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Francis C. Fekel
Tennessee State University

Gregory W. Henry
Tennessee State University

Michael R. Busby
Tennessee State University

Joseph J. Eitter
Iowa State University

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CHROMOSPHERICALLY ACTIVE STARS. XI. GIANTS WITH COMPACT HOT COMPANIONS AND THE BARIUM STAR SCENARIO

FRANCIS C. FEKEL[1,2,3]

Center of Excellence in Information Systems, Tennessee State University, 330 Tenth Avenue North, Nashville, Tennessee 37203-3401 and Space Science Laboratory, ES-52, NASA Marshall Space Flight Center, Huntsville, Alabama 35812
Electronic mail: fekel@ssl.msfc.nasa.gov

GREGORY W. HENRY[1] AND MICHAEL R. BUSBY[1]

Center of Excellence in Information Systems, Tennessee State University, 330 Tenth Avenue North, Nashville, Tennessee 37203-3401
Electronic mail: henry@tsu.bitnet

JOSEPH J. EITTER

Erwin W. Fick Observatory, Iowa State University, Ames, Iowa 50011

ABSTRACT

We have determined spectroscopic orbits for three chromospherically active giants that have hot compact companions. They are HD 160538 (K0 III+wd, $P=904$ days), HD 165141 (G8 III+wd, $P\sim5200$ days), and HD 185510 (K0 III+sdB, $P=20.6619$ days). By fitting an *IUE* spectrum with theoretical models, we find the white dwarf companion of HD 165141 has a temperature of about 35 000 K. Spectral types and rotational velocities have been determined for the three giants and distances have been estimated. These three systems and 39 Ceti are compared with the barium star mass-transfer scenario. The long-period mild barium giant HD 165141 as well as HD 185510 and 39 Ceti, which have relatively short periods and normal abundance giants, appear to be consistent with this scenario. The last binary, HD 160538, a system with apparently near solar abundances, a white dwarf companion, and orbital characteristics similar to many barium stars, demonstrates that the existence of a white dwarf companion is insufficient to produce a barium star. The paucity of systems with confirmed white dwarf companions makes abundance analyses of HD 160538 and HD 165141 of great value in examining the role of metallicity in barium star formation.

1. INTRODUCTION

During the course of a program to obtain ultraviolet spectra of chromospherically active stars, four stars were found to have compact hot companions. Simon *et al.* (1985) extensively discussed the first of these, AY Cet=39 Ceti=HR 373 and its newly discovered white dwarf companion. An improved orbit for this system was given by Fekel & Eitter (1989). Fekel & Simon (1985) presented an initial discussion of the characteristics of the cool primaries and hot companions of two additional systems, HD 160538=DR Dra [$\alpha=17^h32^m41^s$, $\delta=74°13'38''$(2000), $V=6.55$] and HD 185510=V1379 Aql [$\alpha=19^h39^m38^s$, $\delta=-6°11'35''$(2000), $V=8.3$]. While the hot companion of HD 160538 is a white dwarf, that of HD 185510 was identified as a B subdwarf (Fekel & Simon 1985). Of these two systems HD 185510 has generated the greater interest because of the discovery (Balona *et al.* 1987) that it is eclipsing. Orbital elements for its K giant component were first computed by Balona (1987). Jeffery *et al.* (1992) obtained additional ultraviolet spectra of HD 185510 with the *International Ultraviolet Explorer* (*IUE*) satellite. From an improved orbit for the cool giant and two radial velocities for the hot companion they determined the approximate masses of the components. These masses, a preliminary analysis of the eclipse light curve, and the flux distribution of the system enabled them to discuss the evolutionary status of the hot companion. HD 165141 =V832 Ara [$\alpha=18^h07^m00^s$, $\delta=-48°14'49''$(2000), $V=7.08$] is the final star whose white dwarf companion has been discovered (Strassmeier *et al.* 1988). MacConnell *et al.* (1972) classified the cool star in this system as a marginal barium star. This makes it one of the very few barium stars for which a white dwarf companion has been directly confirmed.

Although these systems would not be classified as RS CVn binaries under the definition proposed by Hall (1976), Strassmeier *et al.* (1988) noted that such a restrictive definition is less useful today and a variety of stars with similar characteristics are more generally discussed as chromospherically active binaries. Indeed, the cool components of our systems have the same crucial characteristics as the chromospherically active component of such RS CVn binaries.

As a result of our extensive spectroscopic ground-based observations, we have determined the orbital elements of HD 160538 and HD 185510 and preliminary elements for

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[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research, Inc., under contract with the National Science Foundation.

[2] Guest Observer with the *International Ultraviolet Explorer* satellite.

[3] NRC Senior Research Associate.

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HD 165141 as well as the spectral types and rotational velocities of the cool giants. Because these three systems and 39 Ceti have many properties similar to barium stars, we summarize the development of the current scenario of barium-star formation and then use our results to discuss whether these systems are consistent with it. Key elements in the formation model are: (1) barium stars are binaries having periods of hundreds to thousands of days, (2) *s*-process elements, including barium, are created and eventually mixed to the atmosphere of the initially more massive star, (3) this star transfers the *s*-process material to its companion creating a long-lived barium star, and (4) the system now consists of a barium star and a white dwarf.

The results in this paper supercede those published previously. Because we primarily discuss the spectroscopic characteristics of these stars, they will be identified by their HD numbers and not their variable star names.

2. OBSERVATIONS AND VELOCITY REDUCTIONS

At McDonald Observatory and Kitt Peak National Observatory (KPNO) 41 observations have been obtained of HD 160538, 41 of HD 185510, and 10 of HD 165141. In 1980 and 1981 the observations were made with the 2.7 m telescope of McDonald Observatory, its coudé spectrograph, and a Reticon detector. Since 1982 the observations have been obtained with the KPNO's coudé feed telescope, coudé spectrograph, and several different charge-coupled devices (CCDs); in 1982 a Fairchild CCD, in 1983 April an RCA CCD, and finally, since 1983 July, a Texas Instruments CCD. Three observations have been centered at 6695 Å to include the lithium line at 6708 Å, while all the rest have been centered at 6430 Å. The vast majority of the spectrograms cover a wavelength range of about 80 Å and have a resolution of about 0.2 Å. The few McDonald and early KPNO spectrograms have a slightly lower resolution of 0.3 to 0.45 Å [see Fekel & Eitter (1989) for additional information]. Most of the spectra have signal-to-noise ratios of 100:1 or better.

Only lines of the cool components can be seen in the ground-based observations. Thus, nearly all of the radial velocities were determined relative to μ Her A, a G5 IV star. Stockton & Fekel (1992) have determined a velocity of -16.4 km s^{-1} for it relative to β Oph, which is an International Astronomical Union (IAU) radial-velocity standard star (Pearce 1957). A few of the radial velocities were determined relative to the IAU standards α Ari, β Oph, or HR 7560. Assumed velocities for these stars are -14.5, -12.2, and 0.0 km s^{-1}, respectively (Scarfe *et al.* 1990). For HD 160538 and HD 185510, Fekel *et al.* (1986) have published the radial velocities obtained through 1984. The velocities listed in the present paper are slightly different because different velocities were assumed for the standard stars. Details of the velocity-reduction procedure have been given by Fekel *et al.* (1978).

Additional observations for two of the stars, 59 for HD 160538 and 53 for HD 185510, have been obtained at the Erwin W. Fick Observatory with a radial-velocity spectrometer. The telescope–spectrometer system and reduction procedures have been described by Beavers & Eitter (1986).

3. SPECTRAL TYPES AND $v \sin i$

We have determined the spectral type of the three cool components with a spectrum-comparison technique used by Strassmeier & Fekel (1990). They identified several luminosity-sensitive and temperature-sensitive line ratios in the 6430–6465 Å region and used them, along with the general appearance of the spectrum, as spectral-type criteria. Since the comparison is done by trial and error, previous spectral classifications are important as a starting point. Most of the reference stars used for the comparison come from the list of Strassmeier & Fekel (1990). Spectra of stars from G5 to K3 and luminosity classes IV or III were rotationally broadened and shifted in velocity space to search for the best match.

For HD 160538 one of the line ratios, 6450 Å/6449 Å, suggests a slightly later type than the others. Except for this problem, β Gem (K0 IIIb) provides a very good overall fit to the spectrum. Spectral types as early as G8 III and as late as K2 III may be ruled out. The spectrum of HD 185510 has a similar line ratio problem and again β Gem provides a very good fit. However, an almost perfect fit to the red spectrum of HD 185510 is found if it is compared to an appropriately broadened spectrum of HD 160538 (Fig. 1). No such line-ratio problems occur for HD 165141. A very good fit to the spectrum results with κ Gem (G8 III). Thus, we classify both HD 160538 and HD 185510 as K0 III and HD 165141 as a G8 III. The iron abundances of β Gem and κ Gem are close to solar according to the references found in the catalog of Cayrel de Strobel *et al.* (1992). This implies similar abundances for our program stars.

The rotational velocity of HD 165141 was determined in the same manner as the $v \sin i$ values previously determined by Fekel *et al.* (1986) for HD 160538 and Fekel & Simon (1985) for HD 185510, 8 and 15 km s^{-1}, respectively. The full width at half maximum of several lines was measured, instrumental broadening was taken into account, and then this line broadening was converted into a rotational velocity and multiplied by an empirical constant of 0.591. A macroturbulent broadening of 3 km s^{-1} was assumed and removed. The resulting $v \sin i$ value of HD 165141 is 14 ± 2 km s^{-1}.

The rotational velocity of HD 160538 was redetermined. Examination of our spectra showed that 8 km s^{-1} is indeed the value for the strong lines in the 6430 Å region but that the weaker lines are clearly narrower and have a value of 6 ± 1 km s^{-1}. The greater broadening of the stronger lines is presumably because of line saturation effects. Although the value of 6 km s^{-1} approaches the resolution limit of our observations, all lines are clearly broader than those of β Gem for which Gray (1982) found a $v \sin i$ of 2.5 km s^{-1}.

As a result of the velocity revision for HD 160538, the rotational velocity of HD 185510 was reanalyzed. We mea-

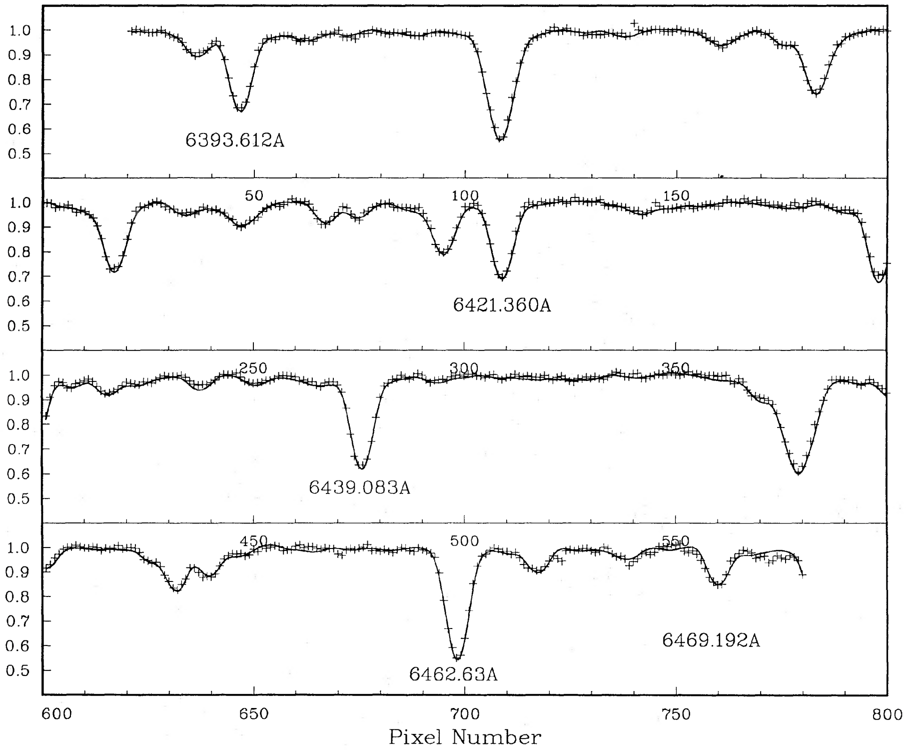

FIG. 1. A portion of the observed spectrum of HD 185510 in the 6430 Å region (pluses) compared with an appropriately broadened spectrum of HD 160538 (solid line). The y axis is relative intensity. The wavelengths of several lines are indicated.

sured the lines of several recent spectra of HD 185510 and determined $v \sin i = 15 \pm 2$ km s^{-1}. In this case the rotational velocity confirms the value determined by Fekel & Simon (1985) although the estimated uncertainty is decreased.

4. HD 160538=29 Dra=DR Dra

4.1 Introduction

Roman (1955) first found the strong Ca II H and K emission of HD 160538 and classified the star as a K2 III. In his extensive catalog of emission-line stars Bidelman (1954) noted Roman's discovery and gave its spectral type as K0 III. Such a classification is consistent with the colors found by Roman (1955), $U-B=0.81$ and $B-V=1.05$. She also found $V=6.55$ mag, which makes it one of the brightest known chromospherically active stars. The Strömgren photometry of Giménez *et al.* (1991) also is consistent with such a spectral type.

Hall *et al.* (1982) found light variations with an overall range of 0.12 mag in V, a period of 31.5 days, and a long-term brightening trend. Strassmeier *et al.* (1989) analyzed additional photometry obtained from 1983 through 1987. However, a significant amount of data was obtained only in the 1985 season from which a period of 28.8 days was determined.

Fekel & Simon (1985) had only a very small number of radial-velocity observations and could say little about the orbit of HD 160538. Despite an additional number of measured velocities, Fekel *et al.* (1986) were unable to suggest an orbital period. The preliminary period of 39 days, listed in Strassmeier *et al.* (1988), turned out to be much too short. The chromospheric activity of HD 160538 led to the expectation of an orbital period of 150 days or less. This assumption combined with the small velocity amplitude resulted in the erroneous preliminary determination from a portion of our current data set.

From *IUE* spectra obtained in the short wavelength region, Fekel & Simon (1985) discovered its white dwarf companion and found that the ultraviolet spectrum is matched best with a model atmosphere having $T_{\rm eff}=30\,000$ K and $\log g=8.0$.

4.2 Orbital Solution

From 1982 through 1993, 41 observations of HD 160538 were obtained at KPNO and 59 were obtained at Fick Observatory. Table 1 lists the observation dates and observed velocities as well as the velocity residuals of the final solution. Also listed are the orbital phases determined from the time of periastron passage. To determine the orbital elements, we found an initial value of the period for the KPNO radial velocities of the cool star with the period-finding program of Deeming (Bopp *et al.* 1970). Preliminary orbital elements were determined with a slightly modified version of the Wilsing–Russell method (Wolfe *et al.* 1967). These elements were refined with a differential corrections computer program of Barker *et al.* (1967). Separate orbital solutions for the velocities from the two observatories enabled us to determine any zero point shifts in

TABLE 1. Velocity observations of HD 160538.

HJD − 2400000	Phase	Velocity (km s^{-1})	(O−C) (km s^{-1})	Observatory
45077.915	0.342	−10.5	−0.4	KPNO
45078.955	0.344	−10.8	−0.6	KPNO
45079.930	0.345	−10.0	0.2	KPNO
45175.680	0.451	−12.4	−0.3	Fick
45448.966	0.753	−14.4	0.2	KPNO
45450.904	0.755	−13.7	0.9	KPNO
45489.769	0.798	−15.2	−1.1	Fick
45507.736	0.818	−15.7	−1.9	Fick
45525.810	0.838	−13.1	0.4	KPNO
45528.678	0.841	−10.9	2.6	Fick
45541.651	0.856	−14.0	−0.8	Fick
45594.667	0.914	−11.7	0.2	KPNO
45811.929	0.155	−8.2	−0.1	KPNO
45812.940	0.156	−7.5	0.6	KPNO
45814.953	0.158	−8.1	0.0	KPNO
45853.896	0.201	−7.7	0.6	KPNO
45855.873	0.203	−8.3	0.0	KPNO
45941.710	0.298	−9.4	0.0	KPNO
46171.932	0.553	−14.0	−0.2	Fick
46206.800	0.592	−15.8	−1.6	Fick
46239.712	0.628	−15.6	−1.0	Fick
46254.658	0.645	−16.3	−1.6	Fick
46268.636	0.660	−16.0	−1.3	Fick
46288.614	0.682	−10.7[a]	4.1	Fick
46530.961	0.950	−11.1	−0.1	KPNO
46532.982	0.953	−11.2	−0.2	KPNO
46583.882	0.009	−9.7	0.0	KPNO
46585.833	0.011	−10.5	−0.8	KPNO
46624.699	0.054	−9.2	−0.3	Fick
46631.664	0.062	−8.8	0.0	Fick
46637.613	0.068	−9.0	−0.3	Fick
46646.618	0.078	−6.9	1.6	Fick
46651.612	0.084	−8.0	0.5	Fick
46673.588	0.108	−7.1	1.2	Fick
46867.035	0.322	−9.6	0.2	KPNO
46869.032	0.324	−9.1	0.7	KPNO
46916.856	0.377	−10.8	0.0	Fick
46923.794	0.385	−10.5	0.4	Fick
46970.769	0.437	−12.1	−0.2	Fick
46970.828	0.437	−11.1	0.8	KPNO
46973.778	0.440	−11.3	0.7	KPNO
46977.741	0.445	−12.2	−0.2	Fick
46990.693	0.459	−14.5	−2.2	Fick
46997.679	0.467	−12.7	−0.3	Fick
47002.657	0.472	−12.3	0.2	Fick
47008.561	0.479	−14.3	−1.7	Fick
47008.566	0.479	−12.6	0.0	Fick
47024.621	0.496	−12.9	0.0	Fick
47037.624	0.511	−12.7	0.5	Fick
47245.993	0.741	−15.1	−0.4	KPNO
47247.984	0.744	−14.9	−0.3	KPNO
47248.979	0.745	−14.6	0.0	KPNO
47258.932	0.756	−16.8	−2.2	Fick
47302.839	0.804	−14.8	−0.8	Fick
47310.885	0.813	−13.9	0.0	KPNO
47312.811	0.815	−13.7	0.2	Fick
47313.875	0.817	−14.3	−0.4	KPNO
47319.773	0.823	−16.2	−2.4	Fick
47323.776	0.828	−15.0	−1.3	Fick
47326.763	0.831	−15.1	−1.5	Fick
47347.701	0.854	−14.0	−0.8	Fick
47359.671	0.867	−12.1	0.9	Fick
47379.620	0.889	−10.8	1.7	Fick
47380.616	0.890	−11.6	0.9	Fick
47390.596	0.901	−11.0	1.2	Fick
47458.563	0.977	−10.3	0.1	KPNO
47626.952	0.163	−8.5	−0.4	KPNO
47635.938	0.173	−8.6	−0.5	Fick
47649.870	0.188	−9.1	−0.9	Fick
47667.789	0.208	−10.8	−2.5	Fick
47684.766	0.227	−9.4	−0.9	Fick
47701.769	0.246	−7.6	1.1	Fick
47728.651	0.276	−9.3	−0.2	Fick
47744.644	0.293	−8.6	0.7	Fick
47769.568	0.321	−7.9	1.9	Fick
47810.578	0.366	−11.1	−0.5	KPNO
47812.578	0.368	−11.2	−0.6	KPNO
48002.942	0.579	−13.8	0.3	KPNO
48042.822	0.623	−13.6	0.9	Fick
48056.779	0.639	−14.0	0.6	KPNO
48060.860	0.643	−14.9	−0.3	KPNO
48065.771	0.649	−15.7	−1.0	Fick
48078.698	0.663	−13.5	1.2	Fick
48095.655	0.682	−14.7	0.1	Fick
48108.620	0.696	−13.3	1.5	Fick
48127.584	0.717	−13.3	1.5	Fick
48162.620	0.756	−15.6	−1.0	KPNO
48345.984	0.959	−10.7	0.1	KPNO
48429.785	0.051	−9.0	−0.1	KPNO
48439.726	0.062	−7.3	1.5	Fick
48469.663	0.095	−8.7	−0.3	Fick
48482.598	0.110	−8.2	0.0	Fick
48505.692	0.135	−8.4	−0.3	KPNO
48506.565	0.136	−6.9	1.2	Fick
48774.921	0.433	−12.4	−0.6	KPNO
48800.752	0.462	−11.4	0.9	Fick
48853.592	0.520	−12.4	0.9	Fick
48914.560	0.588	−14.1	0.1	KPNO
49102.951	0.796	−13.6	0.6	KPNO
49104.963	0.798	−13.5	0.6	KPNO

[a] Given zero weight

the velocities between the two sets and to estimate weights for the Fick data relative to the KPNO data. For HD 160538, −1.2 km s^{-1} was added to each of the Fick velocities, which were weighted 0.15 (except for one given zero weight) in the combined final solution. The eccentricity of this solution is small, 0.078 ± 0.030, and the error is large enough so that zero eccentricity may be appropriate (Lucy & Sweeney 1971). Indeed, because the velocity residuals are large relative to the small total amplitude, a circular orbit also fits the observations well. Main-sequence binaries with periods of a few days usually have had their orbits circularized by tidal forces. For stars with longer periods whose orbits are not circularized while the stars are on the main sequence, theoretical calculations indicate that giant-star evolution and mass transfer significantly decrease the circularization time scale. Nevertheless, we have chosen to retain the eccentric-orbit solution because of the relatively long period of 2.47 years. The observed radial velocities and the computed radial-velocity curve are plotted in Fig. 2. The final orbital elements are given in Table 2.

4.3 Discussion

At first glance the long period of 2.47 years is rather surprising since Strassmeier *et al.* (1988) list only three chromospherically active stars whose orbits have periods greater than 150 days. Although HD 160538 is a member of a binary system, the separation of the components is quite large, about 2.4 AU, compared to the vast majority of chromospherically active binaries. The relatively weak tidal forces in this system effectively make the cool star a chromospherically active *single* giant. Simon & Drake (1989) suggested that rapid rotation at the surface of such stars may result from the transfer of angular momentum from a rapidly rotating core. From a more extensive exam-

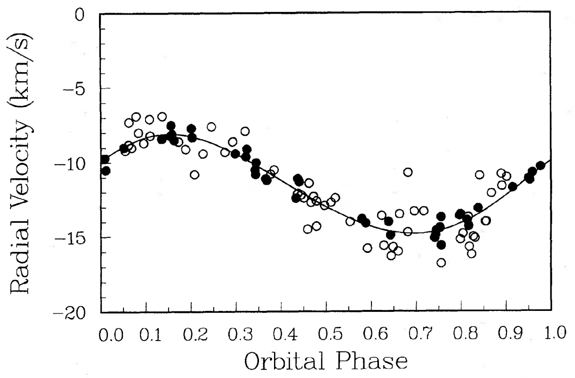

FIG. 2. Radial velocities of HD 160538 compared with the computed radial-velocity curve. Filled circles represent the KPNO velocities and open circles represent the Fick Observatory velocities. Zero phase is the time of periastron passage.

ination of such active single giants, Fekel & Balachandran (1993) concurred with this suggestion. Although our revised value of $v \sin i = 6$ km s^{-1} is not nearly as large as most of those single giants, it is larger than the mean value of 2.7 km s^{-1} found for "normal" K0 giants (Gray 1989). This suggests that the excess rotational velocity of HD 160538 may also result from angular momentum transferred from the core.

Fekel & Simon (1985) estimated a distance to the system of 88 pc from parameters determined for the white dwarf companion. For comparison, if a K0 III effective temperature of 4820 K (Bell & Gustafsson 1989) and a radius of $8R_\odot$, similar to that of HD 185510, are assumed, the resulting distance is 105 pc and is in reasonable agreement with the previous distance estimate.

5. HD 165141=V832 Ara

5.1 Introduction

Bidelman & Keenan (1951) identified the barium stars as a group of peculiar G and K giants because of the prominence of the Ba II line as well as several other spectral anomalies. MacConnell *et al.* (1972) classified HD 165141 as a marginal barium star. As such, its 4554 Å Ba II line appeared slightly stronger than normal on their classification dispersion plates. Bidelman & MacConnell (1973) included it in the list of stars with Ca H and K emission, classified it as a G8 III, and repeated its identification as a marginal Ba star. From the same objective prism plates used by Bidelman & MacConnell (1973), Houk (1978) independently classified it as G8/K0 II/IIIp and likewise noted that the cores of Ca II H and K are in emission. Lu *et al.* (1983) obtained DDO photometry of it and also classified it as K0 with a Ba intensity of 1, confirming the modest barium anomaly.

TABLE 2. Orbital elements of HD 160538.

P	903.8 ± 0.4 days
T	2447479.67 ± 55.30 JD
γ	-11.553 ± 0.069 km s^{-1}
K	3.353 ± 0.098 km s^{-1}
e	0.072 ± 0.031
ω	297°.5 ± 22°.0
f(m)	0.00351 ± 0.00031 M$_\odot$
$a \sin i$	41.6 ± 1.2 x 10^6 km

Standard error of an observation of unit weight = 0.45 km s^{-1}

At the South African Astronomical Observatory (SAAO) a photometric and spectroscopic survey of the Ca emission stars listed by Bidelman & MacConnell (1973) was carried out. The photometric observations of Lloyd Evans & Koen (1987) showed HD 165141 to be a variable star, similar to other chromospherically active stars, with an amplitude of 0.07 mag in V and a period of 34.6 days. In Balona's (1987) companion spectroscopic survey of photoelectric-velocity observations, 23 velocities are listed from which Balona concluded that HD 165141 is a single star. Collier Cameron (1987) obtained seven velocities of HD 165141 over a one month interval and stated that there was no evidence for velocity variability. From his spectra of the Ca K line region Collier (1982) determined absolute Ca K emission-line surface fluxes that were somewhat lower than most other chromospherically active stars that he investigated. However, he noted that these fluxes were still an order of magnitude greater than those for inactive stars of similar spectral type.

Our interest in HD 165141 was sparked by the detection of the hot companion. This led to a close examination of the velocities of Balona (1987), which appear to show a small long-term velocity change despite their significant scatter. Such results plus its identification as a mild barium star indicated that HD 165141 should be a long-period binary. Although the cool giant is an active-chromosphere star, we previously had shown little interest in this system because its large southern declination of −48° made it a less than inviting target from the northern hemisphere. However, it is indeed observable from the latitude of KPNO, rising some 10° above the horizon for a very brief period of time! With our interest sufficiently piqued we began to observe it in 1987 from Kitt Peak.

5.2 Orbital Solution

Unlike our observations of the other two stars in this paper, a full orbital cycle for HD 165141 has not been covered because of its extremely long period. In addition, phase coverage of significant portions of the orbit is lacking. Because of these circumstances, we emphasize that our orbital solution is a *preliminary* one. Three sets of observations for this star have been examined. The seven velocities of Collier Cameron (1987) are of little value since they were made over a one month period and have a velocity range of nearly 6 km s^{-1}. The other two sets are listed in Table 3 where the columns are the same as those given in Table 1. The 23 velocities of Balona (1987), ob-

TABLE 3. Velocity observations of HD 165141.

HJD − 2400000	Phase	Velocity (km s^{-1})	(O−C) (km s^{-1})	Observatory
43940.632	0.787	7.5	0.4	SAAO
43941.651	0.787	7.4	0.3	SAAO
43969.654	0.792	7.1	0.1	SAAO
43970.604	0.793	4.8[a]	−2.2	SAAO
43971.634	0.793	7.8	0.8	SAAO
43972.647	0.793	7.7	0.7	SAAO
43973.620	0.793	7.2	0.2	SAAO
43977.643	0.794	6.8	−0.1	SAAO
43979.652	0.794	2.6[a]	−4.3	SAAO
43980.664	0.795	8.1	1.2	SAAO
44026.540	0.803	4.2[a]	−2.5	SAAO
44177.280	0.832	7.5	1.4	SAAO
44180.228	0.833	0.5[a]	−5.6	SAAO
44299.659	0.856	4.9	−0.7	SAAO
44300.618	0.856	6.4	0.8	SAAO
44301.606	0.856	6.6	1.0	SAAO
44444.500	0.884	1.8[a]	−3.3	SAAO
44445.491	0.884	3.2	−1.9	SAAO
44446.525	0.884	3.7	−1.4	SAAO
44447.503	0.884	3.1	−2.0	SAAO
44448.489	0.885	3.4	−1.7	SAAO
44449.463	0.885	4.9	−0.2	SAAO
44536.271	0.901	−2.6[a]	−7.5	SAAO
46974.820	0.370	12.0	−0.5	KPNO
47308.900	0.435	12.2	−0.2	KPNO
47313.896	0.436	12.5	0.1	KPNO
48059.853	0.579	11.0	−0.1	KPNO
48163.584	0.599	10.4	−0.4	KPNO
48425.858	0.649	10.0	0.0	KPNO
48506.633	0.665	9.6	−0.1	KPNO
48774.892	0.717	8.9	0.2	KPNO
49104.983	0.780	7.5	0.2	KPNO
49105.985	0.780	7.8	0.5	KPNO

[a] Given zero weight

TABLE 4. Orbital elements of HD 165141.

P	5200±188 days
T	2 450 249±1888 JD
γ	9.2±2.3 km s^{-1}
K	3.9±1.4 km s^{-1}
e	0.18±0.27
ω	209°.6±77°.6
$f(m)$	0.03±0.03$\mathscr{M}_\odot$
$a \sin i$	276±102×10^6 km

Note to TABLE 4

The above preliminary elements should be treated with caution.

tained at the SAAO, cover only about 600 days but, fortunately, appear to occur at a time of "rapid" velocity change. With our most recent observations in 1993 April, the KPNO velocities now span almost six years and nearly overlap in phase the first velocities obtained by Balona (1987) 14 years ago. This enables us to determine a period of about 5200 days and to solve for the other elements. Because of the scatter of the SAAO velocities, we have made several assumptions. We have applied no zero point shift to these velocities and have assumed that the more positive SAAO velocities approximate the orbit. The velocities have been given a weight of 0.1 relative to our velocities, except for six velocities that were given zero weight. We note that a zero point correction of −1 km s^{-1} would increase the period by about one year. Velocities obtained over the next three to four years will enable us to test these assumptions and the resulting orbit.

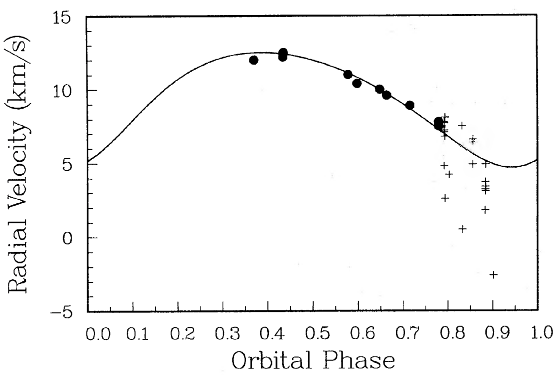

FIG. 3. Radial velocities of HD 165141 compared with the computed radial-velocity curve. Filled circles represent the KPNO velocities and pluses represent the SAAO velocities. Zero phase is the time of periastron passage.

The radial velocities of Table 3, which cover only half of the orbit, are compared with the computed orbit in Fig. 3. Since the velocity minimum has not been observed yet, significant changes to the elements listed in Table 4 are certainly possible. Note that the eccentricity is relatively low and the mass function is small, as expected. Forced solutions with a significantly larger eccentricity cause the semiamplitude to increase markedly. This quickly results in a mass function that is incompatible with a white dwarf secondary.

5.3 Ultraviolet Observations

One ultraviolet observation of HD 165141, image number SWP 30963, was obtained with the *IUE* satellite and the short wavelength primary (SWP) camera through the large aperture. This spectrum had an exposure time of 2 h, a resolution of about 6 Å, and a wavelength range of 1150–2000 Å. It was absolutely calibrated with the standard computer software routines at Regional Data Analysis Facility of the Goddard Space Flight Center.

Such observations of late-type chromospherically active stars show a number of chromospheric and transition region emission features but little or no continuum blueward of about 1650 Å [e.g., Simon & Fekel (1986)]. Thus, as seen in Fig. 4, the presence of a relatively featureless continuum that increases in flux toward shorter wavelengths as well as a significant Lyman α absorption line (the emission feature is geocoronal in nature) indicates that HD 165141 has a hot companion. No evidence of such a hot companion is indicated by ground-based photometry or spectroscopy. The only stellar emission feature appears to be a weak C IV emission line at 1549 Å. Its observed flux is 1.3×10^{-13} ergs cm^{-2} s^{-1}.

The continuum and Lyman α absorption line were compared with theoretical fluxes predicted by the high-gravity

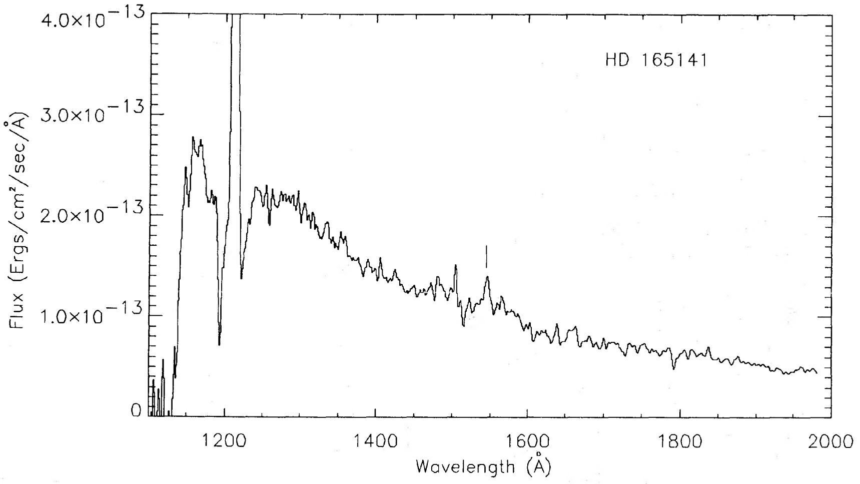

FIG. 4. A low-resolution *IUE* spectrum of HD 165141 that shows an increased flux at shorter wavelengths indicating the presence of a white dwarf. The only obvious absorption feature, Lyman α at 1206 Å, is contaminated by geocoronal emission. A tick mark indicates the C IV emission feature at 1549 Å.

model atmospheres of Wesemael *et al.* (1980). The models include hydrogen line blanketing, assume LTE, but have no metals or helium. The shape of the computed ultraviolet continuum is relatively insensitive to the effective temperature of the model but the profile of Lyman α depends on both effective temperature and surface gravity. This line becomes deeper and broader with higher surface gravity and lower effective temperature. A best fit of $\log g = 8.0$ and $T_{\rm eff} = 35\,000$ K is interpolated from the models.

5.4 Discussion

Given the questionable status of the supposed marginal barium star ξ^1 Cet mentioned below, one might also wonder if HD 165141 is indeed a marginal barium star. Its position in Lu's (1991) DDO color–color diagram of C(42–45) vs C(38–41) is well away from the line for normal giants and is consistent with those of other barium stars and, thus, supports its barium star classification.

Like HD 160538, HD 165141 contains a rapidly rotating chromospherically active giant whose rotation significantly exceeds the mean velocity of normal giants of similar spectral type (Gray 1989). Its preliminary orbital period of 14 years translates into a semimajor axis of about 7.5 AU. Thus, its rapid rotation of 14 km s^{-1} is not the result of tidal forces but instead presumably results from angular momentum transferred from its core.

The photometric period and $v \sin i$ value result in a minimum radius of 9.6 $R_\odot$. Such a radius is quite consistent with its classification as a giant. This minimum radius and an assumed temperature of 4970 K (Bell & Gustafsson 1989) for a G8 III result in a minimum distance of 174 pc. An assumed radius of $15R_\odot$, corresponding to an inclination of 40°, increases the brightness of the cool star by 1 mag and results in a distance of 275 pc. Thus, we estimate a distance of 225 ± 50 pc.

6. HD 185510

6.1 Introduction

The initial interest in HD 185510 resulted from its inclusion in Bidelman & MacConnell's (1973) list of late-type stars with Ca II H and K emission. Fekel & Simon (1985) first detected the spectrum of its hot companion. They obtained a reasonable fit to its ultraviolet spectrum with a model atmosphere having $T_{\rm eff}$ between 20 000 and 30 000 K and $\log g = 6.0$. Fekel & Simon (1985) suggested that the hot companion was a B subdwarf similar to those analyzed by Heber & Hunger (1984). From a modest number of photometric observations, Henry *et al.* (1982) discovered light variations with an amplitude of 0.2 mag in *V* and suggested a period of about 25 days. Lloyd Evans & Koen (1987) refined the photometric period to 25.4 days, significantly different from the orbital period of 20.659 days determined by Balona (1987). Balona *et al.* (1987) discovered eclipses of the hot companion and began to obtain additional ultraviolet observations. Their work culminated in the study of Jeffery *et al.* (1992) who determined the masses of the two stars, analyzed the eclipse light curve, refined the effective temperature and gravity of the hot companion, and extensively examined its evolutionary status. They concluded that the hot companion is the result of Case B mass exchange and that it is not a subdwarf B star in the "classical" sense. Instead, they suggested that it is currently either a low-mass helium main-sequence star or a nascent helium degenerate.

Robertson & Etzel (1993) have obtained contemporaneous photometric and spectroscopic observations of HD 185510 in the 1990–93 seasons. Their spectroscopy and photometry indicate that the cooler component appears to be a fairly normal K0 III star with its Hα line filled in by emission. They determined a photometric wave period of

1993AJ....106.2370F

TABLE 5. Velocity observations of HD 185510.

HJD − 2400000	Phase	Velocity (km s^{-1})	(O−C) (km s^{-1})	Observatory
43970.643	0.557	−28.0	3.7	SAAO
43971.663	0.607	−26.9	2.8	SAAO
43972.665	0.655	−24.8	2.3	SAAO
43973.660	0.703	−25.9	−2.0	SAAO
43977.678	0.898	−8.5	1.6	SAAO
44026.593	0.265	−22.0	4.6	SAAO
44178.275	0.607	−33.5	−3.8	SAAO
44180.260	0.703	−24.5	−0.5	SAAO
44363.548	0.573	−30.2	0.9	SAAO
44364.527	0.621	−30.1	−1.1	SAAO
44415.496	0.088	−15.5	−2.9	SAAO
44416.495	0.136	−14.4	1.9	SAAO
44420.550	0.332	−30.2	0.2	SAAO
44421.540	0.380	−27.6	4.5	SAAO
44422.542	0.429	−28.1[a]	5.0	SAAO
44423.502	0.475	−31.7	1.5	SAAO
44424.523	0.524	−32.0	0.6	SAAO
44425.490	0.571	−29.8	1.4	SAAO
44426.484	0.619	−28.2	0.9	SAAO
44428.513	0.718	−24.7	−1.8	SAAO
44445.588	0.544	−32.9	−0.8	SAAO
44446.579	0.592	−30.5	−0.1	SAAO
44447.550	0.639	−27.9	0.1	SAAO
44448.510	0.685	−21.8	3.4	SAAO
44449.505	0.734	−22.5	−0.8	SAAO
44474.659	0.951	−8.8	−0.5	McDonald
44476.653	0.048	−8.9	1.2	McDonald
44480.779	0.247	−25.8	−0.5	McDonald
44506.355	0.485	−35.5	−2.3	SAAO
44511.352	0.727	−18.1	4.1	SAAO
44512.310	0.773	−21.8	−3.2	SAAO
44535.233	0.883	−11.5	−0.6	SAAO
44536.322	0.935	−16.2[a]	−7.6	SAAO
44537.243	0.980	−13.3[a]	−5.1	SAAO
44538.250	0.029	−14.0	−4.7	SAAO
44539.237	0.076	−14.7	−2.9	SAAO
44540.251	0.126	−19.7	−4.2	SAAO
44894.578	0.274	−27.1	0.1	McDonald
44897.550	0.418	−33.5	−0.5	McDonald
45447.981	0.058	−11.1	−0.4	KPNO
45448.988	0.107	−14.2	−0.2	KPNO
45450.934	0.201	−19.8	2.0	KPNO
45575.654	0.237	−22.4	2.2	Fick
45596.763	0.259	−26.8	−0.6	KPNO
45813.977	0.772	−18.8	0.0	KPNO
45939.692	0.856	−12.2	0.3	KPNO
45972.584	0.448	−33.9	−0.7	Fick
46239.809	0.381	−30.5	1.7	Fick
46288.671	0.746	−21.9	−1.1	Fick
46392.627	0.777	−18.6	−0.3	KPNO
46582.973	0.990	−7.3	1.0	KPNO
46585.924	0.133	−16.5	−0.4	KPNO
46586.897	0.180	−20.6	−0.6	KPNO
46717.628	0.507	−33.2	−0.3	KPNO
46718.691	0.558	−32.3	−0.6	KPNO
46720.658	0.654	−28.1	−0.9	KPNO
46721.631	0.701	−25.4	−1.3	KPNO
46868.038	0.787	−16.7	0.9	KPNO
46973.896	0.910	−8.8	0.7	KPNO
46974.975	0.962	−8.0	0.2	KPNO
47245.026	0.032	−10.1	−0.7	KPNO
47246.009	0.080	−12.4	−0.4	KPNO
47249.019	0.225	−23.3	0.4	KPNO
47313.959	0.368	−32.5	−0.7	KPNO
47321.875	0.751	−18.7	1.6	Fick
47323.869	0.848	−11.3	1.7	Fick
47324.866	0.896	−9.9	0.2	Fick
47325.865	0.945	−3.1[a]	5.3	Fick
47335.846	0.428	−39.6[a]	−6.5	Fick
47339.828	0.620	−31.0	−2.0	Fick
47346.813	0.958	−9.5	−1.3	Fick
47349.798	0.103	−16.2	−2.5	Fick
47353.795	0.296	−29.0	−0.5	Fick
47361.766	0.682	−25.5	−0.1	Fick
47364.756	0.827	−14.5	0.0	Fick
47368.750	0.020	−7.3	1.7	Fick
47369.744	0.068	−6.8[a]	4.5	Fick
47370.737	0.116	−15.2	−0.5	Fick
47374.736	0.310	−28.6	0.7	Fick
47375.725	0.358	−30.4	1.0	Fick
47376.725	0.406	−35.7	−2.9	Fick
47379.728	0.551	−25.8[a]	6.1	Fick
47383.702	0.744	−18.9	2.0	Fick
47384.705	0.792	−16.6	0.6	Fick
47387.693	0.937	−8.2	0.4	Fick
47388.699	0.986	−8.8	−0.6	Fick
47389.689	0.034	−9.7	−0.2	Fick
47390.689	0.082	−12.2	0.0	Fick
47391.660	0.129	−15.6	0.2	Fick
47397.665	0.420	−33.0	0.0	Fick
47398.662	0.468	−33.1	0.2	Fick
47399.656	0.516	−28.5	4.2	Fick
47402.655	0.661	−21.4[a]	5.3	Fick
47404.642	0.757	−22.0	−2.1	Fick
47421.599	0.578	−31.9	−0.9	Fick
47429.645	0.967	−8.4	−0.2	Fick
47431.608	0.062	−10.7	0.2	Fick
47455.576	0.222	−24.0	−0.5	KPNO
47625.988	0.470	−32.2	1.1	KPNO
47701.819	0.140	−14.9	1.8	Fick
47706.807	0.382	−32.2	0.0	Fick
47712.824	0.673	−25.2	0.8	Fick
47713.786	0.719	−22.2	0.6	Fick
47715.775	0.816	−17.3	−1.9	Fick
47735.748	0.782	−16.1	1.8	Fick
47740.745	0.024	−11.7	−2.6	Fick
47744.710	0.216	−22.1	0.9	Fick
47746.695	0.312	−27.9	1.5	Fick
47750.673	0.505	−30.4	2.5	Fick
47753.706	0.651	−26.8	0.5	Fick
47755.676	0.747	−19.6	1.1	Fick
47757.656	0.843	−13.8	−0.4	Fick
47762.681	0.086	−12.2	0.3	Fick
47768.658	0.375	−34.5	−2.5	Fick
47769.664	0.424	−36.4	−3.4	Fick
47809.654	0.359	−32.2	−0.7	KPNO
47810.698	0.410	−32.7	0.1	KPNO
47812.633	0.503	−32.9	0.1	KPNO
47813.661	0.553	−31.7	0.1	KPNO
47815.596	0.647	−26.6	1.0	KPNO
48002.969	0.715	−22.8	0.3	KPNO
48056.903	0.326	−30.5	−0.4	KPNO
48167.650	0.686	−25.2	0.0	KPNO
48573.586	0.332	−29.5	0.9	KPNO
48605.580	0.881	−11.8	−0.8	KPNO
48606.571	0.929	−9.6	−0.8	KPNO
48773.920	0.028	−8.6	0.7	KPNO
49105.001	0.052	−9.7	0.7	KPNO
48132.558	0.987	−125.0	−1.4	IUE
48142.441	0.466	63.4	0.2	IUE

[a] Given zero weight

26.3 days and observed several eclipses. With an assumed inclination range of 90°–80° and reasonable radius values of the K0 III star, they have concluded that the hotter component is a fairly typical sdB star with a radius of a few tenths of a solar radius.

6.2 Orbital Solution

The orbital solution of HD 185510 was determined in the same manner as that of HD 160538 except that three sets of data were used to obtain the elements. The velocities

TABLE 6. Orbital elements of HD 185510.

P	20.66187 ± 0.00058 days
T	2446583.183 ± 0.372 JD
γ	−21.869 ± 0.095 km s^{-1}
K$_a$	12.56 ± 0.13 km s^{-1}
K$_b$	93.7 ± 2.5 km s^{-1}
e	0.094 ± 0.011
ω_a	$11\overset{\circ}{.}9 \pm 6\overset{\circ}{.}5$
f(m)	0.00419 ± 0.00013 M$_\odot$
$a_a \sin i$	3.552 ± 0.038 x 10^6 km
$a_b \sin i$	26.50 ± 0.68 x 10^6 km
$M_a \sin^3 i$	2.24 ± 0.12 M$_\odot$
$M_b \sin^3 i$	0.300 ± 0.014 M$_\odot$
M_a/M_b	7.46 ± 0.16

Standard error of an observation of unit weight = 0.65 km s^{-1}

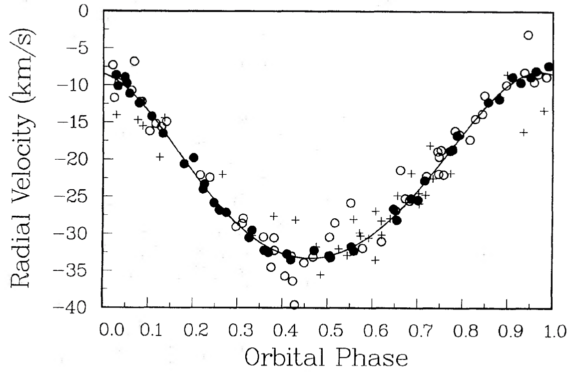

FIG. 5. Radial velocities of HD 185510 compared with the computed radial-velocity curve. Filled circles represent the McDonald/KPNO velocities, open circles represent the Fick Observatory velocities, and pluses represent the SAAO velocities. Zero phase is the time of periastron passage.

of Balona (1987), obtained at the SAAO, as well as our velocities from Fick Observatory and from McDonald/KPNO are listed in Table 5. Compared with HD 160538, HD 185510 is fainter and its lines are broader, which leads to larger velocity uncertainties. Separate solutions of the three data sets were used to determine the zero point corrections and weights of the velocity sets relative to the McDonald/KPNO set. No zero point shift was applied to the Fick velocities and all were given a weight of 0.1 except for five velocities given zero weight. To each velocity of Balona (1987), −1.3 km s^{-1} was added and all velocities were also given a weight of 0.1 except for three velocities given zero weight. A comparison of the orbital element solution of the McDonald/KPNO velocities alone with the combined solution of all the velocities shows that the elements are quite similar with the uncertainties slightly reduced in the combined solution. Elements for the combined solution are given in Table 6 and the computed radial velocity curve is plotted with the observations of the cool giant in Fig. 5. A comparison with an earlier set of our elements listed in Jeffery *et al.* (1992) shows only modest differences. Finally, a double lined solution was computed with the addition of the velocities of the B subdwarf (Table 5) determined from the *IUE* spectra of Jeffery *et al.* (1992). All orbital elements were fixed at the values determined in the combined single lined solution of the cool giant except for the velocity semiamplitude of the B subdwarf. The resulting mass ratio, minimum masses, and minimum separations are listed in Table 6. Despite slightly smaller values of both semiamplitudes, our mass ratio and minimum masses are quite close to the values determined by Jeffery *et al.* Thus, the masses for the cool giant and B subdwarf range from 2.24$\mathscr{M}_\odot$ and 0.30$\mathscr{M}_\odot$, respectively, if $i=90°$, to 2.70$\mathscr{M}_\odot$ and 0.36$\mathscr{M}_\odot$, respectively, if $i=70°$.

6.3 Discussion

From our computed orbit, primary eclipse occurs at phase 0.7466 from periastron while secondary eclipse is at phase 0.1882 corresponding to JD 2446587.0705. Jeffery *et al.* (1992) estimated mid-eclipse form their observations as JD 2447094.472±0.052. Our ephemeris for primary eclipse is JD 2446577.947+20.6619 (E) and results in a predicted eclipse date of 2447094.495, only 0.55 h later than observed. While such agreement is excellent other comparisons result in some conflicts.

The modest eclipse depth makes the light curve of HD 185510 very difficult to analyze. Thus, although the analysis of Jeffery *et al.* (1992) is an important step forward, their assumptions and results should be carefully examined. From a blackbody fit, Jeffery *et al.* (1992) assumed an effective temperature of 4000±100 K for the cool star. Such a low temperature corresponds to a K4 III (Bell & Gustafsson 1989) and is at odds with our spectral classification as well as with the K0 III/IV classification of Bidelman & MacConnell (1973), the results of Robertson & Etzel (1993), and to a lesser extent with the $(B-V)$ color index. The spectral classification of the cool star results in an effective temperature of 4820 K (Bell & Gustafsson 1989), a value that is significantly hotter than the value of 4000 K used by Jeffery *et al.* Such an apparent conflict may be partially resolved by noting that Fekel *et al.* (1986) found chromospherically active stars to have red color indices that are significantly redder than inactive stars. This cannot, however, completely account for the differing results and so the system may have a modest amount of interstellar reddening. Our conclusion is supported by the excellent agreement of the spectrum of HD 160538 with that of HD 185510 (Fig. 1). Although there is certainly a spread in the colors of nearby stars classified as K0 giants, a comparison of the $B-V$ colors of the above two stars with the calibration of Johnson (1966) suggests an E($B-V$) of about 0.10 mag for HD 185510. Whether any part of this apparent excess is because of circumstellar reddening around the giant remains to be determined.

We note that our conclusion of a modest reddening for HD 185510 is at odds with the ultraviolet results of Jeffery *et al.* (1992). They compared the flux distribution of the B subdwarf and its Lyman α profile with theoretical models and concluded that the Lyman α fit ruled out a possible $E(B-V)$ as large as 0.05.

The rotation period of 25.4 days (Lloyd Evans & Koen 1987) and the $v \sin i$ value of 15 ± 2 km s^{-1} result in a minimum radius of $7.5 \pm 1 R_\odot$ for the giant. [The slightly longer period of Robertson & Etzel (1993) increases the minimum radius to $7.8 R_\odot$.] Jeffery *et al.* (1992) argued that the orbital inclination is between 70° and 90°. This results in a radius range of 19–$9 R_\odot$ from their light-curve solutions. If it is assumed that the orbital and rotational inclinations are the same, our computed radius is increased to $8.0 R_\odot$ for $i = 70°$. Thus, our radius range is much more restrictive and our radius is at the very low end of their range.

The radius range for the cool giant and its assumed effective temperature result in a luminosity range of $20.4 L_\odot$ to $39.2 L_\odot$, which translates into a distance to the system of 227 ± 36 pc.

The effective Roche lobe radius of the giant is about $29 R_\odot$. The evolutionary model of Schaller *et al.* (1992) for a $2.5 \mathscr{M}_\odot$ star with solar abundances indicates that it attains a radius of $33 R_\odot$ on its first ascent of the giant branch. Since the giant in HD 185510 currently fills about 25% of its Roche lobe, overflow will occur in less than 5 million years unless significant mass loss occurs first.

HD 185510 has several unusual properties. Fekel & Eitter (1989) examined 114 chromospherically active binaries listed by Strassmeier *et al.* (1988) and found that the vast majority were synchronously or pseudosynchronously rotating. Of the binaries with orbital periods shorter than 30 days, less than 10 per cent, including HD 185510, are asynchronously rotating. From the equations of Hut (1981) we predict a pseudosynchronous period of 19.6 days, a value significantly different from its rotation period of 25.4 days (Lloyd Evans & Koen 1987). Like nearly all of the nonsynchronous rotators, it is rotating more slowly than predicted. The radius of the late-type giant may be changing so rapidly that pseudosynchronization is not currently possible. For very different reasons Jeffery *et al.* (1992) suggested that the outer envelope of the late-type giant may be out of equilibrium following the rapid mass transfer phase.

While the eccentricity of HD 185510 is small, it is definitely not zero. Several competing theories exist that predict how quickly a binary star orbit circularizes. In all those theories, the circularization time scale depends strongly on the ratio a/R, where a is the semimajor axis of the binary and R is the radius of the larger star. The dependences range from $(a/R)^{6.125}$ to $(a/R)^{10.5}$ (Tassoul 1988). The orbital period of 21 days is too long to expect circularization to occur while the stars were on the main sequence. However, after the more massive star evolved off the main sequence and rapidly increased its radius, relatively rapid circularization would be expected.

7. BARIUM STAR SCENARIO

As noted above, Bidelman & Keenan (1951) were the first to identify the barium stars as a separate class of anomalous abundance giants. The name of this class comes from the Ba II line at 4554 Å, which is normally used to characterize the strength of the abundance peculiarity on classification dispersion plates. An important step in understanding the evolutionary status of such stars was made when Burbidge & Burbidge (1957) identified the abundance anomalies with the *s*-process or slow neutron capture reaction that is believed to occur in the interiors of red giants. This process produces overabundances of elements such as yttrium, zirconium, barium, lanthanum and other heavy elements. In stellar evolution, *s*-processing is expected to occur after He burning begins and might get mixed to the surface only after the He shell-flash stage on the asymptotic giant branch. Unfortunately, the evolutionary state of most barium stars is not believed to be that advanced. New insight was provided by McClure (McClure *et al.* 1980, 1983) who after several years of radial-velocity observation determined that the vast majority of barium stars were binaries with long periods and quite small mass functions. An extension of this study (McClure & Woodsworth 1990) and preliminary results from a study of barium stars in the southern hemisphere (Jorissen & Mayor 1988) have confirmed the thesis that all barium stars are binaries.

The terms "marginal" and "mild" usually have been used, sometimes interchangeably (as in this paper) and sometimes with slightly different definitions, to describe stars with modest *s*-process enhancements. Whether mild or marginal barium stars also are components of binary systems was initially uncertain although Griffin (1982) quickly asserted that they mostly are. Dominy & Lambert (1983) and Böhm-Vitense *et al.* (1984) suggested that such stars simply have wider separations between the components and, thus, longer periods. Such a situation would lead to smaller velocity variations over a longer time interval and make the identification of duplicity more difficult. Griffin's optimistic conclusion appears to be justified since several mild barium stars have indeed been found to be very long-period binaries (see Griffin 1991, Griffin & Keenan 1992). The above results gave a new direction to theoretical explanations of the barium star peculiarities.

Just as important as the discovery of their binary nature was the suggestion of McClure *et al.* (1980) that the low mass companions are white dwarfs. This led them to propose that mass transfer from the white dwarf precursor polluted the outer atmosphere of the companion star with the *s*-process elements. The conclusion that the current secondaries are white dwarfs rests primarily on the small dispersion of the mass functions and the distribution of orbital eccentricities compared to normal late-type giants (Webbink 1988; McClure & Woodsworth 1990) rather than their direct detection. Ultraviolet spectroscopic searches with the *IUE* satellite for the putative white dwarf companions of the current barium stars have resulted in several successes but many failures; with even some of the successes being questionable. Böhm-Vitense (1980) first found a white dwarf companion to the bright barium star ζ Cap and suggested that three other stars, including ζ Cyg, had ultraviolet flux excesses. Dominy & Lambert (1983) observed four barium stars and two mild barium stars. They supported the suggestion of Böhm-Vitense that ξ Cyg has a white dwarf companion but found no others. Despite this agreement, Böhm-Vitense *et al.* (1984) noted that the match of the star's ultraviolet flux distribution and the expected energy distribution of a white dwarf is not particularly good. Schindler *et al.* (1982) found a white dwarf companion for the supposed mild barium star 56 Peg. However, Luck's (1977) abundance analysis of this supergiant indicates that its *s*-process elements are not enhanced. Böhm-Vitense *et al.* (1984) increased the number of barium and mild barium stars observed with the *IUE* satellite to 16. Their only additional claimed white dwarf detection was that of ξ^1 Cet. Böhm-Vitense & Johnson (1985) presented more extensive results on this claimed cool white dwarf companion but had some difficulty reconciling its properties. Fekel & Simon (1985) followed later by Jorissen & Boffin (1992) questioned the white dwarf identification. Both noted problems with such an identification since McAlister *et al.* (1984), using speckle interferometry at *visual* wavelengths, have detected a secondary having a separation of 0.056″ and this separation is consistent with it being the secondary of the 4.5 year spectroscopic binary. Such a companion seen at visual wavelengths cannot be a white dwarf.

The question of whether ξ^1 Cet is indeed a mild barium star has produced conflicting answers. Keenan (Griffin & Keenan 1992) discussed the history of his classification of mild barium stars and the problems associated with the identification of slight abundance anomalies on classification dispersion plates. Although Jorissen & Boffin (1992) list it with other normal red giant binary systems, presumably because of Keenan's (Keenan & McNeil 1989) revised type that had no barium designation, the latest word from Keenan (Griffin & Keenan 1992) is that high dispersion spectrograms confirm it as a mild barium star with a type of G7 III Ba 0.4. However, Jorissen & Boffin (1993) showed that its abundances of the *s*-process elements yttrium and lanthinum (McWilliam 1990) are very similar to normal red giants rather than barium stars. In addition ξ^1 Cet is grouped with normal giants in Lu's (1991) DDO color–color plot of C(42–45) vs C(38–41). These quantitative results indicate that ξ^1 Cet is not a mild barium star. With at most four previous detections of white dwarf companions, our detection of an unequivocal white dwarf companion for the HD 165141 is significant. However, the abundances of its *s*-process elements need to be determined quantitatively to confirm its status as a mild barium star.

Since hot white dwarf companions were not detected for most barium stars, it is presumed that the white dwarfs are not visible at ultraviolet wavelengths because they have become too cool. As Dominy & Lambert (1983) pointed out, their cooling time scales are greater than the lifetime of a low-mass star in the giant phase. To alleviate this difficulty, a barium star usually must be formed while still on the main sequence. Surveys by Lu (1991) and others have suggested a number of possible dwarf barium stars. In addition, at least two groups of peculiar stars have been suggested as such nascent barium stars. These are the F dwarfs with a strong strontium λ 4077 line (North & Duquennoy 1991), and the CH subgiants (Bond 1974; Luck & Bond 1982, 1991), some of which are actually dwarfs. Luck & Bond (1991) argue that the group of peculiar F dwarfs is simply an extension to hotter temperatures of the subgiant CH phenomenon. The identification of these stars as an earlier stage in the life of barium giants appears to solve the white dwarf cooling time scale problem. Bond (1984) searched for white dwarf companions of 21 subgiant CH stars but failed to find any such hot companions. Thus, even among the barium giant precursors, hot white dwarf companions are extremely elusive.

Two mass transfer mechanisms for stars on the asymptotic giant branch have been suggested to create the barium stars. McClure (1983) suggested that mass transfer resulted from Roche lobe overflow while Boffin & Jorissen (1988) and Jorissen & Boffin (1993) have argued strongly that stellar-wind accretion before Roche-lobe overflow is more likely. Tout & Eggleton (1988) independently proposed that a significantly enhanced stellar wind occurs before Roche-lobe overflow in some Algol-like binaries and suggested that such a mechanism is applicable to barium stars as well.

Boffin & Jorissen (1988) noted that Roche-lobe overflow of the asymptotic giant branch star in these systems should lead to common-envelope evolution and circularized orbits, neither of which is seen in the barium stars. They developed a preliminary wind-accretion model, concluded that their model is in better agreement with current observational results for barium stars, and claimed that their model could produce such systems with periods as long as 100 years. Whether mass transfer in long-period systems can be squared with the conclusion of Luck & Bond (1991) that subgiant CH stars must have thick mantles of processed material remains to be seen. Abundance analyses of supposed mild barium stars with long-period orbits should be done to see if the *s*-process enhancements are indeed present in such systems.

We examine the characteristics of the four chromospherically active systems with hot compact companions in the context of the barium star scenario. HD 185510 ($P = 20.7$ days) and 39 Cet (56.8 days) have periods so short that mass transfer must have begun in both systems when each former primary star ascended the giant branch for the first time. Thus, there is no possibility that the mass donor reached the asymptotic giant branch phase where *s*-process elements might be transferred to its surface. Tout & Eggleton (1988) modeled Case B mass transfer when the mass donor possessed a deep convective atmosphere. They argued that if common envelope evolution is not to be the result, the mass donor must develop an enhanced stellar wind. Although in many cases Roche-lobe mass transfer would eventually begin, in some cases the wind might deplete the entire envelope of the donor before it reached its Roche-lobe limit. They concluded that 39 Cet and HD 185510 are examples of this revised Case B mass transfer model. Thus, the evolutionary state of these systems is consistent with a lack of abundance anomalies seen in the cool star and a white dwarf or pre-white dwarf companion.

Despite the conclusion that mass transfer from the now compact companion is complete, we note that HD 185510 still has a modest nonzero eccentricity.

At the other end of the period range is HD 165141. This mild barium system has one of the longest orbital periods, about 14 years, known for such stars. Its period is similar to that of ζ Cyg, which has a period of almost 18 years (Griffin & Keenan 1992), and 16 Ser, whose period is about 16 years (Griffin 1991). Like the two other mild barium stars just mentioned, the separation of the components is so large that HD 165141 must have been a detached system at all times. That such stars have enhancements of *s*-process elements lends support for mass transfer by an enhanced stellar wind.

The last system, HD 160538, appears to be more difficult to reconcile. Its period of 904 days and eccentricity of <0.1 are quite consistent with those of barium stars. Jorissen & Boffin (1992) list 21 red giant binaries whose orbits have similar characteristics to those of the barium stars but apparently have "normal" abundances of *s*-process elements. Thus, they conclude that duplicity is not sufficient to produce a barium star. Although they identify three normal giants with white dwarf companions, the white dwarf identification for two of the three is questionable (one is ξ^1 Cet) and the third star has an unknown period. The existence of HD 160538, which has an appropriate orbital period and hot white dwarf companion, means that the conclusion of Jorissen & Boffin (1992) can be taken one step further. The existence of a white dwarf companion is not sufficient to produce a barium star. Indeed, Jorissen and Boffin suggest that another parameter is important for the creation of a barium star. In particular they note a tendency for strong barium stars to be metal poor and suggest that stars with solar or greater than solar iron abundances do not become barium stars. Abundance analyses of HD 160538 and HD 165141 could test such a hypothesis. Our spectrum comparisons indicate that these two stars as well as HD 185510 have near solar iron abundances.

Note added in proof: In 1993 September two additional spectroscopic observations of HD 165141 were obtained at KPNO with the coudé feed telescope and spectrograph system. The new velocities at phases 0.807 and 0.808 are in excellent agreement with the preliminary 14 yr orbit and show that the "rapid" velocity decrease is continuing as predicted.

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