1-1-1998

The spectroscopic orbit of the evolved binary HD 197770

Karl D. Gordon
Louisiana State University

Geoffrey C. Clayton
Louisiana State University

Tracy L. Smith
The University of Toledo

Jason P. Aufdenberg
Arizona State University

John S. Drilling
Louisiana State University

See next page for additional authors

Recommended Citation

Gordon, K., Clayton, G., Smith, T., Aufdenberg, J., Drilling, J., Hanson, M., Anderson, C., & Mulliss, C. (1998). The spectroscopic orbit of the evolved binary HD 197770. *Astronomical Journal, 115* (6), 2561-2565. https://doi.org/10.1086/300385

The Spectroscopic Orbit of the Evolved Binary HD 197770

Karl D. Gordon[1], Geoffrey C. Clayton[1], Tracy L. Smith[2], Jason P. Aufdenberg[3], John S. Drilling[1], Margaret M. Hanson[4,6], Christopher M. Anderson[5], & Christopher L. Mulliss[2]

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 & B, respectively. The $m \sin^3 i$ values for A & B are 2.9 and 1.9, respectively, and are close to the actual masses due to the eclipsing nature of this binary. Both components of HD 197770 have spectral types near B2 III. This means both components are undermassive by about a factor of five and, thus, 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 2 apparent shells centered on HD 197770; a bright 60 μm shell with a $14'$ diameter and a larger ($1\overset{\circ}{.}2$ diameter) bubble-like feature. At least one of the components of HD 197770 is likely to be a post-AGB star.

Subject headings: stars: individual (HD 197770) – binaries: spectroscopic

1. Introduction

Interest in the star HD 197770 (HR 7940, $\alpha(2000) = 20^{\rm h}43^{\rm m}13\overset{\rm s}{.}52$, $\delta(2000) = +57^\circ 6' 50\overset{''}{.}9$) 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 sightlines with UV spectropolarimetry, such a polarization bump has only been seen along one other sightline (Wolff et al. 1997). HD 197770 has long been known to have a variable radial velocity (Adams, Joy, & Sanford 1924; Plaskett & Pearce 1930). Observations originally intended to study the

[1]Department of Physics & Astronomy, Louisiana State University, Baton Rouge, LA 70803

[2]Ritter Astrophysical Research Center, The University of Toledo, Toledo, OH 43606

[3]Department of Physics & Astronomy, Arizona State University, Tempe, AZ 85271

[4]Steward Observatory, University of Arizona, Tucson, AZ 85721

[5]Space Astronomy Laboratory, University of Wisconsin, Madison, WI 53706

[6]Hubble Fellow

sightline towards HD 197770 have shown it to be a double-lined spectroscopic binary (Hanson et al. 1994; 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) 0.9m coudé feed telescope using the coudé spectrograph. The June observation was obtained using an échelle 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 échelle grating and a cross disperser grism giving orders which covered 5580–7160 Å (HJD 2448901.6) or 3990–4490 Å (HJD 2448902.6 & 2448903.6) at a resolution of 80,000. Between 1996 September and 1997 October, 17 observations of HD 197770 were taken at the 1m Ritter Observatory telescope using a fiber-fed échelle 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 échelle, 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 (HJD) 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 λ6578 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 identify the broad line as component A of this binary and the narrow line as component B. Since the lines were never fully separated, blending effects are always present. Therefore, we used TODCOR, the 2D 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 TODCOR are sensitive to the assumed model spectra, we constrained the

Table 1. Observations and Radial Velocites

UT Date [yy/mm/dd]	UT time [hrs:min]	exp. time [sec]	HJD - 2400000 [days]	phase	A O [km s^{-1}]	A O-C [km s^{-1}]	B O [km s^{-1}]	B O-C [km s^{-1}]
92/06/07	7:10	4018	48780.798	0.957	-0.4	-7.3	-52.2	-3.4
92/10/06	2:30	5400	48901.607	0.168	-41.2	-1.5	21.9	0.4
92/10/07	3:05	14400	48902.630	0.179	-39.3	1.5	28.8	5.6
92/10/09	2:42	5400	48904.614	0.199	-43.1	-0.5	24.7	-1.2
96/09/19	4:03	3600	50345.671	0.654	···	···	-31.4	4.4
96/09/20	3:10	3600	50346.634	0.663	···	···	-39.6	-1.6
96/09/25	4:33	3600	50351.692	0.714	···	···	-52.2	-3.5
96/10/01	1:38	3600	50357.570	0.773	···	···	-57.4	1.5
96/10/04	3:12	3600	50360.636	0.804	···	···	-51.2	11.4
96/10/29	1:40	3600	50385.571	0.054	···	···	-9.8	3.0
96/11/04	0:32	3600	50391.524	0.114	···	···	6.8	-1.4
96/11/15	1:53	3600	50402.580	0.225	···	···	27.4	-0.8
96/12/21	0:32	3600	50438.522	0.585	···	···	-24.2	-4.0
97/08/01	6:02	3600	50661.753	0.824	···	···	-64.6	-0.5
97/08/03	6:07	3600	50663.756	0.844	···	···	-63.6	1.1
97/08/05	7:54	3600	50665.831	0.865	···	···	-62.4	2.0
97/08/10	5:36	2400	50670.735	0.914	···	···	-59.2	-0.2
97/09/04	3:26	3600	50695.645	0.164	···	···	17.0	-3.7
97/09/19	3:22	3600	50710.642	0.315	···	···	24.4	-2.8
97/09/26	3:10	3600	50717.634	0.385	···	···	21.2	1.9
97/10/06	2:59	3600	50727.626	0.485	···	···	4.8	3.2

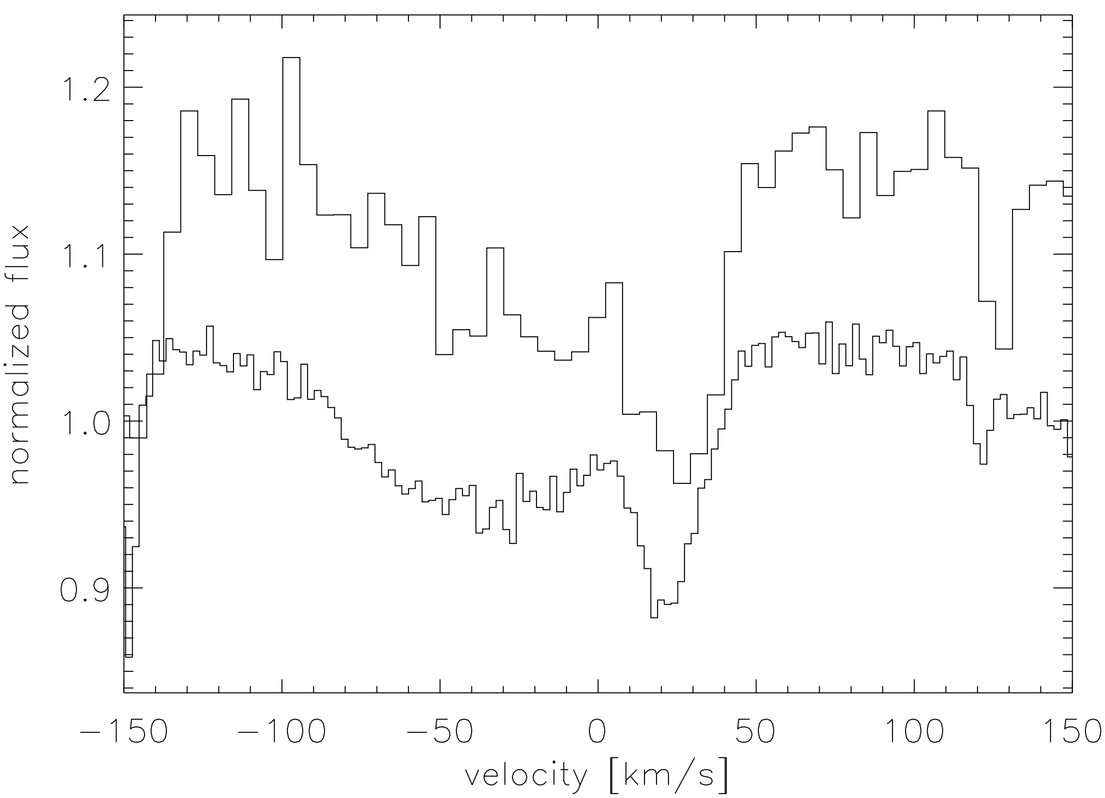

Fig. 1.— The C II λ6578.03 Å in the HJD 2448901.6 KPNO spectrum (bottom) and HJD 2450710.6 Ritter spectrum (top). The resolutions of the spectra are 80,000 (bottom) and 25,000 (top).

model atmosphere parameters as follows. The effective temperature ($T_{\rm eff}$) for HD 197770, derived using a reddening-free photometric index, is $21,000 \pm 3,000$ K (Gulati, Malagnini, & Morossi 1989). We checked this $T_{\rm eff}$ 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 (*IUE*) and UBV (Harmanec, Horn, & Juza 1994) observations and dereddened assuming a $R_V = 3.1$ and $E(B-V) = 0.58$ (Cardelli, Clayton, & Mathis 1989). The unreddened SED was well fit by a model with a $T_{\rm eff} = 21,000$ K and $\log(g) = 4.0$. In addition, since the eclipse depths are similar, the $T_{\rm eff}$ of both stars must be close to 21,000 K (Clayton 1996). We used a PHOENIX LTE model SED with a $T_{\rm eff} = 21,000$ K and a $\log(g) = 4.0$ 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$6578,6582 doublet in the HJD 2448901.6 spectrum ($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 most B-type stars are underabundant compared to the Sun (Snow & Witt 1996 and references therein). The HJD 2448901.6 spectrum and the best fitting composite model spectrum is 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 ~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 gave us radial velocities for both components, but neither was measured with great accuracy due to 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 motion of the broad component was only measured 4 times, 3 times accurately. We fit the narrow component radial velocities using all but the HJD 2450360.6 measurement. This one radial velocity is quite deviant (4σ from final fit, $\sigma = 2.8$ km s^{-1}) and a much better fit is achieved by rejecting this point. We fit the 3 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 velocites (O), and observed minus calculated (O-C) radial velocities.

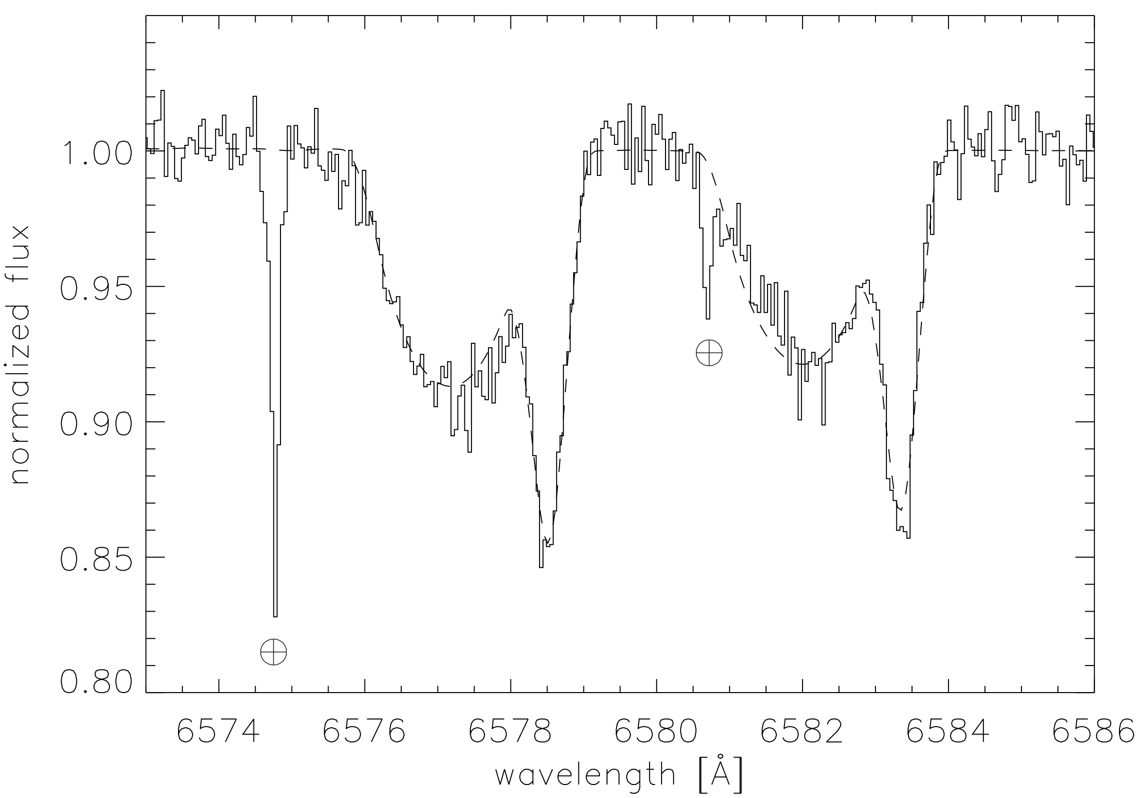

Fig. 2.— The C II λλ6578,6582 doublet in the HJD 2448901.6 spectrum is plotted along with the best fit composite model spectrum.

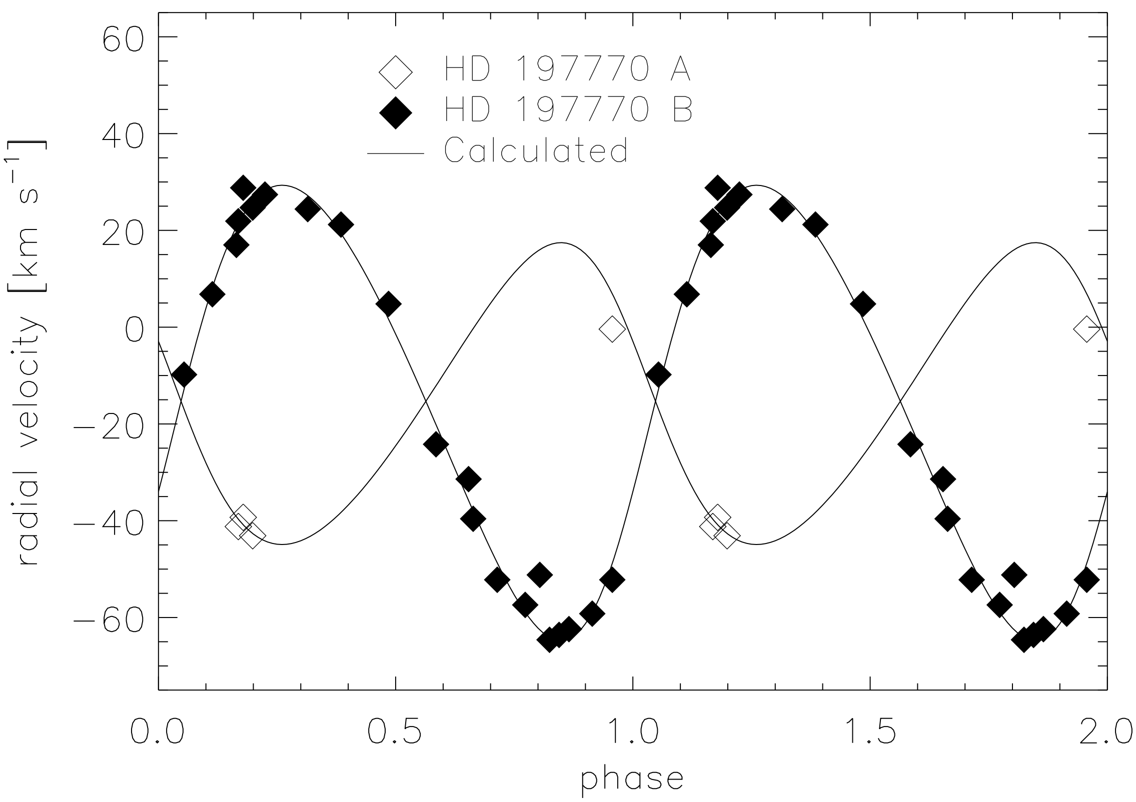

Fig. 3.— The radial velocities for HD 197770 A & B are plotted phased to the period given in Table 2. The radial velocities calculated from the fits to the orbital motion are plotted as solid lines.

4. Discussion

Since HD 197770 exhibits shallow eclipses ($\delta V \sim 0.05$), 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 to 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 $T_{\rm eff}$ 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 radii of a B2 III star (12 $R_\odot$; Drilling & Landolt 1997) for both components, the inclination of this eclipsing binary is $\geq 73°$. The masses of components A & 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 1997). 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 non-stellar on the IRAS map at 60 μm. Figure 4 displays the $2° \times 2°$ region centered on HD 197770 for the IRAS 12, 25, 60, 100 μm bands. The IR SED peaks at 60 μm implying warm dust in the immediate vicinity of the binary (Gaustad & Van Buren 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.°6. 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 upper and lower 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 bubble of cleared dust surrounding HD 197770 imply 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 3σ lower limit on the distance of 495 pc. This is consistent with the "guilt by association" distance given in the last paragraph. By assuming the distance to HD 197770 is 440 pc, $L_B/L_A = 2$, and $T_{\rm eff} = 21,000$ K, we can estimate the luminosity and radii of the components of this binary. The resulting luminosities and radii are 9.3×10^3 $L_\odot$

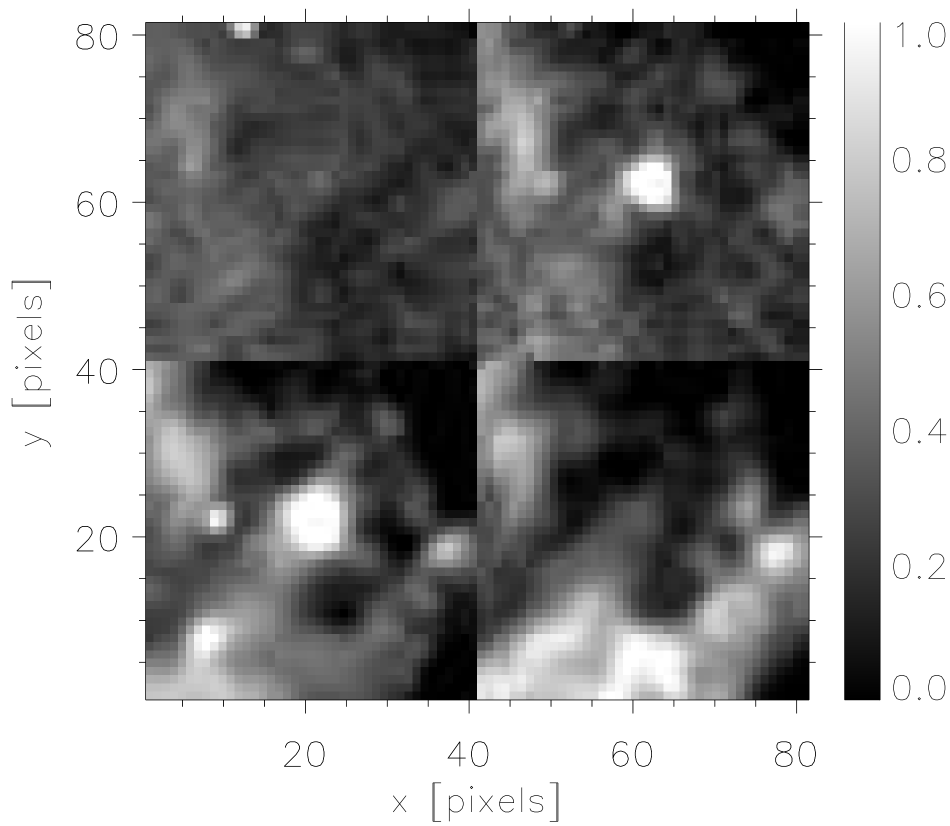

Fig. 4.— The IRAS 2° × 2° images centered on HD 197770 are displayed. The image intensity ranges are 1.2-2.5 MJy sr^{-1} for the 12 μm image (upper left), 4.2-4.95 MJy sr^{-1} for the 25 μm image (upper right), 4.0-6.0 MJy sr^{-1} for the 60 μm image (lower left), and 25-35 MJy sr^{-1} for the 100 μm image (lower right).

($M_V = -3.2$) and 7.4 $R_\odot$ for HD 197770 A and 4.7×10^3 $L_\odot$ ($M_V = -2.5$) and 5.2 $R_\odot$ for HD 197770 B. These radii result in an inclination for the binary of $\geq 81°$ and, thus, masses of $\sim$3.0 and 2.0 $M_\odot$ for HD 197770 A & B, respectively.

We note the similarity between this system and the eclipsing binary υ Sgr ($m_p \sin^3 i = 2.5$ $M_\odot$, $m_s \sin^3 i = 4.0$ $M_\odot$, & $a \sin i = 210$ $R_\odot$; Dudley & Jeffery 1990) for which the primary is a hydrogen-deficient A-type supergiant and the secondary has a spectral type of B2 Ib (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-AGB 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 $\sim$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 give an accurate distance measurement when coupled to the results of this work. The Navy Prototype Optical Interferometer could perform this imaging when it is fully operational (Armstrong et al. 1998). Calculation of each star's luminosity would help in understanding their evolution stage.

The Ritter observations were possible only with the help of the Ritter technician Bob Burmeister and the crack Ritter observing team. Team members contributing observations to this effort were Karl Gordon, David Knauth, Anatoly Miroshnichenko, Nancy Morrison, Christopher Mulliss, & Tracy Smith. Support for observational research at Ritter Observatory is provided by NSF grant AST-9024802 to B. W. Bopp and by The University of Toledo. This research has made use of the Simbad database, operated at CDS, Strasbourg, France. The IRAS data were obtained using the ISSA postage stamp server at IPAC. IPAC is funded by NASA as part of the IRAS extended mission under contract to JPL. K. D. Gordon & G. C. Clayton acknowledge support from NASA grant NAS5-3531. C. M. Anderson acknowledges support from NASA grant NAS5-26777.

REFERENCES

Adams, W. S., Joy, A. H., & Sanford, R. F. 1924, PASP, 36, 138

Anderson, C. M., et al. 1996, AJ, 112, 2726

Armstrong, J. T., et al. 1998, ApJ, in press

Aufdenberg, J. P., Hauschildt, P. H., Shore, S. N., & Baron, E. 1998, ApJ, 498, in press

Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245

Clayton, G. C. 1996, PASP, 108, 401

Clayton, G. C., et al. 1992, ApJ, 385, L53

Dewey, R. J., Taylor, J. H., Weisberg, J. M., & Stokes, G. H. 1985, ApJ, 294, L25

Dobashi, K., Bernard, J.-P., Yonekura, Y., & Fukui, Y. 1994, ApJS, 95, 419

Drilling, J. S. & Landolt, A. L. 1998, Astrophysical Quantities, 4th ed., ed. A. Cox, in press

Dudley, R. E. & Jeffery, C. S. 1990, MNRAS, 247, 400

Gaustad, J. E. & Van Buren, D. 1993, PASP, 105, 1127

Gordon, K. D. & Mulliss, C. L. 1997, PASP, 109, 221

Gulati, R. K., Malagnini, M. L., & Morossi, C. 1989, A&AS, 80, 73

Hanson, M. M., Clayton, G. C., Anderson, C. M., & Venn, K. A. 1994, in The First Symposium on the Infrared Cirrus and Diffuse Interstellar Clouds, ASP Conf. Ser., 58, 84

Harmanec, P., Horn, J., & Juza, K. 1994, A&AS, 104, 121

Iben, I. Jr. & Livio, M. 1993, PASP, 105, 1373

Jerzykiewicz, M. 1993, A&AS, 97, 421

Plaskett, J. S. & Pearce, J. A. 1930, Pub. Dominion Astrophys. Obs., 5, 1

Plavec, M. J. 1973, in Extended Atmospheres, ed. A. H. Batten, (Dordrecht: Reidel), 216

Schoenberner, D. & Drilling, J. S. 1983, ApJ, 268, 225

Snow, T. P. & Witt, A. N. 1996, ApJ, 468, L65

Uomoto, A. 1986, ApJ, 310, L35

Walborn, N. R. & Fitzpatrick, E. L. 1990, PASP, 102, 379

Wolff, M. J., Clayton, G. C., Kim, S.-H., Martin, P. G., & Anderson, C. M. 1997, ApJ, 478, 395

Zucker, S. & Mazeh, T. 1994, ApJ, 420, 806

This preprint was prepared with the AAS LaTeX macros v4.0.

Table 2. Orbital Parameters

	A	B
V_o [km s^{-1}]	-15.31 ± 0.32	
K [km s^{-1}]	31.21 ± 0.81	47.05 ± 0.36
e	0.147 ± 0.008	
w [°]	69.76 ± 3.34	249.76 ± 3.34
P [days]	99.6918 ± 0.0223	
T_o [days]	41906.392 ± 1.975	
$m \sin^3 i$ [$M_\odot$]	2.89 ± 0.08	1.92 ± 0.09
$a \sin i$ [$R_\odot$]	60.8 ± 1.6	91.7 ± 0.7