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MASS LOSS IN THE 96 DAY BINARY UU CANCRI

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ABSTRACT

UU Cnc is a long-period binary containing a tidally distorted K giant. The system is most likely semidetached with the K4 giant losing mass in a wind and through Roche lobe overflow. We have obtained a series of 16 high-dispersion spectra at Hα (covering orbital phases 0.65–0.02 and 0.26–0.42) which let us (1) study the K giant's Doppler profiles and (2) look for effects of accretion onto the second component. The radial velocities and recent photometry from an automatic photometric telescope are combined with existing observations to refine the orbital period (96.692 ± 0.005) and epoch of conjunction (HJD 2,446,483.12 ± 0.08). Doppler profiles of the system for a semidetached configuration fit the observations very well; however, those for *existing* overcontact light-curve solutions all give poorer fits, some very much poorer. The best representative value of $v \sin i$ for this star is 25 km s^{-1}, higher than our previous estimate, which leads to a mass ratio near $M_2/M_{gK4} = 1.2$ for a semidetached system. The Hα line is always stronger than those of the common giants, α Tau, for example, but its equivalent width (1.31 Å) is consistent with a K4 II classification, reflecting the star's large ($\sim 50\ R_\odot$) radius. The phase dependence of the Balmer lines, noted previously by Popper in blue-violet spectra, has the form of greatly strengthened Hα absorption when the K giant is behind its unseen companion and emission in the wings, sometimes redshifted, when it is in front. The nature of the absorbing gas is somewhat unexpected. Velocities of the excess absorption are inconsistent with formation solely in a disk; they imply a large-scale flow away from the binary at superior conjunction and probably result from outflow past the outer Lagrangian point. Emission wings in Hα are possible evidence for an accretion disk, but scattering off this outflow may contribute to them as well.

Subject headings: line profiles — stars: eclipsing binaries — stars: individual (UU Cancri) — stars: mass loss

1. INTRODUCTION

The binary UU Cnc is remarkable in that it contains a K4 giant so highly distorted that it must be filling its Roche lobe. This makes a knowledge of UU Cnc critically important for testing theories of response of giants to Roche-lobe overflow (Hjellming 1989), of dynamos in luminous evolved stars (Hall 1990b), and of the relative importance of mass loss and exchange in giant binary systems (Tout & Hall 1991).

In the first thrust of the concentrated attack called for by Popper (1977), we recently (Eaton 1990a) combined optical photometry, ultraviolet (*IUE*) spectroscopy, and extremely limited optical spectroscopy to determine the structure of UU Cnc. The system seems to be semidetached, consisting of a K4 giant of $\sim 50\ R_\odot$ radius and an undetected, somewhat more massive star. Most of the 0.5 mag light variation in the optical is ellipsoidal, although ~ 0.05 mag of the primary minimum may be contributed by an eclipse of the K giant by the second star or by a disk around it, represented by a star with $r_2 = 0.07$ in the light-curve solutions. Our understanding of the system, however, is still incomplete, and there remains controversy over the interpretation of the evidence in hand. Three light-curve solutions have been presented in which the star is a contact binary with *both* components overfilling their Roche lobes (Winiarski & Zola 1987; Barone et al. 1989; Lee, Nha, & Leung 1991). This configuration would seem to be inconsistent with the observed broadening of photospheric spectral lines (Eaton 1990a). Yet the validity of using $v \sin i$ as a constraint on light-curve solutions of giant binaries has been questioned (e.g., K.-C. Leung 1989, telephone conversation). In addition, there is the hanging question of the Balmer absorption. Popper (1977) found the Balmer lines in the blue-violet to be abnormally strong throughout the orbit and to strengthen markedly near the K4 star's superior conjunction. The phase-dependent Balmer absorption seemingly implies a semidetached accreting system, but a strong, phase-dependent chromosphere or wind from the unseen component of a contact system is an alternative possibility.

We have obtained 16 high-dispersion optical spectra in the Hα region and a season of photometry from an automatic photometric telescope to use in confronting the photometric solutions and in investigating the wind and accretion structures in this binary.

2. OPTICAL PHOTOMETRY

We have made ~ 100 observations in the B and V bands of the UBV system with the Vanderbilt 16 inch (41 cm) automatic photometric telescope (APT) at Mount Hopkins, Arizona. These cover the interval HJD 2,447,800 to HJD 2,447,980. Being ninth magnitude, UU Cnc was a difficult object for the

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TABLE 1

TIMES OF CONJUNCTION

Epoch	Time (HJD)	$(O - C)$	Source
−129	2,434,010.58 ± 0.97	0.73	1
−56	2,441,069.26 ± 0.45[a]	0.89	2
0	2,446,483.08 ± 0.11	−0.04	3
−113	2,435,560.2	3.28	4
−19	2,444,645.63 ± 0.28	−0.34	5
−15	2,445,032.00 ± 0.08	−0.74	5
0	2,446,482.3	−0.82	6
3.5	2,446,821.20	−0.34	6
4	2,446,870.24	0.35	6
4.5	2,446,918.78	0.55	6
15	2,447,932.92 ± 0.25	−0.58	7
15	2,447,933.76 ± 0.28	0.26	8

[a] Recomputed by D. S. Hall.

SOURCES.—(1) Popper 1977; (2) Eggen 1973; (3) all V-band data; (4) Beyer 1964; (5) Winiarski & Zola 1987; (6) Lee et al. 1991; (7) APT − V; (8) V_R, Table 2.

current generation of APTs, which must center their stars by groping about on the sky. Furthermore, UU Cnc is situated so as to be passed very closely by the full moon once per month. In fact, several nights' data were lost to contamination by moonlight. Nevertheless, the resulting data were no less precise ($\sigma \sim 0.01$ mag) than the published photometry of Winiarski & Zola (1987) and Lee et al. (1991). The comparison star was HD 65450, chosen because Winiarski & Zola's comparison star was too faint for the APT. HD 66116 served as a check star.

The new photometry was taken to determine more accurate phases for the spectroscopy and to search for changes in the light curve. Results are given in Table 1. We now have photometry over an interval of 16 yr in the three data sets (Winiarski & Zola 1987; Lee et al. 1991; APT). A set of light curves by Eggen (1973) extends this interval to 18 yr, and Popper's (1977) radial-velocity curve extends the interval for a period determination further, to 38 yr. Although UU Cnc is primarily an ellipsoidal variable, it is still possible to determine accurate times of conjunction by fitting a Fourier series

$$l = A_0 + A_1 \cos \theta + A_2 \cos 2\theta \qquad (1)$$

to the photometry, where θ is the orbital phase (Hall 1990a). By minimizing χ^2 with respect to the zero point of the phases, the time of conjunction may be found. Furthermore, by minimizing χ^2 with respect to period, an improved period may be obtained as well. We have fitted equation (1) to the three V-band data sets as a group, shifting the APT data by −1.208 mag and the data of Lee et al. by −1.363 mag to agree with those of Winiarski & Zola. This process gave a period of 96.679 ± 0.010 days and a mean epoch for the data set of HJD 2,446,483.08 ± 0.11. In addition, we have applied the technique to the V-band data from the APT alone and to the photometry of Eggen (see Table 1). Application of a program that calculates the length of a line connecting adjacent points for assumed periods to the V-band data of Winiarski & Zola plus APT gave a period of 96.675 days, versus 96.68 (Eaton 1990a) from Winiarski & Zola alone.

The radial-velocity curve of Popper (1977) provides a much earlier epoch of conjunction which may be use to improve the period marginally. Since the theoretical curve in Popper's Figure 1 is demonstrably shifted in phase with respect to the data, we have redetermined the time of conjunction from his data by fitting a sine curve ($e = 0.0$) to them, being careful to omit two suspect velocities near conjunction. We found a second spectroscopic time of conjunction by fitting a sine curve to the radial velocities in Table 2. These two values are listed in Table 1; combined, they yield a period of 96.693 ± 0.007 days. We have derived a revised ephemeris for UU Cnc from the photometric epoch (of all V data) and the two spectroscopic epochs,

$$\mathrm{HJD(Obs.)} = 2{,}446{,}483.12 + 96.692\ \mathrm{phase}\ , \qquad (2)$$
$$\pm 0.08 \qquad \pm 0.005$$

and have used it throughout our analysis. Table 1 gives deviations from this ephemeris which measure in practical terms the accuracy expected for calculated phases. We have included all available published times of conjunction, most of which were included indirectly in the epoch determination. The times for Eggen's light curve (epoch −56) and the APT data (epoch 15) were found by fitting equation (1) to those V-band data. The typical uncertainty in Table 1 is ±0.5 days, so the phases probably cannot be determined to better than ±0.005 phase units.

In general, the three photometric data sets agreed quite well. Primary minimum in the APT data, however, was ~0.02 mag shallower than in Winiarski & Zola's light curve. This would seem to represent a change in the light curve, indicating that a variable atmospheric eclipse is responsible for part of the light loss; however, it may result from contamination of one of our two observed primary minima by moonlight.

3. OPTICAL SPECTROSCOPY

We have obtained observations around the Hα line with the stellar spectrograph of the McMath solar telescope of the National Solar Observatory at Kitt Peak, Arizona. The instrument gave a dispersion of 0.09 Å pixel^{-1}, with ~2 pixels per resolution element, and the spectra were recorded with an 800 × 800 pixel TI CCD. Most of the spectra were taken by Paul Avellar, the resident observer, but we had a run of six nights around conjunction in early 1990 February during which we observed UU Cnc on four nights and obtained

TABLE 2

OPTICAL SPECTRA OF UU CNC

HJD −2,447,000	Exposure (s)	Phase	RV (km s^{-1})	EW(Hα)[a] (Å)
899.018	3900	0.64	86	1.28
901.008	1500	0.66	85	1.32
902.964	1800	0.68	85	1.38
911.949	2700	0.78	87	1.31
915.969	1800	0.82	85	1.29
925.924	5400	0.922	68	2.50
926.967	2700	0.932	70	2.83
928.849	7200	0.952	64	3.29
929.786	4800	0.962	62	3.66
932.766	4800	0.992	52	4.06
933.779	4800	0.003	51	3.78
958.830	2400	0.26	11	1.18
970.793	1800	0.39	24	1.40
971.875	2400	0.40	25	1.33
972.868	2100	0.41	27	1.40
973.800	2100	0.42	30	1.38
644.62[b]	900	0.012	51[b]	4.01

[a] Errors on EW are ±0.10 Å for EW < 1.5 Å, ±0.20 Å for EW > 2 Å. Errors on the velocities are ~ ±2.

[b] From Eaton 1990a.

spectra of many other cool giants for comparison. Table 2 gives a journal of the observations and measurements of the radial velocity from metallic lines and the equivalent width of the Hα absorption. The radial velocities agree with Popper's velocity curve to within their errors of measurement (± 2 km s^{-1}). Fitting a sine curve to Popper's and our radial velocities, we find $K = 38.7 \pm 1.4$ km s^{-1} and $\gamma = 50.7 \pm 0.9$ km s^{-1}, which are marginal improvements over Popper's values (38.3 and 50.3). A value of $K = 39.8 \pm 0.8$ km s^{-1} can be derived from our velocities alone, but since the phase coverage of our velocity curve was poor, we hesitate to use it.

The spectra are plotted in Figure 1. We can easily notice two features of them: the Doppler broadening of the metallic lines and the marked phase dependence of Hα. Except near conjunction, the star has essentially the spectrum of a rotationally broadened K-type bright giant. Hα is sensitive to luminosity in this range, and we have measured its equivalent width in a sample of stars containing most of the intrinsically bright K giants we observed (Table 3). The equivalent width for phases 0.65–0.82 is 1.31 Å, which places UU Cnc among the bright giants (K4 II), unless the equivalent width is affected by the binary system. This luminosity class is quite reasonable for the $\sim 50\ R_\odot$ radius, which is about one-third that of a typical ζ Aur K supergiant. It thus appears unlikely that being in a binary system has enhanced the Hα absorption much. The same conclusion applies to ζ And, a K1 component of a close detached binary which has somewhat elevated Mg II emission for a K1 star.

3.1. *Dopper Profiles of the K Giant*

Because this star is primarily an *ellipsoidal* variable, the solution of its light curve is indeterminate. This was shown by Winiarski & Zola (1977), who published equally good solutions for both a semidetached and an (over)contact configuration. More recently, Barone et al. (1989) and Lee et al. (1991) have presented contact solutions of radically different nature, the latter requiring a system of 57 $M_\odot$. We can use the shapes of rotationally broadened metallic lines (Doppler profiles) to discriminate among these solutions, as we have already done in Eaton (1990a). This technique works primarily because the various photometric solutions give different radii for the K giant. It is especially effective in this case because the appearance of blends near Hα depends critically on the size and shape of the star. The phase dependence is easily seen in blends near 6576 and 6594 Å, marked in Figure 1. All that is necessary to apply this approach is the velocity amplitude of the K giant (we used 38.3 km s^{-1} from Popper) and the elements of the photometric solution (Table 4).

Eaton (1990a) used two determinations of $v \sin i$ near conjunction to constrain a light-curve solution, but this approach is potentially subject to several sorts of error. The line

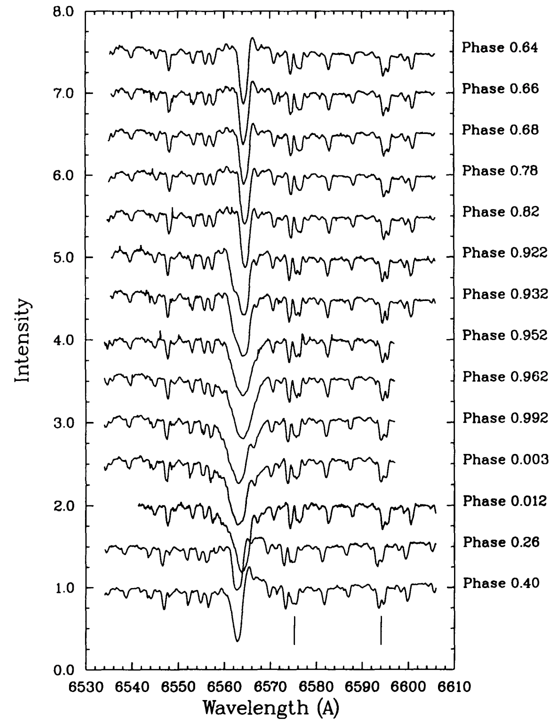

FIG. 1.—Hα spectra of UU Cnc taken over its orbit. All these spectra were obtained on single nights except for the bottom one for phase 0.40, which is a composite of data for phases 0.39 and 0.42. The metallic lines seen here are broadened by the rapid rotation, near $v \sin i = 25$ km s^{-1}. Note how the strength, breadth, and asymmetry of Hα changes with orbital phase. For the earliest phases, there is redshifted emission, possibly extending over the whole profile. At phases 0.64–0.82 and 0.26–0.40, the central absorption is roughly constant in strength, with EW = 1.3 Å, and is roughly the right strength for a normal bright giant. At phases near conjunction (0.92–0.02), the line is much stronger, reaching an equivalent width of 4 Å. Observations for phases 0.25–0.75 show pronounced, redshifted emission in the wing of Hα, with an equivalent width close to 0.9 Å, which may be radiation reflected off the wind seen near conjunction. Also note how the change with phase in Doppler broadening of this tidally distorted binary is detected in the blending of metallic lines in the marked features of 6576 and 6594 Å.

TABLE 3

PROPERTIES OF COMPARISON STARS

Star	Spectral Type	EW(Hα)[a] (Å)
α Tau	K5 III	1.16
β Cnc	K4 III	1.21
α Hya	K3 II–III	1.18
π^6 Ori	K2 II	1.41
HR 2450	K2 II	1.38
ι Aur	K3 II	1.30
ζ Aur	K5 Ib + B	1.65
ψ^1 Ari	K6-M0 Iab	1.32
ρ Per	M4 II(I)	1.05
α Ori	M2 I	1.18
ζ And	K0 II	1.38
HR 439	K0 Ib + B9 V	1.53
HR 958	K1 III + A6 V	1.38
58 Per	K4 III + A3 V	1.75
5 Cet	K2 III + ?	1.21
HR 2137	K0 III + A2	1.23
35 Com	G8 III + A6	1.11

[a] Errors in EW are in the range 0.03–0.10 Å.

TABLE 4

PROPERTIES OF THE LIGHT-CURVE SOLUTIONS

q	i	f	T_m	$R_{side} \sin i$ ($R_\odot$)	Source
0.303	67°0	0.15 (con)	0.82	170	1
1.131	59.0	0.58 (con)	0.70	52	2
1.20	58.5	0.64 (con)	0.00	52	3
1.147	72.0	1.00 (s-d)	0.70	49	2
1.50	75.0	1.00 (s-d)	0.00	41	4

SOURCES.—(1) Lee et al. 1991; (2) Winiarski & Zola 1987 (this semidetached solution used $g = 0.6$); (3) Barone et al. 1989; (4) Eaton 1990a.

broadening was interpreted in terms of a circular limb-darkened disk. Since the relationship of $v \sin i$ to a radius of an ellipsoidal star is somewhat ambiguous, this approach may be expected to incorporate systematic errors. Likewise, since UU Cnc is a rather luminous K star, the intrinsic (turbulent) broadening found in cool supergiants might make the measured value of $v \sin i$ too large. Finally, the derived mass ratio is sensitive to errors in $v \sin i$. Indeed, the new spectra obtained in this program (Eaton 1990b) show our previous value of $v \sin i$ (22 km s^{-1}) was too small, that a value near 25 km s^{-1} is more appropriate. This change, in itself, decreases the derived mass ratio from 1.47 to $\sim$1.20. The effect of UU Cnc's elevated luminosity is easy to evaluate. We have broadened spectra of the following stars to 25 km s^{-1}: α Tau (K5 III), β Cnc (K4 III), α Hya (K3 II–III), ι Aur (K3 II), and ζ Aur (K4 Ib), finding no differences in the blending of the lines, despite the obvious differences in line widths of the original spectra. This is actually to be expected, since the convolution of the $\sim$5 km s^{-1} turbulence of a supergiant with 25 km s^{-1} rotation must be dominated by the rotation.

The question of relationship of $v \sin i$ to a radius of the star remains. To surmount it, we have used a computer program that calculates the line profile for a contact binary from the observed profile of a slowly rotating single star, ι Aur in this case. We assume, of course, that each element of the binary's surface has the same spectrum as this single star, independent of limb and gravity darkening. The surface of the star is taken to be a Roche equipotential. For studying the semidetached solutions, this program was modified to find only the contact component. The photometric elements used are given in Table 4. There, q is the mass ratio, unseen star to K giant, i is the inclination of the orbit, f is a fillout factor, which ranges from 1.0 for stars just filling their Roche lobes to 0.0 for stars filling the next larger limiting Lagrangian surface, and T_m is the temperature multiplier which specifies how hot the second (unseen) component is relative to how hot it would be if temperature varied smoothly over the contact binary's surface according to the gravity-darkening law. We use standard convective gravity darkening ($g = 0.3$), unless otherwise specified, and use a linear limb-darkening coefficient of $x = 0.85$.

This calculation contains a systematic error common to almost all determinations of $v \sin i$; the intrinsic profile is assumed to be constant over the disk. The real profiles must be somewhat limb darkened, and they probably change somewhat over the surface because of changes in gravity and effective temperature. We doubt these effects are important in this case. The limb darkening of the line strengths should be rather insignificant. Calculations of line profiles for a *solar* model with ATLAS (Kurucz 1970) show a mere 15% drop in equivalent width of metallic lines near Hα between $\mu = 1.0$ and $\mu = 0.3$. The effect of this change can be estimated by comparing calculated spectra for different degrees of continuum limb darkening, since this approximates the change in equivalent width by weighting the disk center and limb differently. However, a change of 0.25 in the limb darkening produces somewhat less effect on the line profiles than a change of 0.1 in the mass ratio. Similar spectra calculated for models with $T_{\rm eff} = 5000$ and 4600 K, both with $\log g = 3.0$, show hardly any limb darkening at all in the moderately strong lines used to analyze the Doppler profiles. Furthermore, these calculations show only a slight change in equivalent width with effective temperature, roughly a 10% increase between 5000 and 4600 K. This is because for the Fe I lines we used, the changes in excitation and ionization with $T_{\rm eff}$ roughly balance; this makes the column density roughly independent of effective temperature for them. Even though the semidetached model is expected to have variations over its surface of $\sim$500 K, the effects of this should be no greater than expected from the moderate limb darkening of the solar model.

Calculated Doppler profiles at phase 0.75 are shown in Figure 2. Those for contact configurations are at the top, those for semidetached configurations at the bottom; a composite observed spectrum is in between. It is immediately obvious that the contact configurations all give too much rotational broadening at these phases; they simply have radii that are too large. This could be overcome by making the mass ratio larger ($M_2/M_{\rm gK4} > 1.2$). However, calculations for other phases indicate the *phase dependence* of broadening predicted by these contact models is also incorrect. To see how well the computed spectra fit the observed ones, we calculated spectra for representative phases around the orbit for the solutions of Barone et al. (contact) and Winiarski & Zola (semidetached). Interestingly enough, both models showed roughly the same line profiles for phases 0.93–0.03, and it was only near elongation that differences became significant. The contact solution thus had too much phase dependence to fit the data. The semidetached solution of Winiarski & Zola, on the other hand, gave a very good fit to the profiles, both at elongation (Fig. 2) and near conjunction. In contrast, the profiles for the semi-

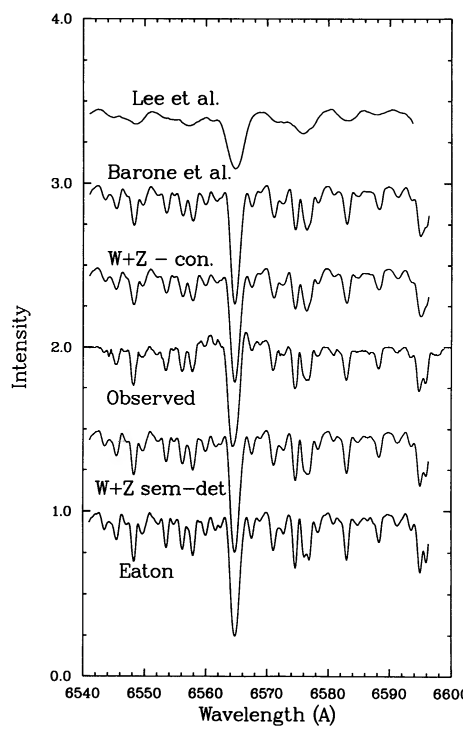

FIG. 2.—Doppler profiles at phase 0.75 for various solutions of the optical light curve. Contact solutions are at the top, semidetached at the bottom. A composite spectrum of UU Cnc (phases 0.64–0.82, shifted to phase 0.75) is given in the middle. The calculated spectra are formed by broadening a spectrum of the K3 II giant ι Aur, which has very nearly the same equivalent widths in Hα and the metallic lines as UU Cnc at these phases. This figure illustrates just how sensitive the blends at 6576 and 6594 Å are to changing $v \sin i$. This sensitivity makes it possible to decide practically at a glance whether the blending in observed and calculated spectra is the same. We thereby may determine precise rotational velocities by using the same efficient methods as applied in classifying stellar spectra.

detached solution of Eaton (1990a) are too narrow, reflecting the incorrectly large mass ratio.

3.2. *Phase Dependence of* Hα

Although we have seen that the strength of the Hα absorption line is just what is expected of a K4 II star, the profiles do have two significant phase-dependent properties: (1) strengthened absorption near the possible eclipse of the K giant and (2) excess emission in the wing far from this eclipse, extending over a range of ~ 10 Å, or 450 km s^{-1}.

Strengthened absorption lines near superior conjunction of the mass-losing star is apparently common in classical Algols (see, e.g., Peters 1989, especially UX Mon near phase 0.5). In UU Cnc, superior conjunction of the mass-losing star occurs at phase 0.0. The absorption lines in UU Cnc are seen to strengthen significantly near phase 0.0, first through the appearance of a blue wing, then by a more general symmetrical broadening and development of extended wings. Velocities in the wings are far too great for absorption by chromospheric material magnetically confined above a synchronously rotating secondary star, for which the absorption would be confined to the 25 km s^{-1} Doppler profile. Likewise, absorption by a prograde disk cannot fit the observations, since disk material would be *redshifted* at these phases. The material responsible for the extra absorption must cover a sizeable fraction of the K star and must have a velocity toward Earth of nearly 140 km s^{-1}. This is in the correct sense for absorption at this phase by an accretion stream, but such a stream would have to originate over an appreciable fraction of the K giant's disk. A second, related possibility is absorption of material outflowing past the outer Lagrangian point. Extra absorption near phase 0.5 is also apparent in some high-inclination cataclysmic variables (CVs), e.g., Downes et al. (1986), Honeycutt, Schlegel, & Kaitchuck (1986). Honeycutt et al. proposed an explanation for the phase 0.5 CV absorption which also involves material gathered near the outer Lagrangian point, but Szkody & Piche (1990) have suggested that this absorption may occur instead in the outer edge of the CV accretion disk. In any case this similar behavior in CVs and Algols is intriguing.

Another alternative explanation for the strengthened absorption is a wind, either from an accretion disk or from the secondary star. In this case we would expect the wind to emerge roughly isotropically from the star or symmetrically from the poles of the disk. The absorption would be seen strongest at the rest wavelength of the line, with wings extending to both the blue and red, since neither sort of wind ever seems to be collimated. In contrast to the case of ζ Aurigae binaries, in which only the blueshifted component is seen, there is no source of hot radiation in this system to ionize the gas producing the red component. Again, the model is not consistent with the velocity structure of the Hα profile, which in most spectra over phases 0.92–0.02 is plainly blueshifted with respect to photospheric lines. This shift would require the wind to blow preferentially but unexpectedly away from the K giant.

The excess wing emission is also seen in the similar interacting binary 5 Ceti (Eaton & Barden 1988) and is reminiscent of the behavior of those Algol binaries with enough room for a large disk (e.g., Peters 1989). Outside eclipse, such systems show emission in the wings of the Balmer lines, presumably formed in optically thin regions of an accretion disk, superposed on the wings of the B star's photospheric Balmer lines. The velocity spread in these shorter period systems is typically 900 km s^{-1}, roughly twice that in UU Cnc or 5 Cet. Smak (1981) derives a relation between the peak velocity of a classical double-peaked accretion emission line profile and V_d, the velocity of the disk at the outer radius, namely

$$v_{\rm peak} = 1.06 v_d \sin i . \qquad (3)$$

In UU Cnc $v_{\rm peak} \sim 100$ km s^{-1}, giving $v_d \sim 100$ km s^{-1} for $i = 75°$. The outer disk radius is then $\sim 39\ R_\odot$, well inside the Roche-lobe radius ($\sim 55\ R_\odot$) of the unseen gainer. We might expect the probable 0.05 mag V-band eclipse and the atmospheric eclipse in Hα also to be caused by this putative disk. However, the inferred radius is *much* bigger than the optically thick disk needed for the V-band eclipse, $R/a = 0.28$ versus 0.07, yet it is barely large enough to allow the duration of the eclipse in Hα while the velocity structure of Hα is not consistent with absorption in an accretion disk at phase 0.92. Further, the Hα emission is mostly redshifted near phase 0.5, implying it may be light scattered by material flowing away from the K giant rather than emitted or scattered by material circulating in a disk. Thus an accretion disk may not be the best explanation for the Hα emission wings. Of course, the double-peaked appearance of the emission wings could be due to a single-peaked emission line, superposed on central photospheric absorption. But the fact that the absorption strength is normal for the spectral class, coupled with the consistent accretion disk velocities, makes a disk a possible contributor to the emission wings. A third possibility is that the emission is all photospheric light scattered off the stream absorbing near phase 0.0; the redshift in the emission is roughly consistent with the blueshift in absorption. However, the strength of the total emission is too great for scattering of photospheric light by the material producing the extra absorption, and thus requiring the same gas to produce both the emission and the absorption seen near conjunction may be overly restrictive.

4. DISCUSSION

The new spectroscopic evidence strengthens greatly the conclusion that this system is semidetached. Changes in line profiles of metallic lines near Hα, specifically in their blending, are predicted by a rotating Roche lobe-filling star. While changes in the broadening of lines in spectra of contact binaries (W UMa systems) are implicitly detected in analyses with cross-correlation functions (e.g., Hill, Fisher, & Holmgren 1989), to our knowledge this is the first detection of the phase dependence in a semidetached binary. This phase dependence is not consistent with the sorts of contact solutions that fit the light curves, while it is actually predicted quite well by a semidetached solution with $q \approx 1.2$. The flow of matter detected in Hα absorption and the putative emission from an accretion disk also require a semidetached system.

The mass ratio must be near 1.20, perhaps a bit less, which presents problems for the light-curve solution. Specifically, the limb-darkening coefficients or gravity exponent must be elevated above their theoretical values, as found for the gravity exponent, g, by Winiarski & Zola (1987). The masses are also increased to $M_{\rm gK4} = 1.72\ M_\odot$ and $M_2 = 2.06\ M_\odot$, with $R_{\rm gK4} = 49\ R_\odot$ and $a = 137\ R_\odot$ for $i = 75°$. This exacerbates the problem of hiding the second star, which is not detected in the ultraviolet as an A or F spectrum (Eaton 1990a). The ultraviolet spectrum, however, is ~ 4 times as bright near 3000 Å relative to the V band than a K4 giant, leaving the possibility that the unseen second star is also evolved past the main sequence, probably a G giant.

Semidetached solutions of the light curve (Winiarski & Zola; Eaton 1990a) estimate that ~ 0.05 mag of the 0.5 mag depth of primary minimum comes from an eclipse of the K giant. The phase dependence of Hα suggests part of this could be an atmospheric eclipse by an accretion disk. However, the metallic lines in Figure 1 are not strengthened at conjunction and therefore do not contribute to the dimming. Balmer lines, themselves, can account for no more than a 1% attenuation. So any eclipse must be by the body of the accreting star or by the inner, optically thick parts of a disk, and the eclipse may well be caused by the body of the unseen second component.

This is a critically important star for binary evolution. For a wide range of masses and radii, it is thought that cool, convective giants in binaries become unstable to rapid mass loss through Roche-lobe overflow when they evolve into contact (e.g., Livio 1988). Some systems clearly must do this to produce the many observed short-period systems with white dwarfs so massive as to have come from asymptotic giant-branch stars. The existence of a cool giant component in contact with its Roche lobe in the 96 day binary 5 Ceti has challenged this conventional wisdom, for in it the giant is actually more massive than its companion (Eaton & Barden 1988). So there may be circumstances in which the giants do not react as rapidly or in the same way as predicted for convective stars by present models. UU Cnc extends this challenge in that, although the K giant is losing mass to a more massive companion, the mass ratio is essentially the critical value $q = 1.28$ at which the mass loser has its minimum radius and, consequently, the transfer rate should be very high (Tout & Hall 1991). In 5 Ceti, the inclination is low enough that we have not yet obviously seen the accretion flow, although there is evidence for mass transfer in the accretion luminosity detected in the ultraviolet. So it might be argued the star is not yet in contact with its Roche lobe. This escape is not possible for UU Cnc, for although there is no clear evidence of accretion luminosity, a likely accretion *flow* is detected in the Balmer lines. Tout & Hall have developed a model in which loss of mass and angular momentum through a magnetized wind drives conservative mass exchange in binaries like UU Cnc. The reality of mass loss in a directed flow out of the system means that the transfer is not conservative and that this analysis will be incorrect at least in detail, with time scales shortened and orbital evolution more extreme.

Finally, we feel this study shows that using line broadening has great potential for determining mass ratios in single lined spectroscopic binaries and for discriminating among light-curve solutions of binaries. Hall (1990a), as well as Eaton & Barden (1987), has used rotational velocity ($v \sin i$) as a crucial constraint in solving light curves of ellipsoidal variables. By showing that it is possible to detect even the predicted *phase* dependence of rotational broadening, our spectra for UU Cnc provide a strong underpinning for this technique. Nevertheless, there will be some systematic errors involved, as discussed in § 3.1, but they must be relatively small in comparison with the large uncertainties inherent in light-curve solutions of primarily ellipsoidal binaries, and they are probably less severe than the uncertainties in light-curve solutions (see, e.g., Winiarski & Zola for UU Cnc) resulting from the fact that the gravity darkening of giant stars has not yet been reliably measured.

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REFERENCES

Barone, F., Milano, L., Russo, G., & Sarna, M. J. 1989, Ap. Space Sci., 159, 67
Beyer, M. 1964, Astr. Nacht, 280, 87
Downes, R. A., Mateo, M., Szkody, P., Jenner, D. C., & Margon, B. 1986, ApJ, 301, 240
Eaton, J. A. 1990a, MNRAS, 247, 62
———. 1990b, Inf. Bull. Var. Stars, No. 3460
Eaton, J. A., & Barden, S. C. 1988, Acta Astr., 38, 353
Eggen, O. J. 1973, PASP, 85, 42
Hall, D. S. 1990a, AJ, 100, 554
———. 1990b, in IAU Colloq. 130, The Sun and Cool Stars: Activity, Magnetism, and Dynamos, in press
Hill, G., Fisher, W. A., & Holmgren, D. 1989, A&A, 218, 152
Hjellming, M. S. 1989, in IAU Colloq. 107, Algols, ed. A. H. Batten (Dordrecht: Kluwer), 155
Honeycutt, R. K., Schlegel, E. M., & Kaitchuck, R. H. 1986, ApJ, 302, 388
Kurucz, R. L. 1970, SAO Spec. Rept, No. 309
Lee, Y. S., Nha, I.-S., & Leung, K.-C. 1991, ApJ, submitted
Livio, M. 1988, in IAU Colloq. 107, Algols, ed. A. H. Batten (Dordrecht: Kluwer), 299
Peter, G. J. 1989, Space Sci. Rev., 50, 9
Popper, D. M. 1977, PASP, 89, 315
Smak, J. 1981, A&A, 31, 395
Szkody, P., & Piche, F. 1990, ApJ, 361, 235
Tout, C. A., & Hall, D. S. 1991, AJ, submitted
Winiarski, M., & Zola, S. 1987, Acta Astr., 37, 375