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# ULTRAVIOLET SPECTROSCOPIC OBSERVATIONS OF VV CEPHEI

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## ABSTRACT

We present observations with the *International Ultraviolet Explorer* satellite (*IUE*) of the recent egress of the eclipsing binary VV Cep (M2 Iabep + B). Egress in the ultraviolet lagged behind the visible egress by 2 to 3 months, as a result of higher opacity of the M star atmosphere in the ultraviolet. Shortly after visible egress, the low-dispersion spectrum from $\lambda\lambda$1200–1900 was dominated by fluorescent emission lines arising in the atmosphere of the M star and excited by the ultraviolet continuum of the hot companion. High-dispersion spectra show a hot continuum blanketed by absorption lines, some of which weaken or disappear as the egress continues. A year after eclipse, the absorption spectrum is still too complex to permit determination of a spectral type for the hot companion. The Mg II *h* and *k* lines both exhibit asymmetric double-peaked emission features indicative of an expanding chromosphere in the M supergiant.

*Subject headings:* stars: binaries — ultraviolet: spectra

## I. INTRODUCTION

The eclipsing binary VV Cephei provides a unique opportunity to study the outer atmosphere and chromosphere of a late-type supergiant. The system, with a period of 20.3 yr, consists of an M supergiant primary with a hot companion. Absorption and emission lines from the outer atmosphere and chromosphere of the M supergiant primary can be seen against the hot continuum of the companion as it enters and emerges from totality. The orbital motion can thus be used to probe the density and velocity structure of the outer atmosphere of the primary. The system emerged from eclipse in 1978 March, remarkably well timed for the launch of *IUE*.

We have observed the eclipse with the *IUE* satellite with two chief objectives: (1) to determine the nature of the secondary star and (2) to study the common circumstellar envelope. The spectral type of the companion is very uncertain; estimates in the literature range from O8 to A0. Because its light dominates that of the M star at wavelengths shorter than 4200 Å, the UV observations should help in studying the secondary. The asymmetric profiles of strong resonance lines in the blue region indicate that the M supergiant is losing mass. Singly ionized metals should represent the dominant ionization state in the circumstellar envelope, but few resonance lines of ionized metals are accessible at visible wavelengths. UV observations are necessary to determine the ionization conditions and to provide good measures of the amount of circumstellar matter and mass-loss rates.

We have observed the egress of VV Cep at intervals from 2 to 8 weeks since 1978 April 1 with the *IUE* satellite (Boggess *et al.* 1978). Both short- (1150–2000 Å) and long- (2000–3400 Å) wavelength cameras have been used, in high- and low- ($\sim$0.2 Å and $\sim$6 Å) resolution modes. Observations of $\alpha$ Orionis obtained for a separate project have been included for comparison, as the visible spectra of the two stars appear very similar (Wright 1977).

## II. LOW-DISPERSION OBSERVATIONS

The emergence of the system from eclipse, as evidenced by the increase in the UV fluxes is shown in Figure 1. The low-dispersion observations were integrated over the wavelength regions 1250–1900 Å and 2000–3100 Å. Preliminary reduction of optical photometry indicates that third contact occurred sometime between JD 2,443,560 and 3580, and fourth contact by 3650 (Guinan 1979). The *IUE* observations show that the egress occurred considerably later in the UV.

Long-wavelength low-dispersion spectra show the continuum to rise first at the longer wavelengths, consistent with the earlier egress in the visible. The spectrum in this region has remained largely unchanged since 1978 July 10. The spectrum is sufficiently chopped up by absorption that it is difficult to use the *IUE* observations to determine the interstellar reddening. In the analysis of this paper, the value of $E(B-V)$ of 0.3 determined by Wawrukiewicz and Lee (1974) was used. If the B star ever fully emerges, a new reddening determination will be possible.

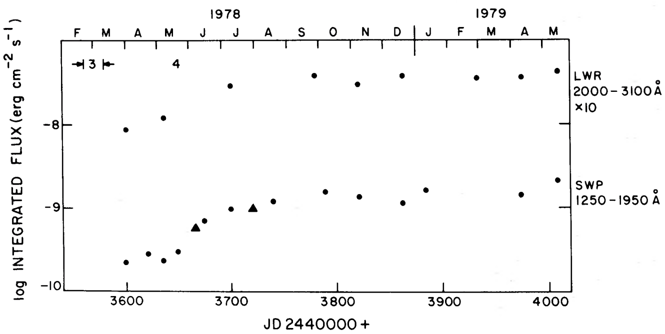


FIG. 1.—The UV egress of VV Cep. The filled circles represent the observations presented in this paper. The triangles are from the observations of Faraggiana and Selvelli (1979). The numerals 3 and 4 represent the times of 3d and 4th contact in the visible (Guinan 1979).

Short-wavelength low-dispersion observations are presented in Figure 2. From 1978 April 1 through 1978 May 20 the spectrum is dominated by emission lines due to fluorescent excitation of the cool envelope by the radiation of the hot companion. No significant change in the spectrum is seen between 1978 April 1 and May 7. As the companion emerges from eclipse, the emission between $\lambda$1700 and $\lambda$1850 is seen to increase. Those spectra which had been processed with the incorrect Intensity Transfer Function have been corrected with the so-called Three-Agency Fourth-File Method. Long-wavelength spectra ($\lambda\lambda$2000–3200) at low dispersion are shown in Figure 3. The most significant aspect of these spectra is that as the flux level increases with time, it increases most rapidly at the longest wavelengths. This behavior presumably reflects the wavelength dependence of opacity through the cool envelope. No significant changes are seen after 1978 August 20.

Virtually all of the emission features in the early short-wavelength spectra can be identified with a characteristic type of transition in abundant species such as C I, Si I, S I, and Fe II. These are all nonresonance transitions which share the same upper state with resonance transitions at shorter wavelengths. Such fluorescent emission lines represent the leakage from the optically thick resonance lines that absorb much of the UV radiation from the background hot star. At later times, as the line of sight to the hot companion passes through less of the M star atmosphere, the optical depths in the resonance lines decrease, and the intensities of the resulting fluorescent lines fall relative to the continuum. The proposed identifications are summarized in Table 1.

The dominant emission feature in the short-wavelength low-dispersion observations occurs at $\lambda$1786 and is tentatively identified with the Fe II multiplet $a\,^6S$–$x\,^6P^o$, $\lambda\lambda$1785–1788. The intensity of this multiplet in laboratory emission spectra appears to equal or exceed that of the resonance transition $a\,^6D$–$x\,^6P^o$, $\lambda$1270, with which it shares a common upper state. If the $\lambda$1786 feature of Fe II is excited by fluorescence, then its flux of $8 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$, observed on 1978 April 1, can be used to infer conditions along the line of sight through the cool atmosphere at that time. In a simple model of the system, we envision a uniform column of cool material in front of a hot star whose energy distribution is given

TABLE 1

PROPOSED IDENTIFICATIONS OF EMISSION FEATURES IN SPECTRUM SWP 1283 (1978 April 1)

| Observed Wavelength (Å) | Species | Identification: Multiplet | Identification: Wavelength (Å) |
|---|---|---|---|
| 1216 | H I | $1\,^2S$–$2\,^2P^o$ | 1215.7 |
| 1236 | S II | $3p\,^2P^o$–$3p^4\,^2P$ | 1234.1 |
| | Fe II | $a\,^2F$–$26^o$ | 1233.7 |
| 1246 | N I | $2p\,^2D^o$–$3s'\,^2D$ | 1243.2 |
| 1254 | C I | $2p^2\,^1D$–$2p11d\,^3D^o$ | 1253.5 |
| 1282 | ? | ... | ... |
| 1289 | C I | $2p^2\,^1D$–$6d\,^3D^o$, –$7s\,^3P^o$, –$6d\,^3F^o$ | 1289 |
| | Fe II | $a\,^2P$–$10^o$ | 1290.2 |
| 1306 | O I | $2p^4\,^3P$–$3s\,^3S^o$ | 1302 |
| | Si II | $3p\,^2P^o$–$3p^2\,^2S$ | 1304 |
| 1360 | C I | $2p^2\,^1D$–$4d\,^3D^o$, –$4d\,^3F^o$, –$5s\,^3P^o$ | 1359 |
| | S I | $3p^4\,^1S$–$5s''\,^1P^o$ | 1361.3 |
| | Fe II | $a\,^2P$–$w\,^6P^o$ | 1360.9 |
| 1366 | C I | $2p^2\,^1D$–$4d\,^1D^o$ | 1364.2 |
| | Fe II | $a\,^2G$–$2^o$ | 1364.6 |
| 1433 | S I | $3p^4\,^3P$–$3p^3\,3d\,^3D^o$ | 1433 |
| 1495 | C I | $2p^2\,^1S$–$2p7d\,^3D^o$ | 1494.5 |
| | N I | $2p\,^2D^o$–$3s\,^2P$ | 1494 |
| | S I | $3p^4\,^1D$–$3p^34d\,^3D^o$ | 1498.9 |
| 1511 | C I | $2p^2\,^1S$–$2p6d\,^3P^o$ | 1510.7 |
| | C I | $2p^2\,^1S$–$2p6d\,^1P^o$ | 1511 |
| 1535 | ? | ... | ... |
| 1544 | C I | $2p^2\,^1S$–$2p5d\,^3D^o$ | 1545.2 |
| | C I | $2p^2\,^1S$–$2p6s\,^1P^o$ | 1544.0 |
| | Fe II | $a\,^6S$–$1^o$ | 1541.0 |
| 1643 | S I | $3p^4\,^1D$–$3p^33d\,^3D^o$ | 1641 |
| 1650 | Fe II | $a\,^4D$–$x^4P^o$ | 1650 |
| 1746 | N I | $2p\,^2P^o$–$3s\,^2P$ | 1742 |
| | Si I | $3p^2\,^1D$–$3p7d\,^3D^o$ | 1740.3 |
| | Si I | $3p^2\,^1D$–$3p7d\,^3F^o$ | 1753 |
| | Si I | $3p^2\,^1D$–$3p7d\,^1F^o$ | 1744 |
| 1786 | Fe II | $a\,^6S$–$x\,^6P^o$ | 1786 |
| 1818 | Si I | $2p^2\,^1D$–$5d\,^1P^o$ | 1818.0 |
| 1843 | Si I | $3p^2\,^3P$–$3p5s\,^3P^o$ | 1843.8 |
| 1880 | Fe I | $b\,^2D$–$3^o$ | 1875.5 |
| | Si I | $3p^2\,^1D$–$3p6s\,^1P^o$ | 1874.8 |

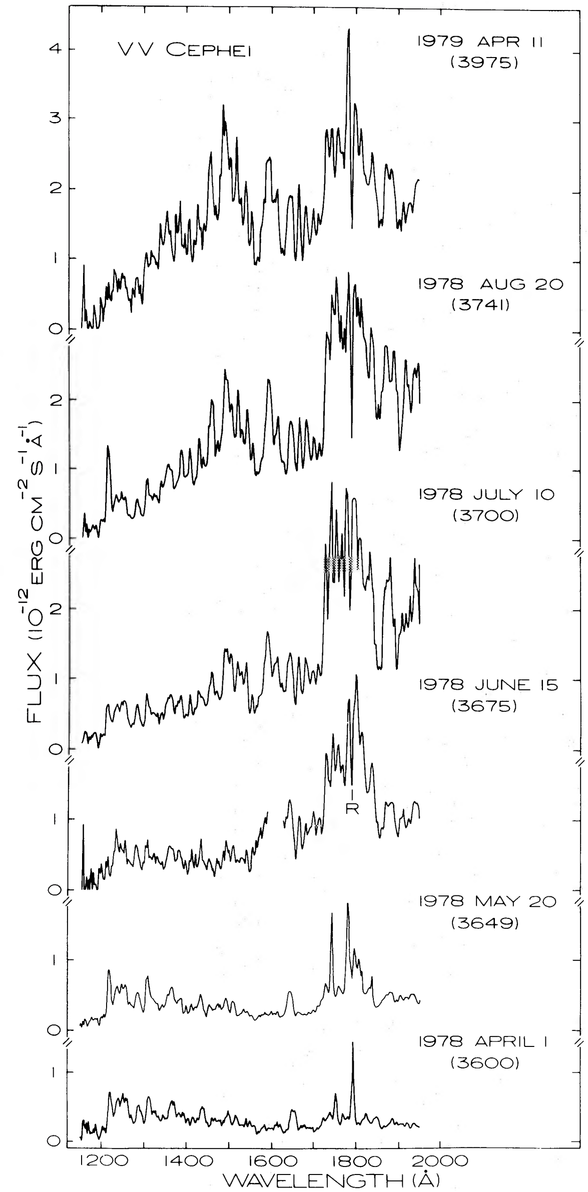


FIG. 2.—Short-wavelength low-dispersion spectra of VV Cep. Note the gross changes in the spectrum with time. In 1978, fluorescently excited transitions dominate; later the continuum of the B star is substantially modified by absorption in the atmosphere of the M star.

by a model atmosphere with $T = 30{,}000$ K and $\log g = 5$ (Kurucz 1979). We adopt a typical UV interstellar extinction curve (Bless and Savage 1972) with color excess $E(B - V) = 0.3$. We assume that in the absence of the M star, the hot star would have the UV fluxes $f_\lambda = 2.9 \times 10^{-12}$ and $6.7 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$ at $\lambda$1910 and $\lambda$1550, respectively, corresponding to broad-band measurement of VV Cep made with *OAO* 2 (A. V. Holm, unpublished data) several years before eclipse. The depth scale through the cool envelope is described in terms of the column density of Fe II:

$$N(\text{Fe II}) = \int_0^x n(\text{Fe II})dx' ,$$

where $n$(Fe II) is the number density of Fe II ions as a function of linear distance through the envelope. The rate of absorption of photons in the $\lambda$1270 resonance multiplet can be written

$$\rho(x) = (\lambda f_\lambda/hc)dW_\lambda(\text{Fe II})/dN(\text{Fe II}) ,$$

at each point $x$ corresponding to $N$(Fe II), where $W_\lambda$ is the equivalent width in the resonance line, and $f_\lambda$ is the model flux from the hot star without correction for interstellar extinction. The flux in the fluorescent emission line, $\phi_{\text{em}}$, is proportional to the rate of absorption in the resonance line:

$$\phi_{\text{em}} = \eta(\lambda f_\lambda/hc)W_\lambda(\text{Fe II}) \exp{(-\tau_{\text{extinction}} - \tau_{\text{envelope}})} ,$$

where $\eta$ is the probability that an ion excited into the $x\,^6P^o$ state decays by emission in the $\lambda$1786 transition, $\tau_{\text{extinction}}$ is the optical depth due to interstellar extinction at $\lambda$1786, and $\tau_{\text{envelope}}$ is the additional opacity of the cool envelope due to overlapping absorption lines. Comparison of the model hot star with the apparent continuum level at $\lambda$1786 suggests that $\tau_{\text{envelope}} \approx 2.9$ on 1978 April 1. Laboratory spectra indicate that $\eta$ might be as large as $\frac{1}{2}$. A lower limit to the column density of Fe II required to produce the observed $\lambda$1786 line is therefore $N(\text{Fe II}) \gtrsim 6.8 \times 10^{16}$ cm$^{-2}$, given that the oscillator strength of the $\lambda$1270 resonance multiplet is $f(1270) = 0.06$ (cf. de Boer *et al.* 1974). If the path length through the cool envelope is comparable to the photospheric radius of the primary star, if the abundance of Fe is like that in the Sun, and if one-third of all Fe is in Fe II, then we can set a lower limit of $n \gtrsim 10^8$ cm$^{-3}$ upon the total density in the envelope. This density represents an average over the line of sight of 1978 April 1 through the region where the fluorescence occurs.

This value can be compared to an estimate of the density in the extensive circumstellar envelope obtained from the degree of asymmetry in the Sr II $\lambda$4077 line. A spectrum at 1.4 Å mm$^{-1}$ (resolution about 0.15 Å) was obtained during totality with the Kron camera and echelle spectrograph on the 1.5 meter telescope at Mount Hopkins Observatory. A total column density of Sr II of $3 \times 10^{11}$ cm$^{-2}$ was derived following Hagen (1978). An inner shell radius of ten stellar radii and a circumstellar gas density distribution proportional to $r^{-2}$ leads to an estimate of the particle density at 10 $R_*$ of $4 \times 10^5$ cm$^{-3}$. This value is a lower limit because it is assumed that all Sr outside 10 $R_*$ is in Sr II. This comparison indicates that the fluorescing Fe II is closer to the M supergiant than the region which gives rise to the blueshifted cores of the circumstellar envelope. These results can also be compared to a density determination of $1.6 \times 10^7$ cm$^{-3}$ at four K-

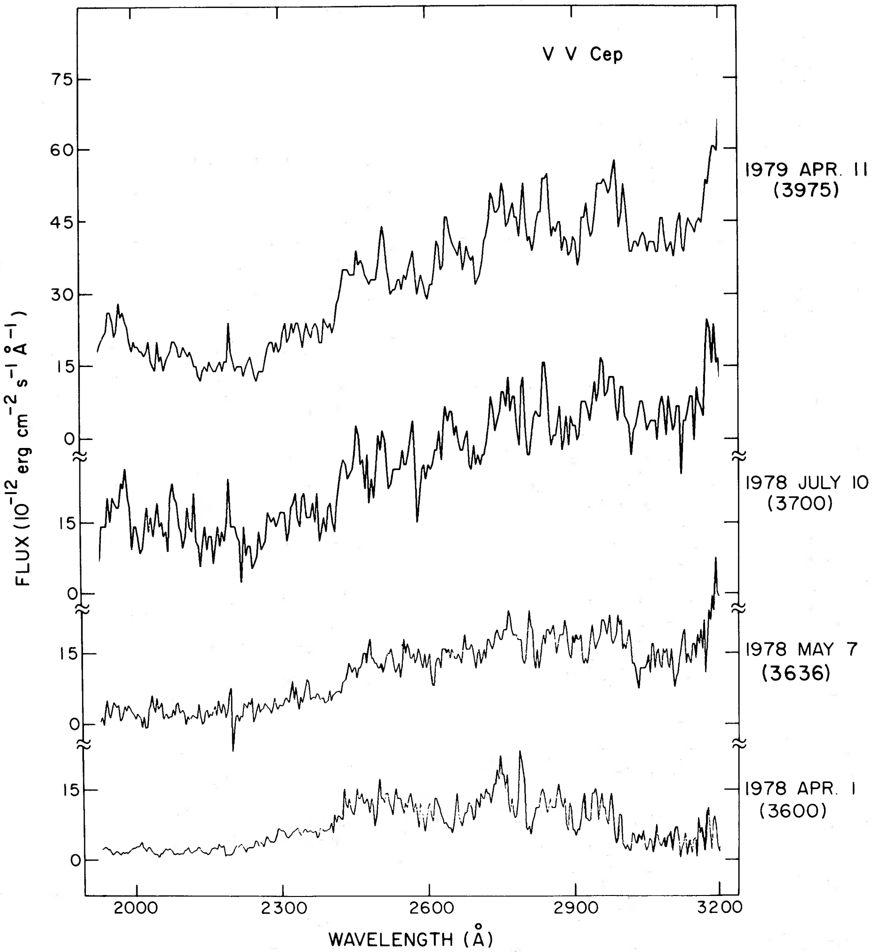


FIG. 3.—Long-wavelength low-dispersion spectra of VV Cep. Note that the flux appears to increase with time most rapidly at the longest wavelengths.

star radii in the ζ Aurigae system 32 Cygni (Stencel *et al.* 1979).

The integrated flux in the O I line at 1304 Å is $1 \times 10^{-10}$ ergs cm$^{-2}$ s$^{-1}$, corrected for extinction. Assuming that VV Cep is at a distance of 700 pc (van de Kamp 1978), consistent with its assignment to the Cep OB2 association (Humphreys 1970), the surface brightness of its O I λ1304 line is 3000 times that of the M2 Iab star α Ori. The O I λ1304 feature in VV Cep is thus not due to the atmosphere of the cool supergiant alone.

## III. HIGH-DISPERSION OBSERVATIONS

The Mg II *h* and *k* lines both exhibit asymmetric emission profiles with blueshifted central absorption and an enhancement of the redward emission peak, indicative of an expanding chromosphere (see Fig. 4). The intensities of the peaks do not vary significantly with phase as the egress progresses. The intensity of the central reversal remains indistinguishable from zero as the B star continuum rises, confirming the circumstellar and interstellar origin of this absorption. These

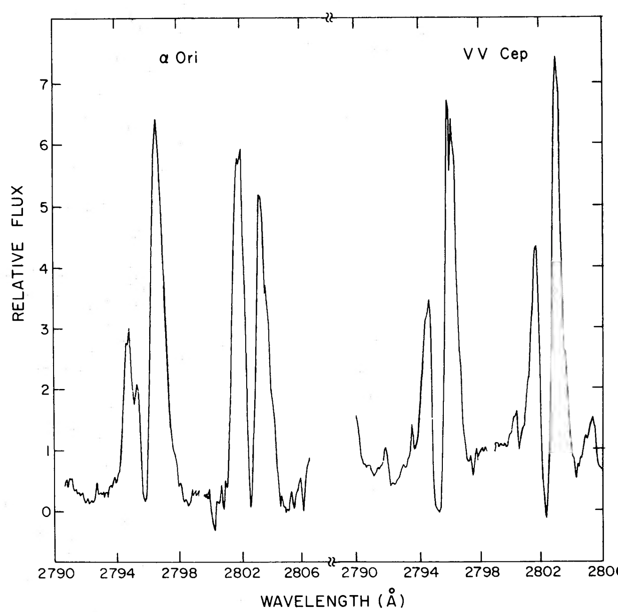


FIG. 4.—The Mg II *h* and *k* lines of VV Cep and α Ori

asymmetric $h$ and $k$ profiles are to be contrasted with those of the M supergiants $\alpha$ Ori (M2 Iab) and $\alpha$ Sco (M1.5 Iab) which show asymmetry in the $k$ line, but not in the $h$ line (Bernat and Lambert 1976).

The full width of the emission at the base of the $k$ line is thought to be a luminosity indicator and can be used to estimate the absolute magnitude of the M supergiant. The emission width was measured at the level of the B star continuum and may thus be somewhat underestimated. The emission width, 3.2 Å, did not change significantly during egress and is similar to a width of 3.8 Å for $\alpha$ Ori. The resulting absolute magnitude is $-3.2$ using the calibration of Dupree (1976), $-4.4$ using that of McClintock *et al.* (1975), and $-3.4$ with that of Weiler and Oegerle (1979). The absolute visual magnitude of $\alpha$ Ori is about 1.5 mag brighter than that of VV Cep. Our values for VV Cep agree with that of $-4$ determined by Faraggiana and Selvelli (1979) from the Mg II $k$ line in their *IUE* data, and by van de Kamp (1978) from astrometric considerations. A compilation of previously determined absolute magnitudes can be found in Cowley (1969); a range of estimates from $-1.4$ to $-6.9$ is quoted.

The peak intensity in the Mg II $h$ line of VV Cep is a factor of 6 higher than that of $\alpha$ Ori when scaled according to distance and reddening. The integrated emergent flux in the $h$ line of VV Cep is 2.7 times that of $\alpha$ Ori. This ratio is actually a lower limit, as an estimated contribution from the B star continuum was subtracted. VV Cep is thus seen to have stronger Mg II emission than a single star of very similar spectral type. It appears that the presence of the hot companion affects the profiles of these two lines. The surface flux in the Mg II $h$ line of VV Cep is 7.4 $\times 10^4$ ergs cm$^{-2}$ s$^{-1}$, assuming a stellar distance of 700 pc, stellar radius of 1640 $R_\odot$ (Wright 1977) and interstellar reddening corresponding to $E(B-V) = 0.3$. The absolute flux calibration at Mg II $h$ and $k$

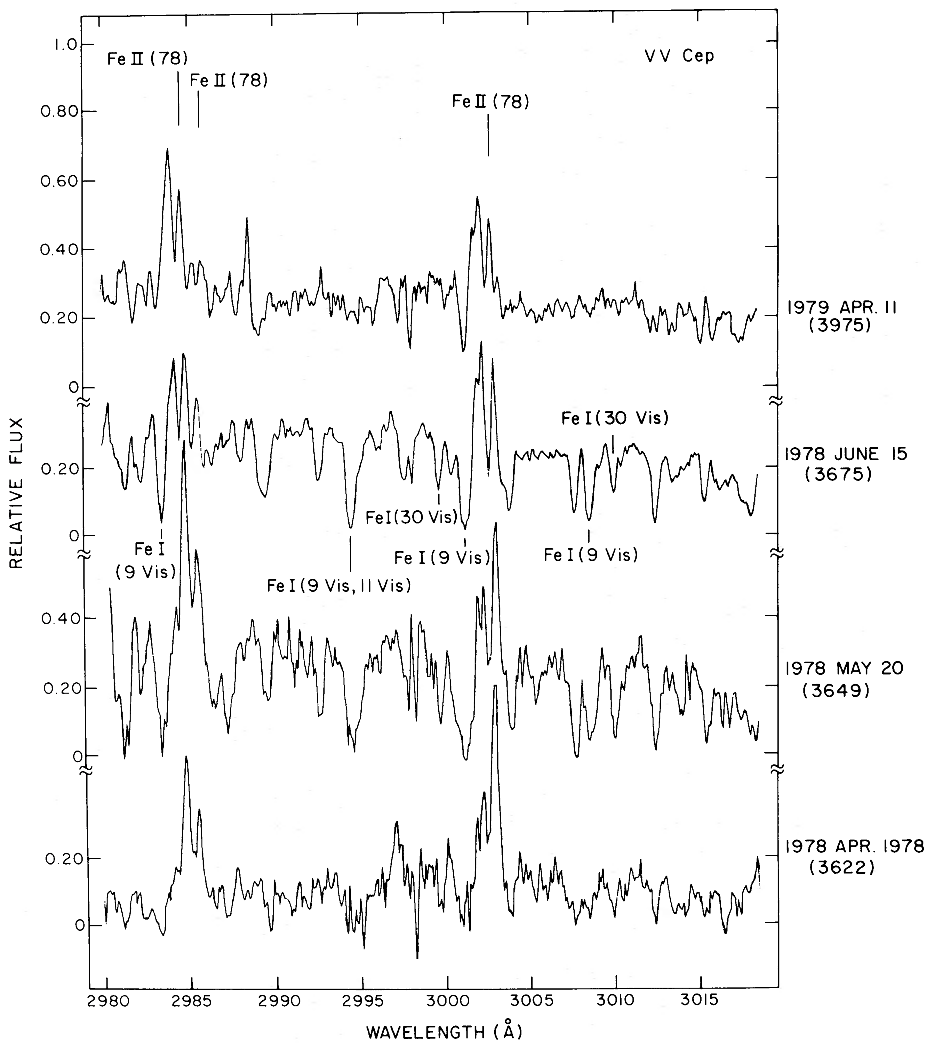


FIG. 5.—A region of the high-dispersion spectrum of VV Cep. Note the disappearance of the Fe I absorption between 1978 July 15 and 1979 April 11 and the change in relative intensity of the red and blue peaks of the Fe II emission between 1978 May 20 and 1978 June 15.

was derived by normalization of high-dispersion to low-dispersion observations of $\lambda$ Andromedae (Baliunas 1979).

The self-reversed absorption feature in the VV Cep *h* line is about 85 km s$^{-1}$ wide and is displaced about 15 km s$^{-1}$ shortward of the center of emission. The *k* line shows the same core width and a displacement of about 25 km s$^{-1}$. The absorption core in both lines of $\alpha$ Ori is seen to be narrower by about 20 km s$^{-1}$, displaced about 15 km s$^{-1}$ shortward in the *k* line and symmetrically placed in the *h* line. In contrast, the circumstellar absorption core in the Ca II H line of VV Cep as observed during totality is about 30 km s$^{-1}$ in breadth, as compared to about 60 km s$^{-1}$ for $\alpha$ Ori.

Emission is also seen from multiplets 60, 62, 63, and 78 of Fe II. However, contrary to the behavior of the Mg II lines, a striking change was observed with phase. The stronger lines were present as double-peaked emission lines. Between 1978 May 20 and July 15 a sudden enhancement of the blue peak relative to the red peak was observed (see Fig. 5). Only minor changes were seen in the profiles in observations made before and after these dates. Integrating the total flux under the profile of Fe II (62) $\lambda$2755.73 indicates that the total flux in the line remained roughly constant and that a redistribution of the flux between the two peaks occurred, as opposed to an increase in the blue peak. Many of these lines appear in emission in $\alpha$ Ori, as previously noted by van der Hucht *et al.* (1979), but they are considerably weaker. The ratio of the total flux in the $\lambda$2755.73 line for VV Cep to $\alpha$ Ori is 17:1, corrected for distance and reddening. As with the Mg II lines, an estimated B star continuum contribution was subtracted, so that the value for VV Cep is a lower limit to the total flux. The emission in these Fe II multiplets is much stronger than that to be expected from a normal M supergiant. In addition, the width at the base of the $\lambda$2755.73 line in VV Cep of 2.0 Å (a lower limit as it was measured at the B star continuum level) is significantly broader than that for $\alpha$ Ori, 1.4 Å. This is in contrast to the behavior of the Mg II lines, where those of $\alpha$ Ori are seen to be broader. Preliminary measurements indicate that the central reversals are blueshifted by about 40 km s$^{-1}$ with respect to lower-excitation lines seen in the high-dispersion spectra. The emission center is further blueshifted by about 30 km s$^{-1}$ with respect to the central reversal.

The high-dispersion spectra at both long and short wavelengths are extremely complex. The spectra are so chopped up by absorption that it is difficult to assign a "B star continuum." The following low-excitation multiplets are seen in absorption in the long- and short-wavelength spectra: Fe I (1, 9, 35, 36, 37, 9vis, 11vis, 30vis), Fe II (1, 2, 36, 38), Ti II (1, 3, 5vis), Mn II (1, 5), V II (1, 2, 3, 10, 11), Ni II (4, 5), and Mg I (1). Possibly present are Cr II (1, 5), Si II (1), Fe II (8), Al III (1), Ca II (4), and Co II (3, 4). Some of these multiplets are seen to show decreasing absorption as the B star emerges from behind the M star chromosphere/outer atmosphere: Fe I (1, 35, 36, 37, 9vis, 11vis, 30vis), Ti II (1), and V II (1). Many as yet unidentified lines decrease in strength as the B star emerges (see Fig. 5).

## IV. DISCUSSION

Ultraviolet observations of other binary systems with cool supergiant primaries and hot companions have recently become available: $\alpha$ Scorpii (M1.5 Iab + B2.5 V; van der Hucht, Bernat, and Kondo 1979), HR 2902 = KQ Puppis (M2 Iabep + B; R. F. Wing, private communication), and 32 Cygni (K2–K5 Iab–b + B; Stencel *et al.* 1980; Stencel 1979). Alpha Scorpii, the most widely separated of the systems, shows absorption of strong low-excitation lines against a fairly featureless B star continuum. 32 Cyg and KQ Pup show P Cygni profiles in the strong low-excitation lines superposed on reasonably smooth B star continua as well. The observations of VV Cep do not clearly show P Cyg profiles for these lines, but the complicated absorption spectrum could obscure the emission. The dramatically increased complexity of the VV Cep spectrum, as compared to these other binary systems, could be a result of the system still showing effects of the eclipse. Also, because of the smaller separation between the stars, we are seeing effects of gas streaming and/or of a shell around the B companion. Continued observations further from eclipse should help establish the nature of the spectra. In our opinion, it is still too early to use the UV observations to estimate the spectral type of the companion. Therefore, the spectral type of A0 determined by Faraggiana and Selvelli (1979) should be viewed with caution.

At this present, preliminary stage of analysis, we are unable to distinguish with confidence between the envelope of the M star and the shell of the hot star as sources of spectral features in the UV. On the other hand, the rapid increase in integrated UV flux between 1978 April and 1978 August (see Fig. 1) can be attributed to the changing path length through the atmosphere of the M supergiant. A very simple model of the system can be used to infer an approximate structure of the extended, cool atmosphere. If we assume that midtotality occurred on $t_0 = 2{,}443{,}362.$ (JD), then the time dependence of the integrated short-wavelength UV flux (*lower half* of Fig. 1) can be expressed as

$$f_\lambda \propto \exp\,[(t - t_0)/80]\ ,$$

where $230 \lesssim (t - t_0) \lesssim 350$ is the time in Julian days since midtotality. If we assume that the orbit is circular over this interval and that the separation of the centers of the two stars is $2.8 \times 10^9$ km, then the projected separation of the centers of the stars as seen from Earth is

$$x = 2.8 \times 10^9 \sin\,[8.46 \times 10^{-4}(t - t_0)]\ \text{km}\ .$$

Finally, if we make the simplifying assumption that the apparent increase in flux is only due to the variation of column density through a spherical atmosphere, then

$$f_\lambda \propto \exp\,(-\tau)\ ,$$

where $\tau = \alpha N$ and $\alpha$ is a constant absorption coefficient. $N$ is the column density along a chord through the sphere. When the density law in the outer atmosphere has the form

$$n = n_0 r^{-\beta} \text{ cm}^{-3} ,$$

the dependence of $N$ upon $x$ and, hence, upon $t$ can be evaluated easily. The "radius" of the atmosphere implied by the flattening of the UV light curve at $(t - t_0) \geq 350$ is $R \approx 8.2 \times 10^8$ km $\approx 1200\ R_\odot$. This radius is in harmony with the result of Hutchings and Wright (1971), but is 25% smaller than the radius derived by Wright (1977). The density law which best fits the observed rate of increase in flux according to this naive model is given by $\beta = 3$. Although the quantitative significance of this result may be slight, such a model appears to be a useful starting point for a more thorough analysis in the future.

As more UV data become available, farther out of eclipse, it will also be possible to study the distribution of matter through the system. Given the resolution (25–30 km $s^{-1}$) and limited life expectancy (of the order of 5 yr) of *IUE*, it will not be possible to analyze the velocity field of the gas streams in the same detail as was done with the Hα line profiles over a 20 yr period by Wright (1977).

## V. SUMMARY

Egress in the UV occurred 2 to 3 months after egress in the visible. The continuum was seen to rise first at the longer wavelengths: the opacity in the M star envelope is larger at shorter wavelengths. The low-dispersion spectra near the time of visible egress are dominated by fluorescent emission lines due to the excitation of the cool envelope by the hot companion. Few changes are seen in the low-dispersion spectra after 1978 August 20. Both the *h* and *k* lines of Mg II show asymmetric self-reversed emission profiles, in contrast to the symmetric *h* lines observed for the other M supergiants α Ori and α Sco. An absolute visual magnitude in the range −3.2 to −4.4 was derived from the width at the base of the emission. VV Cep appears to be about 1.5 mag less luminous than α Ori. Emission in the 1304 Å line of O I and multiplets 60, 62, 63, and 78 of Fe II is significantly stronger in VV Cep than in α Ori. The $V/R$ ratio of these double-peaked Fe II lines was seen to increase dramatically in 3 weeks, otherwise remaining nearly constant. An extremely complex absorption spectrum is seen against the emergent B star continuum. Low-excitation lines of neutral and singly ionized metals have been identified. Lines of Fe II have remained constant in strength, while those of Fe I have weakened or disappeared as egress continues, indicating that ionized iron persists farther into the circumstellar envelope than does neutral iron. Further identification and study of variable lines will yield information on the excitation and ionization structure of the outer atmosphere of the M supergiant. The absorption spectrum of VV Cep is far more complex than those of more widely separated binary systems consisting of a cool supergiant and a hot companion. At the present time, the proximity to eclipse and/or the greater interaction prevent the use of the UV data to determine the spectral type of the hot companion.

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## REFERENCES

Baliunas, S. L. 1979, private communication.
Bernat, A. P., and Lambert, D. L. 1976, *Ap. J.*, **204**, 830.
Bless, R. C., and Savage, B. D. 1972, *Ap. J.*, **171**, 293.
Boggess, A., *et al.* 1978, *Nature*, **256**, 23.
Bohlin, R. C., Holm, A. V., Savage, B. D., Snijders, M. A. J., and Sparks, W. M. 1980, *Astr. Ap.*, in press.
Cowley, A. P. 1969, *Pub. A.S.P.*, **81**, 297.
de Boer, K. S., Morton, D. C., Pottasch, S. R., and York, D. G. 1974, *Astr. Ap.*, **31**, 405.
Dupree, A. K. 1976, in *Physique des Mouvements dans les Atmospheres Stellaires*, ed. R. Cayrel and M. Steinberg (Paris: CNRS), p. 439.
Faraggiana, R., and Selvelli, P. L. 1979, *Astr. Ap.*, **76**, L18.
Guinan, E. F. 1979, private communication.
Hagen, W. 1978, *Ap. J. Suppl.*, **38**, 1.
Humphreys, R. M. 1970, *A.J.*, **75**, 602.
Hutchings, J. B., and Wright, K. O. 1971, *M.N.R.A.S.*, **155**, 203.
Kurucz, R. L. 1979, *Ap. J. Suppl.*, **40**, 1.
McClintock, W., Henry, R. C., Moos, H. W., and Linsky, J. L. 1975, *Ap. J.*, **202**, 733.
Stencel, R. E. 1979, private communication.
Stencel, R. E., Kondo, Y., Bernat, A. P., and McCluskey, G. E. 1979, *Ap. J.*, **233**, 621.
van de Kamp, P. 1978, *Sky and Tel.*, **56**, 397.
van der Hucht, K. A., Bernat, A. P., and Kondo, Y. 1980, *Astr. Ap.*, in press.
van der Hucht, K. A., Stencel, R. E., Haisch, B. M., and Kondo, Y. 1979, *Astr. Ap. Suppl.*, **36**, 377.
Wawrukiewicz, A. S., and Lee, T. A. 1974, *Pub. A.S.P.*, **86**, 51.
Weiler, E. J., and Oegerle, W. R. 1979, *Ap. J. Suppl.*, **39**, 537.
Wright, K. O. 1977, *J.R.A.S. Canada*, **71**, 152.

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