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OUTER ATMOSPHERES OF COOL STARS. X. HR 1099 AT QUADRATURE

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ABSTRACT

We report high dispersion, far-ultraviolet (1150–2000 Å) spectra of the active chromosphere, RS CVn binary HR 1099 = V711 Tauri (K0 IV + G5 V) obtained with the *International Ultraviolet Explorer*. Observations were taken near the opposite orbital quadratures (maximum radial velocity separation). Emission features produced by high temperature species, such as C II and C IV, are very bright, exhibit structure, change significantly in the one week interval separating the two exposures, and generally follow the radial velocity motion of the K subgiant primary. The less massive G dwarf secondary appears only weakly in the composite spectrum, if at all. We conclude, in agreement with previous studies, that chromospheric and transition region emission in RS CVn binaries is genuinely a stellar, rather than a system, phenomenon. The association of the major emission source with the more rapidly rotating and somewhat cooler primary lends support to the rotation-activity connection thought to be at least partially responsible for establishing the magnetic behavior of convective stars. We interpret the structure apparent in some of the emission line shapes as a patchy brightness distribution on and above the K star surface that is spread out in velocity by the rapid rotation. We argue further, from the general appearance of the emission line shapes, that the chromosphere is confined to the stellar surface, while the higher temperature material resides in a more extended volume of space around the K star. A similar argument provides support for the notion that the He II 1640 Å Balmer α emission is formed in the chromosphere by a photoionization-recombination mechanism, rather than at higher temperatures by direct collisional excitation.

Subject headings: stars: binaries — stars: chromospheres — stars: individual — stars: late-type — ultraviolet: spectra

I. INTRODUCTION

The short-period ($P = 2^{d}.8$) RS CVn system HR 1099 = V711 Tauri (K0 IV + G5 V)[3] is an active chromosphere, noneclipsing binary that has been studied intensively in the radio (Owen, Jones, and Gibson 1976; Feldman *et al.* 1978), optical (Bopp and Fekel 1976; Furenlid and Young 1978; Weiler 1978; Dorren *et al.* 1980), ultraviolet (Anderson and Weiler 1978; Linsky *et al.* 1978; Simon and Linsky 1980), and soft X-ray bands (Walter, Charles, and Bowyer 1978). Here, we present two high dispersion spectra (FWHM ≈ 30 km s^{-1}) of HR 1099 obtained with the short-wavelength camera and echelle spectrograph of the *International Ultraviolet Explorer* (*IUE*; Boggess *et al.* 1978).

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[3] We adopt the spectral types of Bopp and Fekel (1976), designate the more massive star as the spectroscopic primary, and follow the convention that measures phases from the conjunction with the primary star in front (ephemeris of Weiler *et al.* 1978).

II. OBSERVATIONS

a) *Observing Sequence*

Far-ultraviolet (1150–2000 Å), *IUE* echelle spectra of HR 1099 were obtained on 1980 July 16 (phase 0.76 ± 0.05) and on 1980 July 23 (phase 0.21 ± 0.05). The exposure times were 435 minutes (image SWP 9530) and 375 minutes (SWP 9571), respectively. The one week delay between exposures was imposed by the fixed spacing of the US low-noise observing shifts, and by our desire to obtain spectra near the opposite quadratures in the orbit so that we might resolve the separate emission contributions of the primary and secondary (cf. Ayres and Linsky 1980). A second motivation was the rapid orbital motion of the HR 1099 components compared with the long exposure times required to measure the far-ultraviolet emission spectrum at high dispersion. The orbital phase of HR 1099 advances by 0.10 during a 7 hr exposure, but near quadrature, when both stars are moving through their radial velocity turning points, the velocity blur imposed by the orbital motion is small (< 10 km s^{-1}) compared with the 30 km s^{-1} FWHM spectral resolution. However, near the conjunctions,

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when the two stars are passing through the system center-of-mass velocity, the velocity blur is comparable to the spectrograph resolution. Pertinent information for each of the HR 1099 exposures is provided in Table 1.

b) *Data Reduction*

i) *Intensity Extraction, Background Correction, Absolute Calibration*

We began with the standard Goddard intensity extractions for the gross and interorder spectra. For each emission feature of interest, we chose a 100 pixel window centered on the rest position of the line and determined the mean and standard deviation of the interorder flux numbers in that window. (For the H I Lyα line, the background sample was centered at 1225 Å in order to avoid the stellar Lyα spillover and geocoronal Lyα emission that contaminate the interorder spectrum in that region.) We then recomputed the mean background level in the sample window, excluding those pixel fluxes beyond $\pm 1\ \sigma$ of the original mean in order to minimize the influence of reseaux marks and strong particle radiation "hits" on the interorder signal level. Finally, we subtracted the properly scaled mean background level from the gross spectrum, applied an echelle blaze correction based on the order-dependent optimum ripple parameters proposed by Beeckmans and Penston (1980), divided by the exposure time, and multiplied by intensity calibration factors, $s_\lambda{}^{-1}$. The latter were obtained from the provisional low-to-high dispersion exposure ratios for emission line sources proposed by Cassatella, Ponz, and Selvelli (1981), and the recently revised low dispersion inverse sensitivity curve, $S_\lambda{}^{-1}$, described by Bohlin and Holm (1980). While the absolute line fluxes are somewhat uncertain, owing to the provisional nature of the echelle mode sensitivity function, the relative fluxes of a particular feature in separate exposures should be quite reliable.

Our calibration procedure yields monochromatic fluxes, f_λ (ergs cm^{-2} s^{-1} Å^{-1}) at the Earth. For comparisons with other stars of different luminosities, we normalize these fluxes to the bolometric luminosity of the HR 1099 system, l_{bol}, measured in flux units (ergs cm^{-2} s^{-1}) at the Earth. (The flux ratios are analogous to surface fluxes; see Ayres, Marstad, and Linsky 1981.)

ii) *The Velocity Scale*

In a spectroscopic study of a binary system that exhibits rapid orbital and rotational motions, it is essential to establish an accurate velocity scale. Unfortunately, *IUE* spectrograms occasionally exhibit small excursions at the tens of km s^{-1} level from the nominal velocity scale adopted during the spectral extractions, owing to thermally induced format shifts between the times of Pt-lamp wavelength calibrations and science exposures (Leckrone 1980). In addition to the random velocity offsets, there are easily calculated systematic velocity shifts produced by the orbital motion of the satellite about the Earth ($\lesssim 4$ km s^{-1}), by the orbital motion of the Earth about the Sun, and by the heliocentric motion of the target star. The likelihood of nonsystematic velocity shifts, particularly between exposures taken a week apart, requires that one find velocity fiducials within the stellar spectrum itself in order to verify, or modify when necessary, the assigned wavelength scale (Leckrone 1980).

We have adopted the following approach:

The stellar Lyα emission profiles at both phases exhibit prominent interstellar absorption cores that are filled in partially by geocoronal emission. The interstellar absorption and geocoronal emission contributions should be stationary in the heliocentric rest frame, since the configuration of the spectrograph and orientation of the satellite were essentially identical in the separate observations. A sharp feature appears on the short wavelength flank of the phase 0.21 (SWP 9571) Lyα absorption core which has been identified in previous *Copernicus* studies of HR 1099 as interstellar D I (Anderson and Weiler 1978). We adopt the deuterium absorption feature as the primary velocity fiducial.

We established the D I velocity in SWP 9571 by a least-squares Gaussian fit after registering the feature to a sloping background to account for the broad wings of the neutral hydrogen absorption. We obtained a D I velocity of about -10 km s^{-1} compared with the position expected for a telluric contribution of -27 km s^{-1} and an assumed interstellar medium velocity of $+20$ km s^{-1} (heliocentric) in the direction of HR 1099 (Anderson and Weiler 1978). Accordingly, we adopted a correction of $+10$ km s^{-1}, in addition to the telluric component, to convert the raw velocity scale of SWP 9571 to the heliocentric rest frame.

Unfortunately, the D I absorption feature in the phase 0.76 image (SWP 9530) is not as sharp as that of SWP 9571 and occurs in a bright portion of the Lyα profile that is close to saturation. Instead of measuring the D I position directly, we numerically cross-correlated the SWP 9530 and SWP 9571 interstellar plus geocoronal cores to establish any velocity offsets between the two images. In both cases, the Lyα cores were rectified by folding out sloping backgrounds to account at least partially for the underlying intrinsic emission profile which appears to shift by as much as 100 km s^{-1} between the opposite quadratures. By this method we obtained a correction of $+20$ km s^{-1}, in addition to the telluric component, to convert the raw velocity scale of SWP 9530 to the heliocentric rest frame. It is somewhat difficult to estimate the uncertainties associated with the D I velocity measurement in SWP 9571 and the cross-correlation of the two images, but they likely are of order

TABLE 1

OBSERVING LOG

Image Number[a]	Mid Exposure (JD 2,444,000+)	Exposure Time (minutes)	Orbital Phase[b]
SWP 9530	436.855	435	0.76 ± 0.05
SWP 9571	443.820	375	0.21 ± 0.05

[a] Both exposures through 10″ × 20″ aperture.

[b] Ephemeris of Weiler *et al.* 1978; zero phase is the conjunction with the more massive star (K0 IV) in front.

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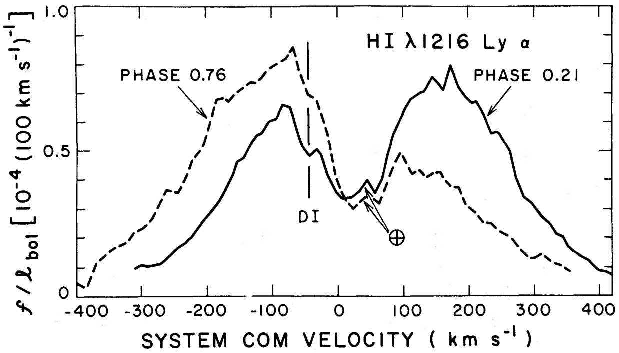

FIG. 1.—Comparison of HR 1099 H I 1216 Å emission profiles obtained near opposite quadratures, to illustrate the registration of the two velocity scales accomplished by numerical cross-correlations of the interstellar plus geocoronal dominated Lyα cores. The absolute velocity scale was established according to the sharp interstellar D I feature, seen clearly in the phase 0.21 profile.

a few times the 5 km s^{-1} internal consistency of the *IUE* wavelength scales (Leckrone 1980).

We have depicted the overall approach in Figure 1, which compares the phase 0.21 and 0.76 Lyα emission profiles on the corrected velocity scale, adjusted to the center-of-mass frame of HR 1099 ($V_R = -14$ km s^{-1}). One sees immediately that the Lyα emission shifts dramatically in velocity between the opposite orbital quadratures. The amplitude and sense of the shift is consistent with that expected if the K star of the system is the dominant emitter, in accord with ground-based studies of Hα and Ca II H and K (Bopp and Fekel 1976), and *Copernicus* measurements of Lyα and Mg II *h* and *k* (Weiler *et al.* 1978; Anderson and Weiler 1978).

Selected prominent emission features from both spectra, *adjusted to the expected K star velocity at the particular orbital phases*, are presented in Figure 2. The predicted positions of the secondary spectra at the two quadratures are indicated by arrows. Listed in Table 2 are line positions, line flux ratios, and FWHMs for selected features. The flux uncertainties cited in the table are a 1 σ measure of how well the observed profiles are matched by the fitted Gaussians. We determined fluxes for H I Lyα and O I 1305, 1306 Å by direct numerical integrations rather than fitted profiles owing to the obviously non-Gaussian character of the former and to the weakness of the latter.

III. DISCUSSION AND CONCLUSIONS

1. Previous *IUE* low dispersion studies of HR 1099 by Linsky *et al.* (1978) and Simon and Linsky (1980) revealed that emission in C IV and He II is enormously

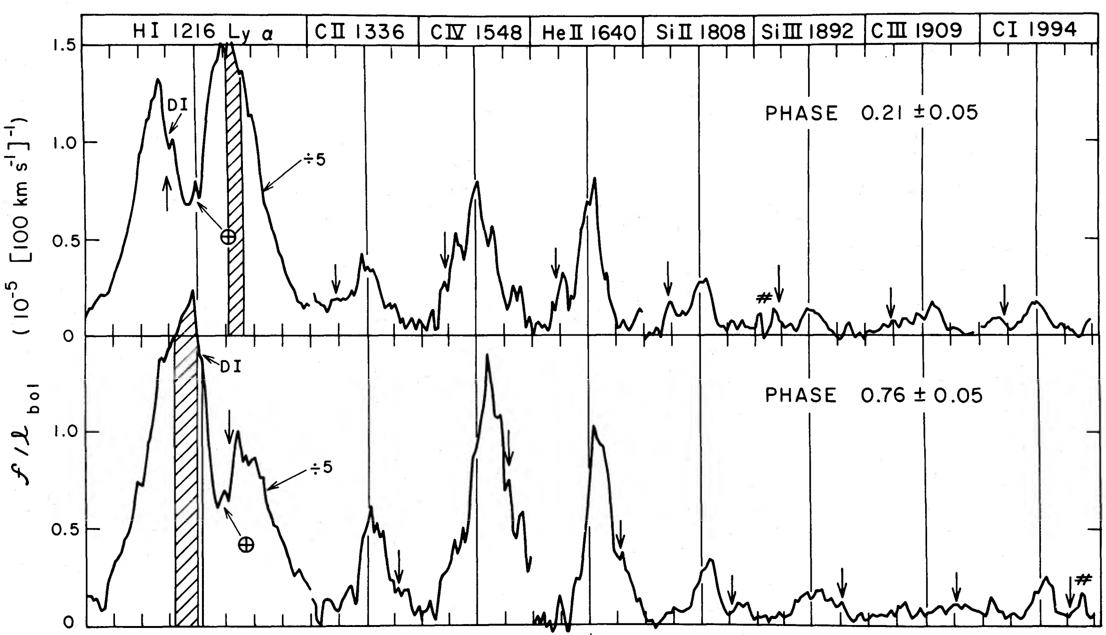

FIG. 2.—High-dispersion profiles of prominent emission features in the HR 1099 = V711 Tauri (K0 IV + G5 V) spectrum at opposite orbital quadratures (maximum radial velocity separation). The ordinate is a normalized monochromatic flux ratio, f/l_{bol} (see § II*b*). The units are commensurate with the segmented velocity scale adopted for the abscissa. Note that velocities are measured relative to the K star (spectroscopic primary) center of mass at both orbital phases. Vertical bars denote the rest velocity of each emission line in that reference frame. Arrows indicate the expected position of the secondary star spectrum at each phase. Prominent particle radiation "hits" are identified by the symbol #; the locations of geocoronal Lyα contamination are shown by the symbol ⊕; the positions of the interstellar deuterium absorption feature are indicated by "D I", and regions of the stellar Lyα profiles that were saturated in the two long exposures are cross-hatched. (Note that the stellar Lyα emission features have been reduced by a factor of 5). The extended emission "wing" shortward of Si II 1808 Å at phase 0.76 very likely is produced by a S I blend.

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TABLE 2

LINE FLUXES AND PROFILE PARAMETERS

			HR 1099 = V711 Tauri (K0 IV+G5 V)						α Centauri A[b](G2 V)	
			Phase 0.21 ± 0.05			Phase 0.76 ± 0.05				
Transition	Wavelength[a] (Å)	s_λ^{-1} [10^{-14} ergs cm^{-2} s^{-1} (FN min^{-1})$^{-1}$]	V[c]	FWHM (km s^{-1})	f_L/l_{bol}[d] (10^{-7})	V[c]	FWHM (km s^{-1})	f_L/l_{bol}[d] (10^{-7})	FWHM (km s^{-1})	f_L/l_{bol}[d] (10^{-7})
H I 1216 Lyα ...	1215.67	8.3	+7	500:	[3000][e]	+10	450:	[2800][e]	250:	[16][e]
D I 1215 Lyα ...	1215.34	...	[+18][f]	...	...	[+21][f]	...	...	...	...
O I 1305	1304.86	4.7	...	80:	[30:][e]	...	100:	[30:][e]	50	0.4
O I 1306	1306.03		...		[20:][e]	...		[20:][e]	...	...
C II 1336	1335.71	4.7	+2	160	60 ± 7	+30	170	80 ± 15	70	0.6
C IV 1548	1548.19	7.1	−7	160	120 ± 14	+47	150	190 ± 11	60	0.7
C IV 1551	1550.77		−6	140	42 ± 7	+44	120:	90 ± 5	...	...
He II 1640	1640.4:	5.4	+12	100	70 ± 7	+37	100	100 ± 4	40:	≲0.05:
			−87	50	17 ± 1					
Si II 1808	1808.01	3.2	+8	80	(16 ± 1)	+20	80	(30 ± 2)	40	(0.8)
			−102	50	(3 ± 1)	+147:	...	[5:][e]		
Si III 1892	1892.03	2.9	+8	70	(6 ± 1)	+27:	110:	(20 ± 3:)	30	(0.2)
C III 1909	1908.73	2.8	...	...	[3:][e]	...	...	[5:][e]	...	(<0.2:)
C I 1994	1993.62	2.6	−2	80	(13 ± 1)	+19	80	(17 ± 2:)	30	(0.5)
			−141	70	(5 ± 1)	+143:	60:	(4 ± 1:)		

NOTE.—Colons indicate uncertain values. Unless otherwise indicated, values are from least-squares Gaussian fits. Parentheses indicate continuum subtraction. First entry is for presumed primary component; second entries are for features that may be associated with secondary spectrum.

[a] Kelly and Palumbo 1973; He II λ1640 Å is a multiplet.

[b] Ayres *et al.* 1981.

[c] Relative to inferred center-of-mass velocity of primary star.

[d] l_{bol} (HR 1099) = 1.44×10^{-7} ergs cm^{-2} s^{-1}; l_{bol} (α Cen A) = 270×10^{-7} ergs cm^{-2} s^{-1}: Ayres, Marstad, and Linsky 1981.

[e] Direct integration: Lyα values were not corrected for interstellar absorption or geocoronal emission.

[f] Heliocentric velocity.

enhanced (in f_L/l_{bol} units) compared with typical quiet chromosphere dwarfs such as α Centauri A (G2 V) or the Sun. (*IUE* high dispersion fluxes and line widths for α Cen A [Ayres *et al.* 1981] are provided in Table 2 for comparison.) The factor of 10^2 enhancement of f_{CIV}/l_{bol} over that typical of solar-like dwarfs implies that the energy deposition in the transition region (TR; T ≈ 10^5 K) of HR 1099 is considerably greater than in the Sun. However, the enhancement of chromospheric emission lines, such as Si II and Mg II, is only a factor of about 10. Consequently, the chromospheric energy deposition is larger in RS CVn systems but comparatively much less than that of the overlying TR. The enhancement of coronal heating is even larger than that of the TR and chromosphere since typical soft X-ray flux ratios, f_x/l_{bol}, for short-period RS CVn systems such as HR 1099 and UX Ari, are 10^3 times those of quiet chromosphere dwarfs (Ayres, Marstad, and Linsky 1981). In fact, the RS CVn coronae emit as much energy in soft X-rays as the RS CVn chromospheres emit in their dominant cooling radiations, Mg II *h* and *k*. By comparison, the *solar* coronal radiative output is dwarfed by that of the chromosphere (Withbroe and Noyes 1977).

A striking exception to the generally modest enhancements of chromospheric emission lines in HR 1099 compared with quiet chromosphere dwarfs is H I Lyα. Although the effects of interstellar absorption are difficult to assess (note: the $f_{Ly\alpha}/l_{bol}$ ratio for the solar twin α Cen A is about half of the corresponding quiet Sun value), it is clear that $f_{Ly\alpha}/l_{bol}$ is of order 10^2 times larger in HR 1099 than in α Cen A. In fact, the $f_{Ly\alpha}/l_{bol}$ ratio of the HR 1099 primary is as large as $f_{Mg\,II}/l_{bol}$ (Ayres, Marstad, and Linsky 1981), whereas in the Sun the latter exceeds the former by a factor of about 5. Consequently, Lyα appears to behave more like a transition region line in HR 1099. If Lyα is produced mainly by collisional excitation, then the factor of 10^2 enhancement must be produced at or above the base of the TR (20,000 K) near the temperature at which the C II resonance lines are formed. A thick temperature plateau at these levels may be produced by thermalization of the intense XUV and soft X-ray back-radiation from the corona. In particular, the observed 0.1–3 keV emission of HR 1099 (Walter, Charles, and Bowyer 1978), which must be comparable to the soft X-ray back-radiation component, is about a factor of 2 larger than the Lyα flux measured here. Consequently, only a fraction of the coronal extreme ultraviolet (EUV) and soft X-ray radiation field, which must be absorbed wholly in the upper chromosphere by hydrogen and helium, need ultimately be converted into Lyα photons by direct collisional excitation (or recombination following collisional ionization) in order to provide the apparent excitation. Indeed, the prominent Hα emission of such systems, which appears to be temporally well correlated with Lyα (Weiler *et al.* 1978), may also be formed in the same layers as Lyα by a similar mechanism.

2. A remarkable, although not unexpected, result of our spectroscopic study is that the prominent far-ultraviolet emission features—Lyα, C II, C IV, He II, and

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Si II—are concentrated near the K star velocity at both orbital phases. This behavior argues that the chromospheres and transition regions of RS CVn binaries are genuinely a "stellar" phenomenon (Weiler *et al.* 1978). In particular, the emission is associated with the more massive, larger, and consequently more rapidly rotating component of the system, rather than with a disk of material surrounding the binary or streams of gas between the two stars.

The narrow components of Si II and He II (near -100 km s^{-1}) at phase 0.21 may arise from the secondary star, since the rotational broadening of the G dwarf component is expected to be less than that of the K subgiant primary (Fekel 1980). However, at phase 0.76 no clearly distinguishable secondary features appear, aside from a distinct asymmetry in the He II 1640 Å profile at positive velocities. In short, the secondary contribution to the composite emission spectrum appears to be at least as small as, if not smaller than, the ratio of surface areas ($\approx 5:1$). Note that because the bolometric luminosity of the warmer secondary star is more nearly comparable to that of the cooler primary (Simon and Linsky 1980), the contrast in $f_L/l_{\rm bol}$ will always be larger for the HR 1099 companions than the contrast in *surface* fluxes.

3. The strength of the primary star emission line spectrum is very likely an example of the rotation-activity connections thought to exist for stellar chromospheres (Skumanich 1972), transition regions and coronae (Ayres and Linsky 1980; Pallavicini *et al.* 1981; Walter 1981; Walter and Bowyer 1981). The components of short period binaries are rapid rotators compared with typical single stars of similar temperature and luminosity owing to synchronization induced by tidal friction. The rotation-activity connection, itself, likely is a consequence of enhanced magnetic field production in rapidly rotating, convective stars compared with slower rotators. (The close association between magnetic fields and chromosphere-corona activity is demonstrated clearly in the particularly well studied case of the Sun [Vaiana and Rosner 1978].)

The weakness of the HR 1099 secondary star in chromospheric and transition region emission lines may impose constraints on possible functional forms of rotation-activity relations (Ayres and Linsky 1980; Walter 1981; Walter and Bowyer 1981; Pallavicini *et al.* 1981), especially if the deficiency of the secondary in C IV emission is continued in coronal soft X-rays. Unfortunately, the HR 1099 primary and secondary probably are not close enough in temperature that spectral-type-dependent effects in X-ray or TR rotation-activity relations can be ignored (Ayres and Linsky 1980; Walter and Bowyer 1981). Consequently, we must defer the question until such effects can be quantified, and until accurate fluxes for the main-sequence components of RS CVn binaries are available.

4. In addition to following the primary star in velocity, several of the far-ultraviolet emission profiles (particularly C IV 1548 Å) exhibit fine structure whose amplitude exceeds the general noise level in line-free regions of the spectrum flanking the given features. Some of the fine structure may be produced by the secondary star, especially in the phase 0.21 profiles of He II 1640 Å and Si II 1808 Å (see above). However, some of the structure that is seen in the C II and C IV resonance lines may represent "limb brightening" by hot material that lies significantly above, but corotates with, the K star photosphere. In particular, the rapidly rotating K primary is thought to have $V \sin i \approx 50$ km s^{-1} (Fekel 1980); consequently, plasma near the leading limb of the primary would be displaced to -50 km s^{-1}, and the trailing limb to $+50$ km s^{-1} with respect to the K star center of mass (COM) velocity. If most of the C IV broadening is produced by this mechanism, 10^5 K material must extend to as much as a stellar radius ($\approx 3\ R_\odot$) above the surface of the K star. In the case of the Sun, extended, limb brightened emission is common among transition region structures (magnetic loops), although the brightest rarely are larger than a few percent of the solar radius. (Note that the broadening of C IV, here, probably is not produced by the symmetric expansion of a "warm" wind, as was proposed in the case of the red giant α TrA by Hartmann, Dupree, and Raymond [1981], because a wind envelope large enough to exhibit symmetric [i.e. unocculted] C IV emission profiles would be comparable in size to the system itself and therefore under its gravitational influence. Consequently, the C IV line shapes would not follow the radial velocity motion of the "active" star, exclusively.)

5. Unlike the strong C II and C IV resonance lines of the transition region, we find that the C I, Si II, and He II profiles are comparatively smooth and symmetric, aside from distortions that likely are produced by the G-type secondary. The smooth profiles of Si II 1808 Å and C I 1994 Å, which are comparable in width to photospheric absorption lines in the optical region, are easily understood if the chromosphere is essentially a "surface" phenomenon even in the most active stars, and the major line broadening agent is rotation. (Note: the shortward "emission" wing of Si II 1808 Å at phase 0.76 likely is produced by a blend with S I 1807 Å.) The brightest areas of chromospheric emission on the Sun are plage regions that contain a comparatively high surface density of small scale magnetic structures, whereas quiet Sun regions have perhaps a 10% or less filling fraction of the bright flux tubes (Chapman 1981). The factor of 10 or more enhancement of $f_{\rm Si\,II}/l_{\rm bol}$ and $f_{\rm Mg\,II}/l_{\rm bol}$ typical of RS CVn systems compared with the quiet chromosphere dwarfs suggests that the active stars in such systems are covered more or less uniformly by strong plage (cf. Linsky 1980).

If formed in collisional equilibrium, the He II 1640 Å line should be emitted in layers intermediate to the C II and C IV lines and, consequently, should have a width of about 160 km s^{-1} if the rotational interpretation of the line broadening is correct. However, the He II width of 100 km s^{-1} is similar to those of the chromospheric Si II and C I lines, suggesting that the He II multiplet is formed closer to the stellar surface than C II or C IV, perhaps within the chromosphere itself. This suggestion is plausible in light of recent solar studies of the He II 1640 Å feature at high spatial and spectral resolution by Schind-

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ler *et al.* (1981). They find that the narrow components of the He II profile seen over most of the solar disk must be formed deep in the chromosphere at comparatively cool temperatures (≈ 6000 K) by a photoionization-recombination process. If the solar He II line instead were formed primarily by collisional excitation at 10^5 K, as previously suggested by low spatial resolution observations (Feldman *et al.* 1975; Kohl 1977), then the line thermal Doppler widths would be considerably larger than observed. The photoionization-recombination process is even more likely in HR 1099 owing to the very strong coronal radiation field incident on the K star chromosphere (cf. Hartman, Dupree, and Raymond 1980). Note also that the He II feature from the secondary star at phase 0.21 appears to be displaced to positive velocities relative to the expected G star position, as if only the side of the secondary star that faces the primary is bright in He II. The situation at phase 0.76 may be analogous, but it is complicated by additional factors described below.

6. Despite the concentration of emission near the K star velocity, the profiles at phase 0.76 are distinctly stronger than those at phase 0.21, particularly in lines formed at high temperatures, and they are displaced by roughly $+40$ km s^{-1} relative to the K star center-of-mass velocity. The velocity displacement is in the sense that the emission enhancement appears to originate near the limb of the K star that faces the G star. The emission enhancement may be produced by a bright active region on the K star disk that was at least partially occulted at phase 0.21 but which has rotated into view at phase 0.76. Alternatively, the velocity displacement may represent a transient brightening of an established active region that had faded in the one week interval between the phase 0.76 and 0.21 observations. The first alternative would be evidence that the transition region emission of the active primary is compact compared with a stellar radius. The second alternative would be consistent with the sporadic flaring behavior typical of RS CVn systems in radio emission (Feldman *et al.* 1978). Indeed, increases in the fluxes of C IV and other lines by a factor of 50% were found previously in low dispersion *IUE* studies of a similar type of system, UX Arietis (Simon and Linsky 1980), although the authors did not find similar enhancements in their data for HR 1099 itself.

If the limb active region interpretation of the transition region emission displacement is correct, then the appearance and velocity of the He II emission asymmetry at phase 0.76 suggests that much of the visible hemisphere of the G star was being fluoresced by enhanced XUV emission from the bright active region on the K star. Figure 3 illustrates a schematic fluorescence geometry that may explain the appearance of the He II profile structure near the opposite quadratures. Of course, several of the preceding interpretations depend sensitively on the reliability of the derived velocity scales. In the absence of an absolute velocity reference, only repeated observations of these phenomena can provide confidence in their reality.

7. Finally, we call attention to the weakness of the high temperature intercombination lines Si III 1892 Å and C III 1909 Å. Both of these features are much stronger than C IV 1548 Å in β Dra (G2 II); they are comparable in strength to C IV in the F giant secondary of Capella (α Aur Ab; F9 III); and they are both much weaker than C IV in the active subgiant λ And (G8 III–IV + ?) (Ayres *et al.* 1981). The sequence of decreasing relative line strengths between the intercombination and permitted lines very likely maps out a trend of increasing density in the transition region structures that are responsible for the observed emission (Doschek *et al.* 1978). The faintness of Si III and C III emission compared with that of C IV argues that the transition region structures of HR 1099 are at comparatively high pressures (cf. Baliunas *et al.* 1979), although not necessarily as high as encountered in solar active regions (Ayres *et al.* 1981). Furthermore, high pressure outer atmospheres could be responsible for the weakness of the chromospheric O I 1302, 1305, 1306 Å emission, since the triplet is thought to be pumped by a Bowen fluorescence mechanism (Haisch *et al.* 1977), and the pumping should be suppressed at high chromospheric densities.

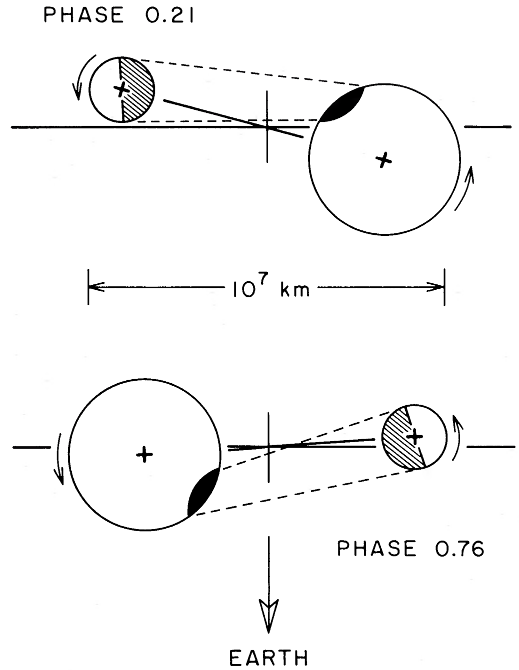

FIG. 3.—Hypothetical emission geometry of HR 1099 near the two quadratures which may explain the structure apparent in the He II 1640 Å Balmer α feature. The dark spot on the larger star (the K subgiant) represents a bright active region whose XUV and X-ray emission fluoresces the He II Bα feature on the side of the companion G star that faces the active region. At phase 0.21 (top portion of panel), the active region is occulted by the K star, itself, although about half of the hemisphere of the secondary star visible from Earth is fluoresced in He II 1640 Å. At phase 0.76, however, the active region has rotated into view, and more than half of the visible hemisphere of the G star is fluoresced in He II.

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