometry, but models with \( i > 62^\circ \) show eclipses that are clearly inconsistent with the Hipparcos light curve. Second, the projected rotational velocities predicted by underfilling models with synchronous rotation are much smaller than the observed values. All the known binaries containing O stars with periods this short have circular orbits (Mason et al. 1998), and we expect that such close systems have attained synchronous rotation as well (Claret & Cunha 1997). The predicted projected rotational velocities are \( V \sin i = 92 \text{ and } 109 \text{ km s}^{-1} \) for the primary and secondary, respectively, in the Roche-filling model, in agreement within errors with the observed values (\( \geq 3 \)). However, the match is worse in higher inclination models (\( V \sin i = 81 \text{ and } 94 \text{ km s}^{-1} \), respectively, for the \( i = 60^\circ \) model illustrated in Fig. 3). Thus, we prefer the secondary Roche-filling model, and we list in Table 3 the corresponding stellar parameters. The system absolute magnitude in this model is \( M_V = -4.57 \), and for \( V = 7.94 \) and \( E(B-V) = 0.50 \) (Turner 1985) we estimate a distance of \( 1.5 \pm 0.2 \text{ kpc} \) (smaller than but comparable to the distance of 1.9 kpc for the cluster Stock 16; Turner 1985).

![Fig. 3.—Hipparcos light curve plotted against spectroscopic orbital phase. The solid line shows the predicted curve for a secondary Roche-filling model with \( i = 48^\circ \), while the dashed line represents the prediction for an underfilling model with \( i = 60^\circ \).](image-url)
TABLE 3

| Property                                    | Primary | Secondary |
|---------------------------------------------|---------|-----------|
| Spectral classification                     | O9.5 V  | B0.2 III  |
| Relative flux $F/F_0$ (5470 Å)              | 1.0     | 1.07 ± 0.06 |
| $V \sin i$ (km s$^{-1}$)                    | 101 ± 10| 132 ± 15  |
| $T_{\text{eff}}$ (K)                        | 32 ± 2  | 29 ± 1.5  |
| $M/M_\odot$                                 | 11.6 ± 1.1 | 6.7 ± 0.7 |
| $R/R_\odot$                                 | 6.5 ± 0.2 | 7.2 ± 0.2 |
| log g                                       | 3.88 ± 0.01 | 3.55 ± 0.01 |
| log $L/L_\odot$                             | 4.60 ± 0.14 | 4.52 ± 0.12 |

6. DISCUSSION

The first striking result from our analysis is the very low mass we find for both components. The stars have temperatures and luminosities that are associated with masses of 18 and 15 $M_\odot$ for the primary and secondary, respectively, in the single-star evolutionary tracks calculated by Schaller et al. (1992). (These estimates would be slightly reduced using evolutionary models that include rotation; Heger & Langer 2000; Meynet & Maeder 2000.) The secondary, in particular, has a luminosity characteristic of a star more than twice as massive as we find (Table 3).

The second remarkable fact is that the secondary star has a spectral classification indicating it has evolved away from the main sequence. Thus, HD 115071 presents the classical “Algol paradox” that the lower mass component is the more evolved one, and we suggest the same solution of the paradox holds here as well, i.e., that the evolved component was originally the more massive object but suffered significant mass transfer to its neighbor.

There are only a small number of O stars that are known to be members of interacting binaries, and we compare in Table 4 the properties of the components in HD 115071 with those of the four other known semidetached binaries that contain O-type stars (Hilditch & Bell 1987; Harries & Hilditch 1998). We excluded from this list contact or over-contact systems and those binaries in which both components are evolved (Vanbeveren, van Rensbergen, & de Loore 1998). All the systems in Table 4 share a number of common properties: the mass donor appears as an evolved star, the donor star is over-luminous for its mass, the donor fills its Roche volume, and the mass gainer is a late O-type, main-sequence star. It is remarkable that all the donor stars have comparable luminosity, log $L/L_\odot$ ≈ 4.5, despite their wide range in mass and radius. Evolutionary models generally predict that the post-RLOF luminosity of the donor is comparable to its zero-age main-sequence (ZAMS) luminosity (Vanbeveren et al. 1998; Wellstein et al. 2001), and so these donors were probably born as B0 V stars with masses in the range 14–20 $M_\odot$. Since the donors were originally the more massive component, the gainers were probably also B-type stars that were promoted to their current O-type status through mass transfer. It is also curious that no semidetached systems are known with primaries earlier than type O8 V. Either this stage is extremely rapid in more massive systems or the donor stars take on a different appearance than they do in Algol-type systems (perhaps as an O star + Wolf-Rayet star binary; Vanbeveren et al. 1998).

Evolutionary models give us some guidance about the initial masses in HD 115071. de Loore & Vanbeveren (1994) give a relationship between the final, post-RLOF mass and the initial ZAMS mass, and this yields an estimate of 14.8 $M_\odot$ for the initial mass of the donor star. If we further assume that 50% of the donor’s mass loss was accreted by the gainer and the rest lost from the system (Meurs & van den Heuvel 1989; de Loore & Vanbeveren 1994), then the original total mass was 22.4 $M_\odot$, and the original gainer mass was 7.6 $M_\odot$. Thus, the system probably began with a relatively low mass ratio, $M_2/M_1$ ≈ 0.5.

The theoretical models of binary evolution by Wellstein et al. (2001) offer some guidance in the interpretation of our results. Wellstein et al. (2001) describe the evolution of several very close systems that begin RLOF during core H burning (Case A). Their models suggest that a mass reversal similar to what we find in HD 115071 can occur in Case A, but the resulting systems generally have a much wider orbit and more extreme mass ratio. Another possibility is that the system began RLOF after completion of core H burning (Case B). The initial period would have been much larger, but the system then shrunk to its current dimensions during a common envelope phase in which the donor’s envelope would have been ejected from the system. This would explain the current mass and luminosity of the donor star, but it does not account for the huge over-luminosity of the contemporary primary star, which is the most over-luminous star of any of the gainers in Table 4. Wellstein et al. (2001) point out one other hybrid scheme that they call “delayed contact,” in which mass transfer begins conservatively until the donor develops a convective envelope and the binary enters the common-envelope stage. This scenario would explain the observed low mass of the donor and the short orbital period, and the over-luminosity of the gainer would result from compression and/or mixing related to mass accretion.

The best fit of the light curve suggests that the secondary donor star is Roche-filling, and so the system may still be

TABLE 4

| Name               | $P$ (days) | Primary Type | Secondary Type | $M_P$ ($M_\odot$) | $M_S$ ($M_\odot$) | log $L_P/L_\odot$ | log $L_S/L_\odot$ | Reference |
|--------------------|------------|--------------|----------------|-------------------|-------------------|-------------------|-------------------|-----------|
| HD 115071 = V961 Cen       | 2.73       | O9.5 V       | B0.2 III       | 11.6 ± 1.1        | 6.7 ± 0.7         | 4.60 ± 0.14       | 4.52 ± 0.12       | 1         |
| HD 209481 = LZ Cep         | 3.07       | O8.5         | O9.5           | 15.1 ± 0.4        | 6.3 ± 0.2         | 4.90 ± 0.03       | 4.65 ± 0.03       | 2         |
| BD +66°1521 = XZ Cep     | 5.10       | O9.5 V       | B1 III         | 15.8 ± 0.4        | 6.4 ± 0.3         | 4.58 ± 0.04       | 4.48 ± 0.03       | 3         |
| HD 106871 = AB Cru       | 3.41       | O8 V         | B0.5           | 19.8 ± 1.0        | 7.0 ± 0.7         | 5.21 ± 0.03       | 4.58 ± 0.03       | 4         |
| HD 190967 = V448 Cyg    | 6.52       | O9.5 V       | B1 II-1b       | 25.2 ± 0.7        | 14.0 ± 0.7        | 4.54 ± 0.04       | 4.66 ± 0.06       | 3         |

References:—(1) This paper; (2) Harries, Hilditch, & Hill (1998); (3) Harries, Hilditch, & Hill (1997); (4) Lorenz, Mayer, & Drechsel (1994).
experiencing active mass transfer. Observations of any Hα emission (Thaller 1997) or IR excess (Gehrz et al. 1995) would provide valuable clues about the mass loss and/or mass transfer processes that might be occurring presently in this exceptional binary system.

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