THE SPECTROSCOPIC ORBIT OF THE EVOLVED BINARY HD 197770

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ABSTRACT

We have used spectra taken between 1992 and 1997 to derive the spectroscopic orbit of the eclipsing double-lined spectroscopic binary HD 197770. This binary has a period of 99.69 ± 0.02 days and K amplitudes of 31.2 ± 0.8 and 47.1 ± 0.4 km s⁻¹ for components A and B, respectively. The $m \sin^3 i$ values for A and B are 2.9 and 1.9, respectively, and are close to the actual masses because of the eclipsing nature of this binary. Both components of HD 197770 have spectral types near B2 III. This means that both components are undermassive by about a factor of 5 and, thus, are evolved stars. Additional evidence of the evolved nature of HD 197770 is found in 25, 60, and 100 μm IRAS images of HD 197770. These images show two apparent shells centered on HD 197770, a bright 60 μm shell with a 28' diameter and a larger (0.8 diameter) bubble-like feature. At least one of the components of HD 197770 is likely to be a post-asymptotic giant branch star.

Key words: binaries: spectroscopic — stars: individual (HD 197770)

1. INTRODUCTION

Interest in the star HD 197770 (HR 7940; $\alpha = 20^h 43^m 13^s 52, \delta = +57^\circ 6' 50'' 9$ [J2000.0]) increased greatly with the discovery that its line of sight has a polarization feature coincident with the 2175 Å extinction bump (Clayton et al. 1992; Anderson et al. 1996). Out of the 30 sight lines with UV spectropolarimetry, such a polarization bump has only been seen along one other sight line (Wolszczan 1997). There have been recent photometric observations of HD 197770 (Clayton 1996). Recent photometric observations have shown that HD 197770 is an eclipsing binary (Jerzykiewicz 1993; Clayton 1996). We obtained spectra of HD 197770 between 1992 and 1997 in order to determine the spectroscopic orbit of HD 197770. The spectroscopic orbit, coupled with the eclipsing nature of the binary, allowed us to determine the masses of the binary components.

2. OBSERVATIONS

In 1992 June and October, observations of HD 197770 were acquired at the Kitt Peak National Observatory (KPNO) 0.9 m coudé feed telescope using the coudé spectrograph. The June observation was obtained using an echelle grating and a cross-disperser grism to give disjoint orders between 3870 and 4085 Å with a resolution of 120,000. It was reduced using IRAF. The October observations also used an echelle grating and a cross-disperser grism giving orders that covered 5580–7160 Å (HJD 2448901.6) or 3900–490 Å (HJD 2448902.6 and 2448903.6) at a resolution of 80,000. Between 1996 September and 1997 October, 17 observations of HD 197770 were taken at the 1 m Ritter Observatory telescope using a fiber-fed echelle spectrograph (Gordon & Mulliss 1997). These observations cover nine disjoint 70 Å orders between 5200 and 6600 Å at a resolution of 25,000. The KPNO and Ritter observations were reduced using a package written to reduce Ritter observations. Since the KPNO observations were not acquired with a fiber-fed echelle, the orders were extracted using a direct-sum method instead of the profile-weighted method used for the Ritter observations. Details of the reduction package can be found in Gordon & Mulliss (1997). The UT date and time, exposure length, and Heliocentric Julian Date for the observations are listed in columns (1)–(4) of Table 1.

3. ANALYSIS

From inspection of the spectra, we found that the lines of the two components of HD 197770 were never fully separated. Figure 1 displays the C II 6578 Å line for typical KPNO and Ritter spectra. The separation of the components in the two spectra are similar, and the double-lined nature of this binary is clearly seen, especially in the KPNO spectrum. The lines are clearly resolved in the KPNO spectrum, but not in the Ritter spectrum. We identified the broad line as component A of this binary and the narrow line as component B. Since the lines were not fully separated, blending effects are always present. Therefore, we used TODECOR, the two-dimensional cross-correlation algorithm presented in Zucker & Mazeh (1994), to measure the radial velocities. This algorithm takes model spectra of the two components as input and finds the optimal radial velocities of the two components and their luminosity ratio.

As results of TODECOR are sensitive to the assumed model spectra, we constrained the model atmosphere parameters as follows: The effective temperature ($T_{\text{eff}}$) for HD 197770, derived using a reddening-free photometric index, is $21,000 \pm 3000$ K (Gulati, Malagnini, & Morossi 1989). We checked this $T_{\text{eff}}$ by comparing the ultraviolet...
through $V$ band dereddened spectral energy distribution (SED) of HD 197770 with PHOENIX LTE model SEDs (Aufdenberg et al. 1998). The SED of HD 197770 was taken from International Ultraviolet Explorer and $UBV$ (Harmanec, Horn, & Juza 1994) observations and dereddened assuming $R_V = 3.1$ and $E(B-V) = 0.58$ (Cardelli, Clayton, & Mathis 1989). The unreddened SED was well fitted by a model with $T_{\text{eff}} = 21,000$ K and $\log g = 4.0$. In addition, since the eclipse depths are similar, the $T_{\text{eff}}$ of both stars must be close to 21,000 K (Clayton 1996). We used a PHOENIX LTE model SED with $T_{\text{eff}} = 21,000$ K and $\log g = 4.0$ for both stars for the TODCOR algorithm. The $v \sin i$ values were determined by iteratively running TODCOR and adjusting the $v \sin i$ values until the composite model spectrum matched, by inspection, the C II $\lambda \lambda 6578, 6582$ doublet in the HJD 2,448,901.6 spectrum ($R \sim 80,000$). The strength of the model spectrum C II lines were reduced by 40% to match the observed strengths of the lines. This can be traced to the fact that the model spectrum had solar abundances and that most B-type stars are underabundant compared with the Sun (Snow & Witt 1996 and references therein). The HJD 2,448,901.6 spectrum and the best-fitting composite model spectrum are shown in Figure 2. The best-fit $v \sin i$ values were 55 and 15 km s$^{-1}$ for components A and B, respectively. The TODCOR-determined luminosity ratio ($L_A/L_B$) was $\sim 2$.

Using TODCOR, we were able to measure the radial velocity of the narrow, but not the broad, component in all of the spectra. We were able to accurately measure the broad component in only the 1992 October KPNO spectra. The 1992 June KPNO spectrum yielded radial velocities for both components, but neither was measured with great accuracy because of the low signal-to-noise ratio (S/N). The resolution and S/N of the Ritter spectra were not high enough to allow us to measure the velocity of the broad component (see Fig. 1). As a result, the orbital motion of the narrow component was well sampled, but the orbital

### Table 1: Observations and Radial Velocities

| UT Date | UT Time | Exposure Time | HJD (2,400,000+) | Phase | A (km s$^{-1}$) | B (km s$^{-1}$) |
|---------|---------|---------------|-----------------|-------|----------------|----------------|
| 1992 Jun 7 | 0710 | 4018 | 48,780.798 | 0.957 | $-0.4$ | $-7.3$ |
| 1992 Oct 6 | 0230 | 5400 | 48,901.067 | 0.168 | $-41.2$ | $-1.5$ |
| 1992 Oct 7 | 0305 | 14400 | 48,902.630 | 0.179 | $-39.3$ | $1.5$ |
| 1992 Oct 9 | 0242 | 5400 | 48,904.614 | 0.199 | $-43.1$ | $-0.5$ |
| 1996 Sep 19 | 0403 | 3600 | 50,345.671 | 0.654 | ... | ... |
| 1996 Sep 20 | 0310 | 3600 | 50,346.634 | 0.773 | ... | ... |
| 1996 Sep 25 | 0433 | 3600 | 50,351.634 | 0.804 | ... | ... |
| 1996 Oct 5 | 0138 | 3600 | 50,357.570 | 0.804 | ... | ... |
| 1996 Oct 4 | 0312 | 3600 | 50,360.636 | 0.804 | ... | ... |
| 1996 Oct 29 | 0140 | 3600 | 50,385.571 | 0.804 | ... | ... |
| 1996 Nov 4 | 0032 | 3600 | 50,391.524 | 0.804 | ... | ... |
| 1996 Nov 15 | 0153 | 3600 | 50,402.580 | 0.804 | ... | ... |
| 1996 Dec 21 | 0032 | 3600 | 50,438.522 | 0.804 | ... | ... |
| 1997 Aug 1 | 0536 | 2400 | 50,670.735 | 0.804 | ... | ... |
| 1997 Aug 5 | 0754 | 3600 | 50,695.645 | 0.804 | ... | ... |
| 1997 Aug 10 | 0326 | 3600 | 50,710.642 | 0.804 | ... | ... |
| 1997 Aug 12 | 0322 | 3600 | 50,717.634 | 0.804 | ... | ... |
| 1997 Aug 16 | 0310 | 3600 | 50,724.626 | 0.804 | ... | ... |

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![Figure 1](image1.png)  
**Fig. 1.** C II $\lambda \lambda 6578, 6582$ doublet in the HJD 2,448,901.6 KPNO spectrum (bottom line) and HJD 2,450,710.6 Ritter spectrum (top line). The resolutions of the spectra are 80,000 and 25,000, respectively.

![Figure 2](image2.png)  
**Fig. 2.** C II $\lambda \lambda 6578, 6582$ doublet in the HJD 2,448,901.6 spectrum, plotted along with the best-fit composite model spectrum.
motion of the broad component was only measured four times, three times accurately. We fitted the narrow-component radial velocities using all but the HJD 2,450,360.6 measurement. This one radial velocity is quite deviant (4 σ from final fit, σ = 2.8 km s⁻¹), and a much better fit is achieved by rejecting this point. We fitted the three good measurements of the broad component to determine $K_A$. For this fit, we assumed all the other orbital parameters were those determined from the narrow-component fit, except $w_A = w_B = 180°$. The resulting orbital parameters are listed in Table 2. The values of $m \sin^3 i$ and $a \sin i$ were then computed from the orbital parameters. Figure 3 plots the measured radial velocities along with the radial velocities calculated from the orbital motion fits. Columns (5)–(9) of Table 1 give the phase, measured radial velocities (O), and observed minus calculated ($O - C$) radial velocities.

4. DISCUSSION

Since HD 197770 exhibits shallow eclipses ($δV \sim 0.05$), its inclination must be near 90° (Clayton 1996). Thus, the values quoted in Table 2 for $m \sin^3 i$ are close to the actual masses of the components. Comparing an unpublished Pine Bluff Observatory (PBO) spectrum of HD 197770 with the spectra presented in Walborn & Fitzpatrick (1990), we find the spectral class to be B1 V–III or B2 III for both stars combined. Considering both the PBO spectrum and the $T_{\text{eff}}$ value determined in §3, the most likely spectral type is B2 III. All lines in the spectra of HD 197770 are double, leading to the conclusion that both stars have similar spectral types. Assuming the radius of a B2 III star (12 $R_\odot$; Drilling & Landolt 1998) for both components, the inclination of this eclipsing binary is ≥ 73°. The masses of components A and B are then ≤ 3.3 and 2.2 $M_\odot$, respectively. A normal B2 III star has a mass around 15 $M_\odot$ (Drilling & Landolt 1998). Thus, both components of this binary are undermassive for their given spectral types. This marks both components as evolved stars.

HD 197770 lies in the Cygnus region on the edge of Cyg OB7 and Cep OB2. It seems to be very near and possibly on the edge of a molecular cloud/star formation region, including Lynds 1036 and 1049. HD 197770 is associated with two IRAS point sources, IRAS 20420+5655 and 20418+5700, but it is clearly nonstellar on the IRAS map at 60 μm. Figure 4 displays the 1° × 1° region centered on HD 197770 for the IRAS 12, 25, 60, and 100 μm bands. The IR SED peaks at 60 μm, implying warm dust in the immediate vicinity of the binary (Gaustad et al. 1993). In addition to the 60 μm shell with a radius of 14', the IRAS map shows the signature of an apparent bubble of cleared dust with a radius of approximately 0.4'. This bubble is easiest to see in the 60 and 100 μm images, but is also present in the 25 μm image. The dark regions in the top and bottom right-hand corners of the images mark the edge of a molecular cloud, which has been mapped in CO (Dobashi et al. 1994). The molecular cloud wraps around three sides of HD 197770, roughly surrounding the evacuated area in the IRAS map. In particular, to the west of HD 197770 is a buried young stellar object (Lynds 1036), and to the east of HD 197770 is a pulsar (Dewey et al. 1985). So sequential star formation seems possible, although the pulsar may be a background object. In any event, the HD 197770 binary appears to have formed on the edge of this cloud and cleared out an area around it. The association of HD 197770 with this cloud allows us to use the distance to the cloud (440 pc; Dobashi et al. 1994) as an estimate of the distance to HD 197770.

The existence of IR flux peaking at 60 μm at the position of HD 197770 and the bubble of cleared dust surrounding HD 197770 implies that this binary has undergone at least two episodes of mass loss. A measurement of the luminosity of this binary would greatly help in determining its evolutionary stage, but the distance to the system is not known. Hipparcos gives a parallax of 0.52 ± 0.50 mas, which results in a 3 σ lower limit on the distance of 495 pc. This is consistent with the “guilt by association” distance given in the preceding paragraph. By assuming the distance to HD 197770 is 440 pc, $L_L/L_A = 2$, and $T_{\text{eff}} = 21,000$ K, we can estimate the luminosity and radii of the components of this binary. The resulting luminosities and radii are $9.3 \times 10^3 L_\odot$ ($M_V = -3.2$) and 7.4 $R_\odot$ for HD 197770A and $4.7 \times 10^3 L_\odot$ ($M_V = -2.5$) and 5.2 $R_\odot$ for HD 197770B. These radii result in an inclination for the binary of ≥81° and, thus, masses of ~3.0 and 2.0 $M_\odot$ for components A and B, respectively.
We note the similarity between this system and the eclipsing binary v Sgr \((m_p \sin^3 i = 2.5 \, M_\odot, m_s \sin^3 i = 4.0 \, M_\odot, \text{and } a \sin i = 210 \, R_\odot; \text{Dudley & Jeffery 1990})\), for which the primary is a hydrogen-deficient A-type supergiant and the secondary has a spectral type of B2 Ib \((\text{Schoenberner & Drilling 1983})\). According to Plavec (1973) and Schoenberner & Drilling (1983), the system is the result of type BB binary evolution, where the primary is now a post-asymptotic giant branch star. Uomoto (1986) has discussed the possibility that such systems are progenitors of Ib-type supernovae.

Two kinds of additional observations are needed of this binary. First, high-resolution \((R \geq 50,000)\) and high-S/N optical spectra are needed spaced throughout the \(~100\) day orbit. These observations would confirm the \(K\) amplitude of component A, which is currently only based on three measurements. Second, imaging with an optical interferometer would yield an accurate distance measurement when coupled with the results of this work. The Navy Prototype Optical Interferometer could perform this imaging when it becomes fully operational \((\text{Armstrong et al. 1998})\). Calculation of each star's luminosity would help in understanding their evolutionary stage.

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