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THE VV CEPHEI STARS*

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This paper summarizes the photometric and spectroscopic investigations of the 13 known VV Cephei-type binaries. The cool primaries are found to be luminous supergiants with irregular or semiregular light variations of less than a magnitude. Descriptions of the spectra of both the hot and cool stars as well as the peculiar emission features are given. Variations in the spectrum are noted and, when possible, their relation to the orbital cycle is discussed.

The periods are characteristically long—of the order of a decade or more. Orbital studies indicate that the components have masses in excess of 30 solar masses. The location of these objects in associations or very near the galactic plane implies that they are recently evolved. High dispersion studies of VV Cep itself give evidence for steady mass loss from the primary. The relation of these systems to the much wider pair of stars in α Scorpii is considered.

I. Introduction

The VV Cephei stars were first distinguished as a group by Bidelman (1954) who described them as supergiant binary systems whose spectra show emission lines of hydrogen and [Fe II]. The primary star in the system is always a K or M supergiant while the secondary is generally an early B star. In the case of VV Cephei itself it is very difficult to say what the hot component is as no absorption features have been seen in its spectrum. Several of the systems show only weak hydrogen emission. Frequently the stars also show weaker emission of Fe II, [S II], [O I], [Ni II], and other elements, particularly in the ultraviolet.

*One in a series of review articles currently appearing in the *Publications*.

These stars should be distinguished from the somewhat earlier type of luminous binary stars like ζ Aurigae, and 31 and 32 Cygni which show atmospheric eclipses. None of these stars shows the characteristic emission lines of [Fe II].

In a very general way, the symbiotic stars and the VV Cep stars show similarities. In both, the absorption spectrum is that of a late K or M star. Stars of both groups show emission lines and finally both may have a strong ultraviolet continuum. However, a more detailed examination of the spectral features reveals marked differences.

Without exception the absorption spectrum of the primary of the VV Cep stars is a very luminous object not fainter than a Ib supergiant. Although the absorption spectra of the symbiotic stars have not been studied in great detail, the late-type features are more characteristic of a luminosity class III star.

The second difference is in the emission-line spectrum. The true symbiotic stars show lines of very high stages of ionization and excitation, as well as the forbidden lines characteristic of planetary nebulae. Typically He II and [O III] are present and such features as [Ne III], [Fe V], C III, and N III frequently appear. By contrast the emission lines present in the VV Cep stars are those of the low level, once ionized metals, principally [Fe II], although FR Scuti (Bidelman and Stephenson 1956) also shows [Fe III] and [O III] emission. Since in this case the blue companion dominates the spectrum to much longer wavelengths than in any of the other systems considered, the greater luminosity of the blue star probably accounts for the higher ionization lines.

A further distinction between the symbiotic and VV Cep stars is the character of the ultraviolet continuum. In the case of the VV Cep systems, the continuum in the ultraviolet is clearly due to the presence of a hot B- or O-type companion. The systems are clearly all binaries; the spectra are composite, with a very cool and a hot star together. In most cases one can clearly discern He I absorption lines, particularly the strong line at λ 3819. Often the broad wings of the higher Balmer members are seen. Quite frequently the center of the hydrogen lines is complicated with emission or sharp shell absorption so that the B-type spectrum is not pure, even in the far ultraviolet. In VV Cep itself probably no absorption lines from the photosphere of the blue star have been

seen. We know the hydrogen emission lines arise in a region around the hot component, as they disappear at the time of eclipse. In the symbiotic stars the blue continuum which may appear from time to time is not as easy to interpret. Although the binary hypothesis may be correct for some of these objects (AR Pavonis shows a photometric eclipse, for example), it does not explain all or even most of the peculiarities in their spectra. The blue continua vary very irregularly and absorption features due to a second star have not been observed.

It is perhaps interesting to point out that Merrill, who first applied the term "symbiotic" to the peculiar spectra of the Z Andromedae type, made a distinction between the symbiotic stars and the "M + Bep" binaries (for example, see Merrill 1958).

Table I presents a list of 13 stars now recognized to have spectral features that place them in the VV Cep class. Five objects have been added since Bidelman's (1954) list. Each will be described in some detail, although only the few brightest ones are at all well studied.

II. Light variations

Although the photometric and spectral variations of the VV Cep stars are somewhat related, it is more convenient to discuss these two general properties separately. Historically these stars were first noted as unusual because of their very red colors. Later their brightness variations were detected visually. Probably all of the VV Cep stars are variable by a few tenths of a magnitude, although at the present time only ten of them are named variables. From the historical evidence we conclude that all are probably "quasi"-regular variables of small amplitude. In many cases periodicities existed for a few years, only to be damped out and followed later by a different "period."

The majority of the stars have been only superficially studied. KN Cassiopeiae, WY Geminorum, and FR Scuti all have small light ranges of less than a magnitude and are considered to be irregular or semiregular variables similar to μ Cep. WY Gem was first noted as a slightly variable orange star by Backhouse (1901) and these observations were later confirmed at Harvard (Shapley 1922*b*). The variations of KN Cas were unknown until the work of Zinner (1935). FR Sct was found to be a variable of "short period"

TABLE I
THE VV CEPHEID STARS

Name	Other Designation	α	Position (1900)	δ	l	b	Mag	Spectral Type	Reference
KN Cas	+61° 8	0 ^h 4 ^m 4	+62° 7'	86° 0'	10 ^h 5-11 ^m 1			M1ep Ib + B	Bidelman (1954)
AZ Cas	+60° 310	1 35.5	+60 55	97 0	11.0-11.8			M0ep Ib: + B	Bidelman (unpublished)
HD 237006	+57° 641	2 41.7	+57 35	106 -1	<u>10.7</u>			M1ep Ib + B3:	Humphreys (1969a)
WY Gem	HD 42474	6 5.9	+23 14	156 +4	<u>9.2-9.8</u>			M2ep Iab + B2:	Bidelman (1954), Cowley (unpublished)
Boss 1985† (HR 2902)	HD 60414-5	7 29.2	-14 18	198 +4	<u>6.4-6.6</u>			M2ep Iab + B2 V	Bidelman (1954), Jaschek and Jaschek (1963)
WY Vel	HD 81137	9 18.7	-52 8	242 -1	<u>8.8-10.2</u>			M3ep Ib + B3:	Sahade (1952), Cowley (unpublished)
HD 101712	-62° 2234	11 37.1	-62 51	263 -1	<u>9.6</u>			M2ep Ib + B?	Thackeray and Wesselink (1965)
	-61° 3575	12 38.5	-61 23	270 +1	11.0			M2ep Ia + B:	MacConnell (unpublished) Carlson (1969)
FR Sct		18 17.8	-12 44	346 -1	<u>11.7-12.5</u>			M3ep Ia: + O?	Bidelman (unpublished)
Boss 5481 (HR 8164)	HD 203338-9	21 16.5	+58 12	66 +6	5.8			M1ep Ib + B2 V*	Bidelman (1954), Cowley and Cowley (1966)
VV Cep (HR 8383)	HD 208816	21 53.8	+63 9	72 +7	<u>6.8-7.5</u>			M2ep Ia-Iab + B?	Keenan and Wright (1957)
W Cep	HD 214369	22 32.6	+57 54	74 0	<u>8.9-10.0</u>			K0ep Ia + O?	Bidelman (1954)
U Lac	HD 215924	22 43.6	+54 38	74 -4	<u>10.8-12.0</u>			M4ep Iab + B	Bidelman and Böhm (1955)
								Related Object	
α Sco (HR 6134)	HD 148478	16 23.3	-26 13	320 +14	<u>3.0-3.9</u>			M2e Ib + B4 V	Morgan (1956), Stone and Struve (1954)

*Boss 5481 is also a visual binary (ADS 14864). The secondary of the visual pair has been classified as B2.5V (Cowley and Cowley 1966)

†This star has recently been designated KQ Pup.

Note to Table I: Underlined values of the magnitude indicate photographic or blue photoelectric determinations. If not underlined the value is a visual magnitude.

by Shajn (1935) although more recent observations suggest that it is nonperiodic.

The light variations of several of the stars have been studied in more detail. Again, they are intrinsic variables of small amplitude and with only semiregular periods. Both VV Cep and AZ Cas are also eclipsing variables of rather long period. It is probable that several of the others may also turn out to be eclipsing systems, in particular, WY Gem.

W Cephei. While making observations of red stars, Espin (1886) found this object to vary between 7th and 8th magnitudes within just a few nights. These observations were confirmed by Yendell (1894, 1895) and Parkhurst (1894), each of whom found periods between $6\frac{1}{2}$ and $7\frac{1}{4}$ days. However, Bohlin (1902) described the star as either not variable or of very small range. In the ensuing years other observers published their investigations of the star, but it was not until 1922 that Miss Applegate examined the star on 350 Harvard plates taken between 1892 and 1918 and concluded that the light varies irregularly between 8^m6 and 9^m3 (see Shapley 1922*a*).

U Lacertae. U Lac, like W Cep, has been known as a variable since the work of Espin (1893). Each observer has determined a different period. The earliest observations (Backhouse 1897, 1902; Graff 1902; Derchmuller 1902) suggested that the star was an irregular variable. Later, however, Graff (1914) gave a period of 659 days with a range of half a magnitude. Doberch (1919) again claimed the variations were nonperiodic, only to be followed by Zessewitsch (1928) who introduced an 855-day period for observations made between 1923 and 1927. Ten years later Böhme (1937) published his magnitude estimates and claimed that Zessewitsch's elements no longer held, and that the star was an irregular variable like μ Cep. He gave a range of 10^m7 - 12^m1 which is nearly that adopted by the *Variable Star Catalogue*. Even more recently Gaposchkin (1954) has suggested that the star is a semiregular variable with an approximate period of 150 days. It seems clear that any periodicity which may appear is only temporary. The star is probably a "quasi"-regular variable like many of the others, and the periods found were transient.

WY Velorum. The light variations of WY Vel were studied by Miss Cannon (1923) after her discovery of the bright lines in the spectrum. Harvard plates covering the period 1890 to 1922

showed the star to vary by at least one magnitude. Mrs. Payne-Gaposchkin (1947) summarized her subsequent observations as showing a rough cycle of 550 days superimposed on a long gradual decline in brightness followed by a less certain 370-day period on a slow recovery.

AZ Cassiopeia. Again we find a great deal of confusion as to the type and period of the light variations of this peculiar star. There seems to be no doubt that it is an eclipsing variable with a period of about 9.3 years (Ashbrook 1956). The earliest observations (Beljowsky 1931, 1933) suggested that the star might be a rather short period Algol-type variable, but Hoffmeister (1947) concluded that although there might be small-amplitude short-term variations, the main period was longer than 500 days. However, he thought the period to be somewhat irregular and assigned the star to the R Corona Borealis class. Ashbrook was able to establish the 9.3 year eclipsing period from Harvard plates and found that it would also account for the deep minima which Hoffmeister had observed. The totality lasts 92 days. Some modern photoelectric photometry by Larsson-Leander (1959) gives us a better understanding of what some of the early observers found. In addition to the eclipse of the B star by the large M supergiant, he found that the blue star was also somewhat variable. It would not be surprising to also find irregular variations of the M star, and perhaps that is what Beljowsky observed.

VV Cephei. VV Cep itself is by far the best studied star in its class, both because it is the brightest and because it is such an unusual type of eclipsing variable. In spite of its brightness the variability was unknown until 1908. Even then, the star was only examined for light variations because of the peculiarities in the spectrum found by Miss Cannon (1912). On 68 plates she found a "small but distinct variation of 0.5 magnitude" which was soon confirmed photoelectrically.

The spectrum of VV Cep was investigated a good deal in the 1930's and it became apparent that the changing radial velocity could be accounted for by an orbital period of about 20 years (Harper and Christie 1933). A most unexpected discovery, that the hot star was being eclipsed, was announced by McLaughlin (1936) in October of 1936, on the basis of spectroscopic material. Immediately Gaposchkin (1937*a, b*) re-examined the Harvard plates

which then extended to 1937. He found three well-defined and equally-spaced light minima giving a period of 20.4 years which was in excellent agreement with the radial-velocity data. He found the dimensions of the system to be truly spectacular. The duration of totality was found to be 490 days, implying a radius of the M star of 2400 solar radii. No secondary minima were found (or have been since), but this is easily understood if the B star has a radius of only 1/100 of the primary. Although he found the depth of the eclipse to be 0.8 magnitude photographically, visual observations and plates taken at longer wavelengths hardly showed any significant changes in the light level during eclipse. This is because the B star is several magnitudes fainter than the M star in the visual region and therefore hardly contributes to the combined light. During the most recent eclipse of 1956-57, Larsson-Leander (1957*a*, *b*) observed the star photoelectrically. Curiously he found the depth of the eclipse to be only 0.32 magnitude through his *P* filter. The discrepancy may be due to the greater ultraviolet extension of the photographic plates used at Harvard. Larsson-Leander found only a 0.04 magnitude depression in the visual magnitude during totality. He also concluded that the partial phases of the eclipse were about a week shorter than the values given by Gaposchkin. However, the overall picture which Gaposchkin presented for the photometric eclipse seems to be correct.

Gaposchkin's work further established that the M star must be intrinsically variable since he found light variations during totality. This interpretation fits well with both earlier and more recent observations of the system. For example, Kopal (1932) concluded that VV Cep was a semiregular variable of the RV Tauri type from his observations between 1926 and 1930. (This interval did not include an eclipse.) An excellent summary by McLaughlin (1951) of his visual observations from 1933 to 1950 describes the "quasi"-periodic variations of the star. The amplitude of about 0.5 magnitude as given by Miss Cannon is confirmed. However, in certain years McLaughlin found that the range was smaller. Separation of the maxima varied from several months to a year with individual maxima rarely lasting more than a month. Curiously, he suggested that the two stars might vary together as the relative spectral visibility did not appear to change. More recently Larsson-Leander (1957*b*) has given the same interpretation of the approximate 100-day cycles for which he found no color changes.

Fredrick's (1960) Figure 4 shows McLaughlin's observations assembled in 20-day means. He describes the variations as a combination of a long-term wave (13.7-year period, 0.15-magnitude range) and a short-period fluctuation (349-day period, approximately 0.3-magnitude range, with alternating large and small amplitude maxima). Both variations have a larger amplitude at greater wavelengths and are undoubtedly due to the M star. McLaughlin (1934) has suggested that the radial-velocity data are not incompatible with a pulsating model for the supergiant.

Still a further type of light variation, which is well documented in the literature, is present in the VV Cep system. Small ultraviolet pulses of several hundredths of a magnitude, lasting from half an hour to several days, have been reported by Larsson-Leander (1957*b*, 1961) and Fredrick (1960). During one such brightening which occurred during totality and was seen by both observers, a spectrogram was obtained at Mount Palomar. It showed no trace of the blue component. Twenty days later Wright found H γ brighter than normal during one such outburst. It is still unclear whether the brightening is in the continuum or the hydrogen emission lines. The pulses have the greatest range at the shortest wavelengths which suggests that they may be associated with the hot star. At present there seems to be no satisfactory explanation for them.

Other Stars. Both Boss 1985 and Boss 5481 are only a magnitude fainter than VV Cep itself. It is somewhat surprising that they are not well-known variable stars. The Jascheks (1963) have given evidence for a range of about 0.1 magnitude in Boss 1985. If photoelectric observations were made of Boss 5481 undoubtedly similar variations would be found. This star very recently has been designated KQ Puppis. The work of Miss Humphreys (1969*a*) and Sharpless (1958) also indicates a small variation in the light of HD 237006.

Spectroscopic data suggest that several of the other stars may undergo atmospheric eclipses. These should be followed carefully for evidence of a photometric eclipse. The study of such eclipses is extremely important as these stars are undoubtedly among the most massive stars in the Galaxy.

III. The Spectroscopic Properties

While the presence of a late-type supergiant absorption spectrum, [Fe II] emission lines, and a blue continuum are common to all of the VV Cep stars, there are naturally some individual differences between the spectra, even at low dispersion. Two of the most pronounced differences in the photographic regions are the strength of the emission lines and the wavelength to which the blue companion dominates the spectrum. Plate I shows six of these stars on low dispersion spectra taken by Bidelman. Some of the [Fe II] emission lines are marked as well as other features in the spectrum. All show [S II] (λ 4068) and [Ni II] (λ 3993). Several of the stars show hydrogen and Fe II in emission, although these lines are known to be variable in intensity.

The emission features in these stars were first noted in VV Cep by Miss Cannon (1912). She remarked that the hydrogen lines were bright but that the Balmer decrement was unlike that seen in the long-period variables where some of the emissions are depressed by overlying absorptions. Later (Cannon 1920) she noted that the hydrogen lines were "doubly reversed" and that there were numerous other bright lines. Even before the identification of these lines as [Fe II] (Merrill 1928) in the spectrum of η Carinae, Miss Cannon had remarked on the similarity of the emissions in W Cep to that star. Humason (1922) found the same lines in the spectrum of WY Gem, and soon after, Adams, Joy, and Humason (1925) observed these still unidentified emissions in Boss 1985 and Boss 5481. Boss 5481 had been given by Miss Cannon (1916) in her list of "Stars Having Peculiar Spectra." Although she noted that the spectrum was composite, she apparently failed to see the emission lines, which are rather weak in this particular star (see Plate I).

The similarity of the other stars in the group was only noticed many years later, although KN Cas, AZ Cas and HD 237006 were known to show a bright $H\alpha$ line (Merrill, Humason, and Burwell 1925; Merrill and Burwell 1943).

A. Identification of Features

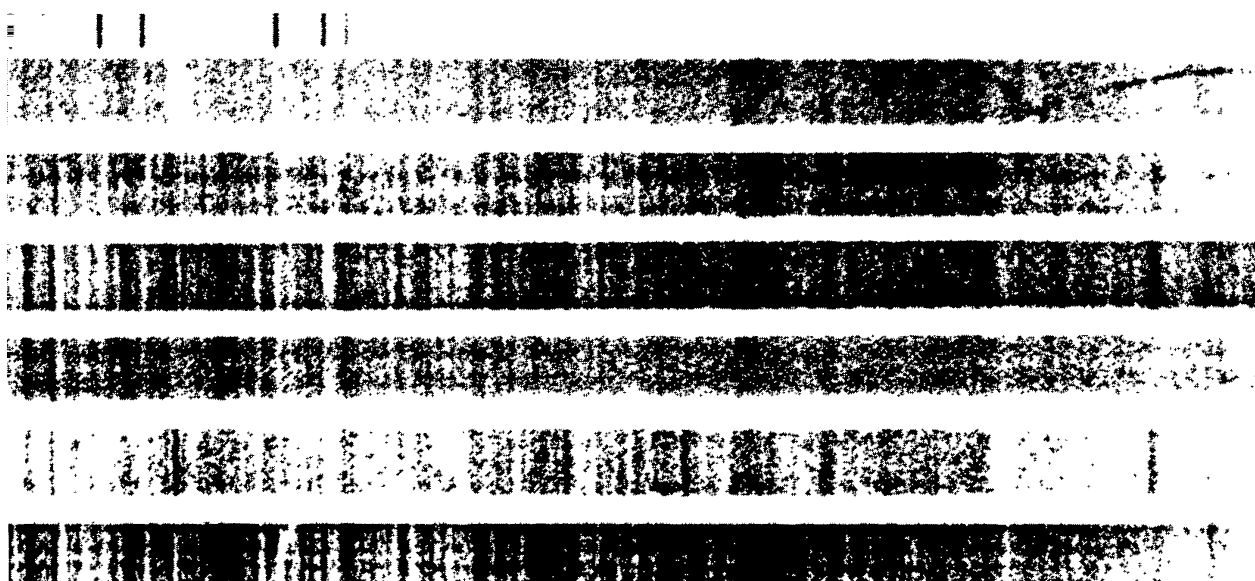
Table II gives reference to the investigations that attempted to measure and identify many features in the spectra of these stars. It is easy to see that only a few of these stars have been studied in

PLATE I
SPECTRA OF SOME OF THE VV CEPHEI STARS

(1) Boss 5481	December 5, 1949	M1 Ib
(2) KN Cas	December 14, 1949	M1 Ib
(3) Boss 1985	November 29, 1949	M2 Iab
(4) WY Gem	November 29, 1949	M2 Iab
(5) VV Cep	December 5, 1949	M2 Iab-Ia
(6) W Cep	December 5, 1949	K0 Ia

All of the spectra shown were taken with the Cassegrain spectrograph on the 82-inch telescope at McDonald Observatory. An attempt has been made to order these by decreasing contribution of the blue star. (For example, note that in Boss 5481 (1) the contribution of the B star is evident at $H\gamma$.) In so doing it turned out that the primary stars were also arranged in order of increasing luminosity as determined from the relative strengths of the $Fe\ I$ lines at $\lambda\lambda$ 4376, 4383, and 4389. In WY Gem (4) only H_ϵ and H_ζ show a central emission while the other hydrogen lines appear to be partially filled by emission. W Cep (6) is a little earlier in spectral type than the other stars so that the TiO bands are not seen.

The prints have been photographically dodged so that the fainter ultraviolet region could be shown without overexposing the region near $H\beta$. All of these plates were taken by W. P. Bidelman and kindly loaned by him for this paper.



4287[FeII]—

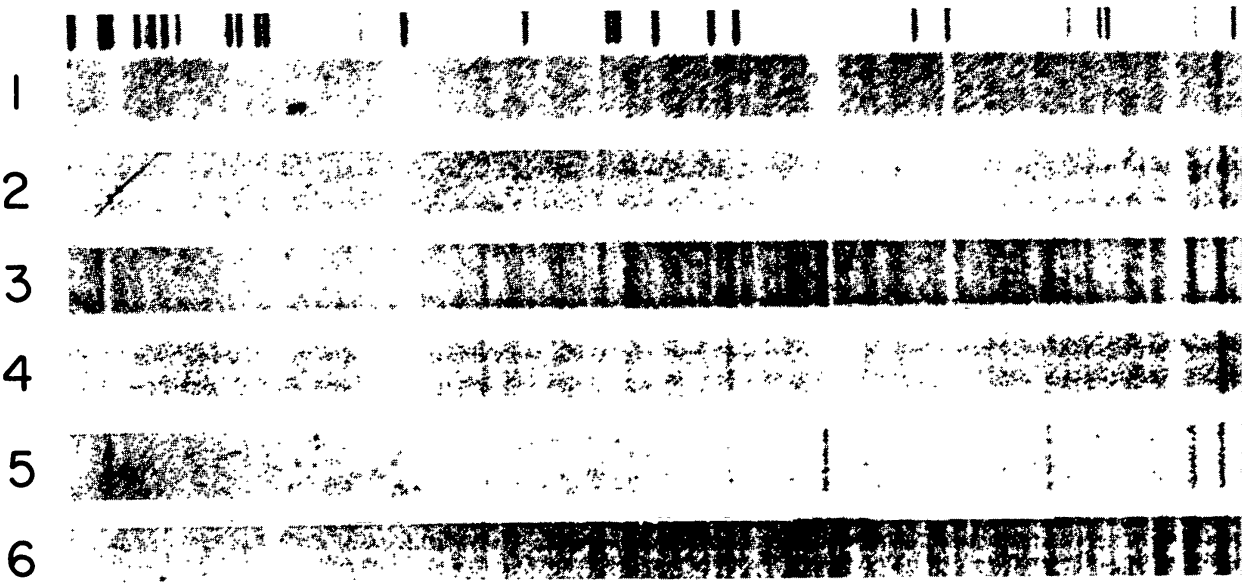
Hγ—

4359[FeII]—

TiO

Hβ—

E I



K—

H+He ϵ —

3993[NiII]—

[SII]—

H8—

4233FeII—
4244[FeII]—

PI

PLATE II

SOME CHANGES IN THE SPECTRA OF BOSS 1985, BOSS 5481, AND VV CEPHEI

Boss 1985

- (1) November 25, 1947
- (2) March 29, 1964
- (3) October 9, 1965

The first spectrum illustrates the shell phase described by Swings (1950). Note the change in the intensity of the hydrogen and calcium emissions between the second and third spectra. Spectrum (3) has a somewhat smaller scale so that the K line appears slightly to the left of the indicated mark.

Boss 5481

- (4) March 29, 1964
- (5) October 9, 1965
- (6) October 10, 1965
- (7) June 13, 1966
- (8) September 23, 1966
- (9) October 18, 1967

Spectra (4) and (9) for Boss 5481 are almost identical. In the intervening period (spectra 5-8) the star developed a weak ultraviolet shell absorption spectrum which is best seen at the Ti II lines at $\lambda\lambda$ 3759 and 3761. Other Ti II, Cr II, and Mn II lines were also enhanced during this time; some of these features are marked. All of the lines which appeared are from very low levels. By contrast with Boss 1985 and VV Cep, only a few weak emissions appear in the ultraviolet spectrum of Boss 5481.

VV Cep

- (10) September 17, 1939
- (11) October 9, 1965
- (12) October 20, 1967

These plates show a few of the changes which occur in the composite spectrum of VV Cep. None of the spectra was obtained during the eclipse. Note that the hydrogen emission changes from a very pronounced "reversed P Cygni" profile in (10), to a much narrower violet emission in (11), and finally to a double emission with V/R about two in spectrum (12). Also note that [Fe II] is probably stronger in Boss 1985 than in VV Cep, while the emissions of Mn II have greater strength in VV Cep.

All of the illustrated spectra were obtained with the 500-mm camera and quartz prisms on the Cassegrain spectrograph of the 82-inch telescope at McDonald Observatory by the author except (1) and (10) which were taken by O. Struve.

TABLE II
WAVELENGTH LISTS FOR THE VV CEPHEI STARS

Star	Region	Dispersion (Å/mm)	Remarks	Reference
Boss 1985	λλ 3280-3670	40, 50, and 100 at λ 3933	[Fe II] emission only	Swings and Struve (1940)
Boss 1985	3130-3430	57 at λ 3220	Fe II, [Fe II], and [Cr II] emissions	Swings and Struve (1941)
Boss 1985	3160-5540	26 at λ 3500	Fe II emission only	Swings and Struve (1943)
Boss 1985	3110-3940	26 at λ 3500	plates between Oct. and Dec. 1947	Swings (1950)
Boss 1985	3190-3860	26 at λ 3500	three plates, 1947-1950	Bosman-Crespin and Swenson (1956)
Boss 1985	3160-3490	68	emissions only	Swings and Swings (1967)
Boss 1985	3140-3630	10	emissions only	Swings (1969)
VV Cep	3270-3720	not given	all lines	Struve (1944)
VV Cep	3100-3370	"small dispersion"	emissions only	Swings and Struve (1945)
VV Cep	3160-3490	68	emissions only	Swings and Swings (1967)
WY Gem	3280-3670	40, 50, and 100 at λ 3933	[Fe II] emissions	Swings and Struve (1940)
WY Gem	3130-3430	57 at λ 3220	[Fe II] emissions	Swings and Struve (1941)
α Sco	3600-6600	3 to 13	all lines	Davis (1939)
WY Vel	3270-6940	42	emissions only	Sahade (1952)

detail, and with published wavelength lists have been looked at primarily in the ultraviolet. This is because most of the emission lines are in this region. No investigations to date have been made that attempt to follow any of the stars over a long period. For example, we know very little about the variations in the ultraviolet spectrum of VV Cep or Boss 1985 throughout their orbital cycles, although changes in the ordinary photographic region are known to be large. By far the majority of work on both the identification and interpretation of the emission lines in these stars has been done by Swings and Struve in their series of papers on peculiar stars (1940, 1941, 1943, 1945). Swings's (1943) work on the spectrum of [Ni II] allowed him to correctly identify λ 3993 (shown in the spectra in Plate I), which had been previously attributed to [Cr II], and numerous other bright lines in the ultraviolet region of Boss 1985 and WY Gem. Additional identifications were made on the basis of Swings's (1944) study of [Cr II] and [Fe II]. However there still remain several moderately strong ultraviolet emissions to be identified in VV Cep, WY Gem, and Boss 1985.

Very little is known about these stars at longer wavelengths. Sahade (1952) has investigated the spectrum of WY Vel and finds Fe II, [Fe II], [O I], [N II], [Ni II], and $H\alpha$ to be present in emission in the red region. All of the stars show emission at $H\alpha$. The Cowleys (1964) have found [O I] in Boss 1985, but it is probably not present in Boss 5481. The neutral oxygen lines observed in the infrared spectrum of VV Cep and KN Cas are discussed later.

B. Discussion of Individual Stars

For a few of the VV Cep stars, everything which is known about the spectra can be summarized in a few sentences. Because many of the stars are faint and have characteristically long periods only a few investigations have been made.

HD 101712. This spectrum has been only briefly described by Thackeray and Wesselink (1965) who note the presence of [Fe II] emissions on the composite M2 Ib + B absorption spectrum.

HD 237006. Sharpless (1958) remarked that this star is composite on the basis of *UBV* photometry. Relatively weak [Fe II] emission lines were found by Miss Humphreys (1969*a*) who has described its spectrum as similar to those of the VV Cep stars. The secondary dominates the spectrum to about $H\gamma$ and is apparently variable.

BD -61°3575. This southern object has been only superficially described in an announcement of its discovery by Henize (1952). It is said to show bright H, [Fe II], Fe II, and [Fe III] in addition to strong TiO bands in the red. Objective-prism plates taken in the Michigan sky survey by MacConnell at Cerro Tololo show the continuum in the photographic region to be mostly dominated by the hot star. Infrared plates show the primary to be a supergiant. On the basis of a 94-Å/mm plate Carlson (1969) has classified the star as M2ep Ia + B. The presence of [Fe III] is unusual; this star should be investigated further.

WY Velorum. At the present time the emission lines in WY Vel are the strongest seen in any of the VV Cep stars. Miss Cannon (1923) described the spectrum as an early M star with bright lines corresponding in wavelength with the unidentified lines in η Car (now known to be [Fe II]). She was careful to state that at least H β was not in emission. From that we might conclude that none of the H lines showed emission. Sahade (1952) has studied a series of plates taken between 1944 and 1952. He confirms that the only hydrogen line which appears in emission is H α . However the spectrum is rich with other bright lines which include [N II], [O I], Si II, [Fe II], Fe II, [Fe III], [Ni II], [S II], and [Cu II]. No outstanding changes occurred in the spectrum during the period which Sahade observed. A recent objective-prism plate taken with the Curtis Schmidt telescope at Cerro Tololo establishes clearly that the hot star is an early-B star. Absorption lines of both hydrogen and helium are clearly visible below H γ . Comparison of the present spectrum with the illustrations in Sahade's article suggests that the M star may be relatively fainter now than it was in the 1940's.

A unique observation of this star was made by Münch (1956). The star was observed on two consecutive nights. On the first plate the H and K lines of Ca II appeared in absorption; on the second plate the lines appeared very strongly in emission. Generally the calcium lines show only weak emission in these stars, and although some variations have been observed in the other stars, this is certainly the most drastic change in these lines which is known. Apparently none of the other features in the spectrum varied.

AZ Cassiopeiae. Surprisingly little work has been done on the spectrum of AZ Cas when one considers that it is an eclipsing system like VV Cep but with a much shorter period. Sahade and

Struve (1957) observed the spectrum a few months before the totality of 1957 which had been predicted by Ashbrook (1956). Unfortunately their plate of the photographic region was too weak to be used, so that they were unable to discuss the chromospheric lines that are strengthened prior to eclipse in VV Cep. They did find that $H\alpha$ was bright and flanked on the short wavelength side by an absorption line. Their suggestion was that perhaps the blue star was surrounded by a rotating gaseous ring and that the approaching edge of the ring had already been eclipsed by the M star. However, in view of the fact that VV Cep generally shows this "reversed P Cygni" structure at the hydrogen lines, the $H\alpha$ structure which they observed may have been "normal."

Bidelman (1969) obtained two blue plates of the object, one before and one during totality. The blue continuum was indeed gone on the second plate. Since the star is eclipsing and therefore the inclination is known, it would be very important to determine the spectroscopic elements so that the masses could be computed. By working in the far ultraviolet it might also be possible to measure the radial velocity of the secondary star and thus accurately determine the mass ratio.

KN Cassiopeiae. Espin (1895) noted KN Cas as a very red star in an article entitled "Stars with Remarkable Spectra." To him of course, the remarkable thing about its spectrum was not that it was a supergiant binary with emission lines, but rather that it was a star of Sechi's type III! Merrill *et al.* (1925) found it to have bright $H\alpha$. The spectrum was not investigated further until Bidelman (1951) called attention to the similarity of this star to Boss 985. It is shown in Plate I. Miss Humphreys obtained an infrared plate at Kitt Peak in 1968 in order to measure the radial velocity in her investigation of late-type supergiants. Her plate is somewhat weakly exposed, but the $O\ I$ lines (also seen by Keenan in VV Cep) are probably present. If Glebocki and Keenan's (1967) interpretation of the variation of these lines in VV Cep as a manifestation of the secondary eclipse is correct, it is possible that future studies will find KN Cas also to be an eclipsing system.

W Cephei. No thorough investigation of the spectrum of this interesting star has yet been carried out. Adams and Joy (1921) found the bright lines in the spectrum and likened it to VV Cep. A short description of the spectrum was given by Swings and Struve

(1940) who intercompared it with WY Gem, Boss 5481, and Boss 1985. Unlike these other stars the Balmer lines are not seen in the ultraviolet. They describe that region of the spectrum as being mostly continuous with a few poorly identified absorption features. The spectrum of the primary is definitely earlier than any of the other systems considered here. Bidelman (1954) has called it a K0 Ia. It is possible that some very short-term variations of importance may occur in the spectrum. Merrill *et al.* (1932) report that the strength of the $H\alpha$ emission line doubled in only five days.

FR Scuti. Very little is known about the spectrum of FR Sct. Bidelman and Stephenson (1956) have pointed out its similarity to VV Cep. The early-type component dominates the spectrum to much longer wavelengths than in VV Cep. Unlike any of the other stars in this class the spectrum contains emission lines of [O III] as well as H, Fe II, [Fe II], and [Fe III]. [N II] and [O I] emission lines are also present in the red region (Bidelman and Perry 1969). It seems likely that the secondary is an O star. The spectrum has also been briefly discussed by Bloch and Mao-Lin (1958).

U Lacertae. Bidelman and Böhm (1955) have presented the only spectroscopic information available on this star. The M4 supergiant has bright lines of [Fe II] and $H\beta$ and shows an early-type continuum near the H and K lines.

WY Geminorum. The existence of bright lines in the spectrum of WY Gem was first pointed out by Humason (1922) who remarked on the similarity of the spectrum to those of W Cep and VV Cep. Many of the emission lines in the ultraviolet have been identified by Swings and Struve (1940, 1941).

This star is currently under investigation at Michigan. Coudé plates taken by Bidelman in 1960 and 1961 at Lick Observatory (Whitford 1962) show some sharp absorption lines of Cr II, Mn II, and Ti II below 3800 Å in addition to numerous emission lines that are also present in the spectra of Boss 1985 and VV Cep. However spectrograms obtained by Struve at McDonald Observatory in the 1940's show none of these sharp absorptions. The resemblance of these features to the very early phases of the atmospheric eclipse in VV Cep led us to take several coudé spectrograms of WY Gem in October 1968 at Kitt Peak. These plates revealed that the "shell" spectrum had greatly increased in intensity with prominent lines extending up to $H\delta$. The Ti II lines at λ 3900 and λ 3919 were out-

standing, and numerous lines of Fe I were present throughout the ultraviolet spectrum. Furthermore the radial velocities obtained from these and other older plates indicate that the presence of these features could be due to an atmospheric eclipse, with the B star passing behind the extended atmosphere of the M star (Cowley 1968).

Wright (1969) has confirmed the similarity of the spectrum to that of VV Cep as it nears totality. Further he finds from a very high dispersion plate that the enhanced lines show doubling as he and McKellar (Wright and McKellar 1956) found in VV Cep. Abt has obtained several more coudé plates of WY Gem during the winter of 1968-69. Each shows the "shell" spectrum strongly with very little change over a period of six months. Portions of the 1960 and 1961 plates taken by Bidelman are compared to the same regions of plates during this past winter in Plate III. The change in the strength of the absorption lines is easily seen. With the onset of the strong atmospheric eclipse (or "shell") phase, the emission lines in the ultraviolet have become very much weaker. The legend describes the spectra in more detail.

By comparison with the spectrum of VV Cep one would have expected the B star to be totally eclipsed sometime in the early spring. However image-tube spectrograms obtained by Kent Ford with the 72-inch telescope in Flagstaff show that the spectrum of the B-type star was still present in April 1969. It is possible that the inclination of the system is not large enough for the B star to be totally eclipsed by the M star and that a grazing atmospheric eclipse is all that will be observed. Alternately, if the period of the system is much longer than VV Cep's orbital period, each phase of the atmospheric eclipse could be much longer. A very preliminary orbit indicates that the second case is likely. It appears that the period will be in excess of 40 years. Furthermore, with the observed velocity range of 15 km/sec over only part of the period, unless the inclination is fairly near 90° the computed masses will turn out to be exceedingly large. Observations of this very interesting system will be continued in the fall.

Boss 5481. Boss 5481 is the least peculiar of all of the stars in this group. The emission lines of [Fe II] are relatively weak. The hydrogen lines do not appear in emission except for very weak bright edges around the $H\alpha$ absorption line. The B star dominates

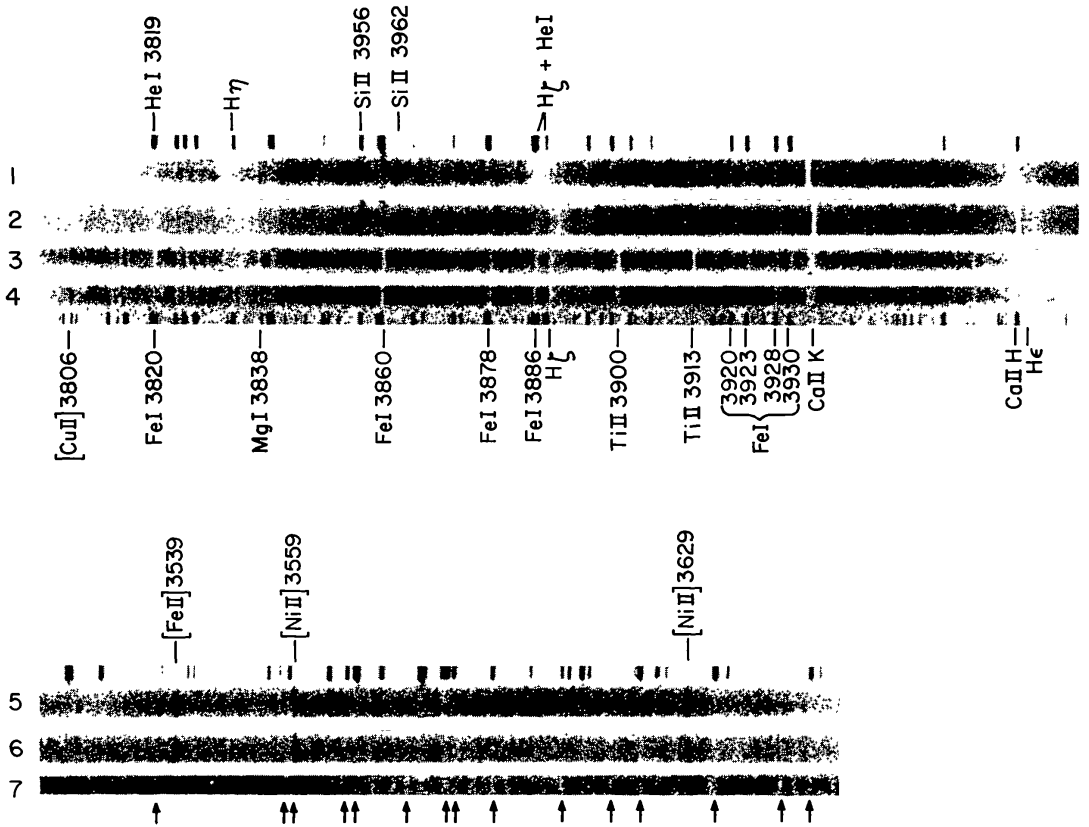


PLATE III

HIGH DISPERSION SPECTROGRAMS OF WY GEM

- | | | |
|-------------|--------------------|-----------------------------|
| (1) and (5) | September 28, 1960 | Lick Observatory (Bidelman) |
| (2) and (6) | December 23, 1961 | Lick Observatory (Bidelman) |
| (3) and (7) | October 14, 1968 | Kitt Peak (Cowley) |
| (4) | January 1, 1969 | Kitt Peak (Abt) |

These spectra show the great difference between the recent appearance of the spectrum and that in the early 1960's. The numerous absorption lines of Fe I, Ti II, and others arise in the outer atmosphere of the M star as the B star passes behind it. The Ca II lines can be seen as double. On higher dispersion the other chromospheric absorptions are also double (Wright 1969). In the bottom three spectra, some of these recent chromospheric lines are indicated by arrows. The emissions of [Ni II] and [Fe II] seem much weaker in (7) than in (5) and (6).

the spectrum to about $H\delta$ (as is easily seen in Plate I) and the broad $He\ I$ lines in its spectrum are prominent. Struve and Swings (1940) have compared its spectrum to Boss 1985 and they find all the emission lines weaker in Boss 5481. It remains one of the most important stars in the group because it is a member of a visual binary. The second star is a normal B3 V star (Cowley and Cowley 1966) whose radial velocity agrees with the center-of-mass velocity of the spectroscopic binary. Like WY Gem, Boss 5481 has a very long period so that reliable elements are not yet available. The period is probably at least 75 years (Cowley 1967). The small velocity range suggests that this star may be viewed at a low inclination.

In 1965 and 1966 the star went through an interesting outburst which is illustrated in Plate II. In March of 1964 the ultraviolet spectrum which is primarily due to the B star looked as it had in previous years. McLaughlin had noted (Bidelman 1954) that no certain changes had occurred in the spectrum between 1933 and 1952. However by October of 1965 numerous sharp shell-like absorptions of Cr II, Ti II, Mn II, and Ni II had appeared shortward of 3800 Å, and a corresponding sharp component was present in the otherwise broad hydrogen lines (Cowley and Cowley 1966). (The spectrum was similar to that of WY Gem in 1960 and 1961 as described above, although sharp hydrogen cores did not appear in WY Gem at this phase.) This shell persisted for about a year before the ultraviolet spectrum returned to normal. The radial-velocity data for the system are insufficient to decide whether this outburst could be due to a very grazing atmospheric eclipse or to some other phenomenon.

Boss 1985. As in several of the other VV Cep systems, the bright lines were first noticed by Adams *et al.* (1925). Swings and Struve (1940, 1941, 1943) have described the spectrum as similar to WY Gem and have given identifications for many of the lines, particularly in the ultraviolet. Table II gives reference to several wavelength studies which have been published.

This is one of the few systems for which we have orbital data and thus are able to understand some of the spectral changes. McLaughlin (1948) observed the system for many years as part of his program on stars with composite spectra, and described the variation of the H and Fe II emission lines. McLaughlin (1948), Swings (1950), and Bosman-Crespin (1956) all discuss a shell absorption

which was present from 1942 to 1947. At that time the higher Balmer lines had strong narrow absorption cores and numerous absorption lines from low levels of Ti II, Ca II, Cr II, and others appeared. This phase is pictured in Plate II. (The strength of the lines greatly exceeded the small outburst of Boss 5481 which was described above.) It later became apparent that the variation in intensity of the Fe II and hydrogen emissions, as well as the appearance of the shell spectrum, was correlated with the phase of the orbital period (Cowley 1965).

The star has a 27-year period and a very eccentric orbit. (See Table III for orbital elements.) Near the time of periastron passage both the Fe II- and H-emission lines strengthen greatly for several years. Like VV Cep the hydrogen lines usually show the "reversed P Cygni" profile with an absorption line on the long wavelength side of the emission. At the time when the B star was farthest from the observer in its orbit the strong shell absorption appeared. It is tempting to conclude that this was another observation of an atmospheric eclipse, although the absorption lines never reached the intensity seen in VV Cep and WY Gem. Perhaps the eclipse was only grazing or the scattered observations were taken too far from the totality, if one occurred. Alternately some sort of an outburst from the B star might produce similar spectroscopic effects.

Broad absorption lines of He I, O II, and Ne II are seen in the ultraviolet. The wide wings of the hydrogen lines from the B star can also be seen on either side of the reversed P Cygni structure. At the time of the investigation of the orbit of Boss 1985 not enough plates extending into the ultraviolet were available to determine the orbit of the secondary. This information should be obtained in order to determine the mass ratio in the system.

VV Cephei. The spectrum of VV Cep has been under close observation at a number of observatories since the discovery of the eclipsing nature of the stars. Even before that some of the peculiarities and variations in the spectrum had been recognized. On the basis of the radial-velocity variations Harper and Christie (1933) announced a preliminary orbit with a period of 20 years. Soon afterwards, Christie (1933) showed that the mass function was six solar masses—still one of the largest known. McLaughlin (1934) described the behavior of the emission lines, and found that the V/R ratio for both H and Ca II varied. He also noted that the

TABLE III
PHYSICAL DATA FOR THE VV CEP SYSTEMS
ECLIPSE INFORMATION

Star	Period	Depth of Eclipse (magnitudes)	Duration of Totality	Duration of Ingress, Egress	Reference
VV Cep	7430 days	0.80 pg	450 days	20, 20 days	Gaposchkin (1937)
VV Cep	7430	.32 P filter	498	40, 28	Larsson-Leander (1957)
VV Cep	(7430)	(.6) blue filter	550	27, 27	Fredrick (1960)
VV Cep	7450	-	521	30, -	Peery (1966)
AZ Cas	3406	1- pg	92	10, 10	Ashbrook (1956)

Star	Period	K	e	w	$a_1 \sin i$	$f(\mathcal{M})$	i	Remarks and References
ORBITAL DATA								
VV Cep	7430 days	20.6	.25	339°	13.6 a.u.	6.05 \odot	72°	Gaposchkin (1937)
VV Cep	(7430)	20.75	.26	24'	13.7	-	(72°)	Goedicke (1939)
VV Cep	(7430)	-	.5	302	6-10	-	$\pm 90^\circ 39'$	Fredrick (1960)
VV Cep	7450	19.1	.34	26	12.3	4.47	-	Peery (1966)
Boss 1985	9752 days	17.1	.46	203.6	13.7	3.6	$> 45^\circ?$	Cowley (1965)—could be eclipsing
WY Gem	> 40 years	~ 10	-	-	-	-	$> 60^\circ?$	pronounced atmospheric eclipse
Boss 5481	~ 75 years	~ 10	-	-	-	-	$< 60^\circ?$	grazing atmospheric eclipse??

Star	R_M	R_B	\mathcal{M}_M	\mathcal{M}_B	Remarks and References
MASSES AND RADII					
	(solar radii)	(solar radii)	(solar masses)	(solar masses)	
VV Cep	2400	24	44.5	34.8	Gaposchkin (1937)
VV Cep	2780	24	-	-	Goedicke (1939)
VV Cep	~ 500	-	~ 10	~ 10	Fredrick (1960)
VV Cep	1620	< 88 (envelope)	84.4	41.3	Peery (1966)
Boss 1985	-	-	> 34	> 22	Cowley (1965)
α Sco ^o	400	-	~ 25	-	Evans (1957)
α Sco	630	-	-	-	Using Evans' (1957) angular diameter but Bertiau's (1958) distance

^oThe present apparent separation of the two stars is about 450 a.u. based on Bertiau's distance.

Note to Table III. Values in parentheses were assumed by the investigator.

radial velocity of the [Fe II] lines did not change. This led to the conclusion later that these emissions must be formed in a large nebula that envelopes both of the stars.

The star had appeared to him to be unusually faint in March 1936 and in October McLaughlin (1936) announced that the B star had been eclipsed.* Futhermore both the blue continuum and the hydrogen emission lines had disappeared from the spectrum. Prior to the disappearance of these features the ultra-violet region of the spectrum had showed strong absorptions of Ti II, Ca II, and Fe II similar to the atmospheric effects in ζ Aur before totality. From his plate material McLaughlin (1937) concluded that the region where the Ti II lines were formed must reach one stellar radius above the photosphere of the M star while the Ca II-forming region must extend all the way to the hot companion. He observed that the hydrogen emission lines were eclipsed successively with H α disappearing last which implied that there was a fairly extensive stratified emitting region around the B star which he thought must have ten times the radius of the hot star itself.

The first study which tried to discuss the atmosphere structure of VV Cep was undertaken by Goedicke. He realized by analogy with ζ Aur that the comparatively small B star would act as an ideal probe as it passed behind the cool star's outer atmosphere. Several preliminary reports of his work were given (Goedicke 1937, 1938) but his detailed study appeared in the Michigan Publications (Goedicke 1939). The first part of this paper was concerned with the determination of the orbital elements, radii, and temperatures of the stars. These data are given in Table III and are compared to the values found by Gaposchkin (1937*b*), Fredrick (1960), and Peery (1966). By following the changes in the equivalent widths of the absorptions produced in the outer atmosphere of the M star as the B star emerged from totality he was able to find the density gradient of various atoms and ions. Lines of Fe I, V I, Co I, and Ti I show the neutral metals to have a very steep gradient by comparison with Ti II and Ca II. From 20 lines of neutral iron with differing levels of excitation he concluded that the temperature gradient out through the atmosphere was small. Subsequently Goedicke (1942)

*Later Gaposchkin (1937*b*) discovered that one of the earliest Harvard spectrograms of VV Cep, taken in September 1895, was probably obtained during totality.

investigated the radial velocity of the chromospheric absorptions very near the limb of the star and determined that the M star has no appreciable rotation.

A high dispersion investigation of VV Cep was undertaken at Victoria to study the 1956-57 eclipse. Not all of the material has been published yet, but two very interesting papers have appeared (Wright and McKellar 1956; McKellar, Wright, and Francis 1957). They find that the ultraviolet emission lines, except for the bright lines of hydrogen, disappear during the atmospheric eclipse stage.* On their high-dispersion plates the chromospheric lines are double with the separation depending on the species. The Fe I lines are closer together than the Ti II lines near 3900 Å, and the Ti II lines at λ 3759 and λ 3761 form still wider pairs. Closer to totality they also find a trend toward smaller separation of these lines. After discussing several hypotheses they conclude that the observations are best explained by picturing several discrete clouds or condensations in the atmosphere of the M star. In the H and K lines of Ca II and other ultimate lines they also find a circumstellar component which gives a velocity of expansion of 20 km/sec.†

During totality some emission lines of Fe II, Mn II, and Cr II are present in the ultraviolet. Some emission also remains at H α throughout the eclipse indicating that the hydrogen-emitting region is not merely confined to the region immediately around the B star.

In direct opposition to the picture of a very large, luminous, and massive system, which we infer from the spectroscopic and photometric data, is the model derived from an astrometric orbit of this binary by Fredrick (1960). He finds the parallax to be 0".005, which would indicate a visual absolute magnitude of the primary of -1.4 as compared to a mean value of about -6 derived by a variety of other methods. (See Table IV.) Correspondingly small masses and radii are determined. Since his observations cover only one complete period it seems best to wait for measurements of further astrometric plates. A relatively low absolute magnitude is also indicated, curiously enough, by Fredrick's (1963) observations of the infrared CN bands which he found similar in strength to those in β Peg (luminosity class II-III).

*The same phenomenon has been noted in the spectrum of WY Gem during the winter of 1968-69.

†Deutsch (1956) found an expansion velocity of 10 km/sec for the circumstellar envelope about α Her.

TABLE IV
ABSOLUTE VISUAL MAGNITUDES AND STELLAR GROUP MEMBERSHIP

Star	M_v	Method and Reference	Cluster or Association†
KN Cas	-4.8	Spec. par.—Blaauw (1963)*	near Cas OB 5 but r.v. wrong
AZ Cas	-4.8	Spec. par.—Blaauw (1963)	Cas OB 8
HD 237006	-4.8	Spec. par.—Blaauw (1963)	Per OB 1
WY Gem	-5.6	Spec. par.—Blaauw (1963)	Gem OB 1
Boss 1985	-5.6	Spec. par.—Blaauw (1963)	near NGC 2422
WY Vel	-4.8	Spec. par.—Blaauw (1963)	
HD 101712	-4.8	Spec. par.—Blaauw (1963)	IC 2944
-61° 3575	-4.7	Cluster membership—Thackeray and Wesslink (1965)	
FR Sct	-7.0	Spec. par.—Blaauw (1963)	
	-7.0	Spec. par.—Blaauw (1963)	
	-5 to -7	In first inner spiral arm—Bidelman and Stephenson (1956)	
Boss 5481	-4.8	Spec. par.—Blaauw (1963)	Cep OB 2
	-4.4	H γ photometry of B star companion—Petrie (1956)	
	-5.2	Spec. par. for B star and Δm —Bidelman (1958)	
VV Cep	-5.0	Spectral type and radius from eclipsing data—Gaposchkin (1937)	
	-4 to -5	Infrared spectrum—Hynek and Keenan (1945)	
	-6.3	Spec. par.—Keenan and Wright (1957)	
	-1.4 to -1.8	Astrometric parallax—Fredrick (1960)	
	-2.6	Infrared CN Bands—Fredrick (1963)	
	-6.9	Hiltner's (1951) polarization of VV Cep and neighboring stars and Blaauw's (1963) calibration of spectra	
W Cep	-8.0	Spec. par.—Blaauw (1963)	Cep OB 1
U Lac	-5.6	Spec. par.—Blaauw (1963)	Cep OB 1
	-5.3	Spec. par.—Bidelman and Böhm (1955)	
α Sco	-4	Infrared Spectrum—Hynek and Keenan (1945)	
	-5.2	Spec. par. of secondary—Stone and Struve (1954)	
	-5.3	Spec. par. and Δm combined—Bidelman (1958)	
	-5.4	Sco-Cent Association—Bertiau (1958)	
	-5.7	Spec. par. of secondary—Kopylov (1958)	
	-6.2	Spec. par. of secondary—Garrison (1967)	
	-4.8	Spec. par.—Blaauw (1963)	
	-4.9	Ca II reversal—Wilson and Bappu (1957)	

†Cluster or association membership is based on work by Miss Humphreys (1969b).

*Means spectroscopic parallax based on Blaauw's calibration.

Even very far from eclipse some variations in the spectrum are known to occur. Occasionally some metallic-shell lines have been seen and McLaughlin has noted "absorption satellites" at the ionized calcium and hydrogen lines with positive displacements of 100 to 200 km/sec. Hynek and Keenan (1945*b*, 1947) found the O I lines in the infrared to be very strong in 1944, but after about a year the lines faded. It was not until 1964 that Keenan (1964) again found them to be strong. Glebocki and Keenan (1967) point out that these lines reached maximum strength at the expected time of secondary eclipse. Their interpretation is that the oxygen atoms are part of a large gaseous cloud which surrounds the B star. As the hot star passes in front of the M star absorption lines are formed in the spectrum of the cool star.

In addition to improving the orbital data (see Table IV) Peery (1966) has attempted to analyze the chromospheric structure of the M star from plates obtained at Michigan during the 1956 ingress. Because of the scarcity of data he was forced to assume that the kinetic and excitation temperatures do not vary with height in the chromosphere. He was then able to combine curves of growth from single epochs into a single "mean" curve. The average value derived for the excitation temperature was 2220° K which he states is "so low that it probably indicates the large departures from thermodynamic equilibrium that surely must characterize the atmosphere at great heights." He finds a very large value of 47.8 km/sec for the turbulent velocity as derived from the neutral metals. As might be expected the chromospheric density falls off more slowly than in the smaller eclipsing system 31 Cyg.

Alpha Scorpii. The visual binary α Sco has such closely related spectroscopic properties to the VV Cep stars that it seems worthwhile to discuss them briefly. It seems reasonable to suppose that the mild peculiarities of the Antares visual binary system may be a reflection of the fact that the two stars are widely separated by comparison with the pairs in other VV Cep systems. The primary is an M supergiant which is known to be irregularly variable both in magnitude and radial velocity. In fact a spectroscopic orbit with a period of 5.8 years was determined by Halm (1909) but subsequent observations by Lunt (1916) and others showed that the periodicity did not persist. Wilson and Sanford (1937) found that the spectrum of the secondary was an early-B star with emission

lines of [Fe II] although no Fe II lines were present. Struve and Swings (1940), and later Struve (1947, 1948, 1955), showed that the [Fe II] was confined to a small nebula ($2''.5$) around the B star which did not extend as far as the M star. In fact some evidence suggested that the nebula might be more elongated in the direction perpendicular to the two stars. For a long time the B star was thought to be underluminous. This apparently resulted largely from an overestimate of the magnitude difference between the two stars. Wallenquist's (1954) value of $\Delta m = 4^m15$ is consistent with a spectral type of B4 V for the secondary. Later Herzberg (1948) found emission lines of Fe II below 3300 \AA , but these lines are due to the M star itself and not to the nebula around the B star.

The spectral types of the two stars and the presence of [Fe II] emission lines makes the star rather similar to VV Cep. However the emission lines are very weak so if the system were viewed from a distance so great that the stars could not be individually resolved, perhaps we would not notice the peculiarities so quickly. On the other hand, the nearness of the system does afford a unique opportunity to study the stars in greater detail and perhaps its behavior can give some understanding of the VV Cep stars. Struve (1955) has raised the interesting question of why we do not see hydrogen emission lines associated with the B star. If [Fe II] is present, then enough hydrogen would be ionized so that we should expect to see recombination lines. He imagines that a region of solid particles might surround both stars and that in the vicinity of the B star these would be evaporated.

Deutsch (see Struve and Zebergs 1962) has found evidence for a net outflow of material at the rate of 15 km/sec in the resonance lines of Na I, Ca I, Cr I, and Sr II. This is similar to the mass loss occurring in other late-type stars in this part of the HR diagram. In the far ultraviolet he also finds negatively displaced sharp Ti II absorption lines in the spectrum of the broad-lined B star. Perhaps it too is losing material. His observations of the [Fe II] lines show the material to be rotating with the B star.

IV. Radii of VV Cephei Stars

The radius of VV Cep has been determined from the eclipse data by Gaposchkin, Goedicke, and Peery. Fredrick has derived a value from the radius based on his measured value of the parallax (and

thus an absolute magnitude) and an assumed temperature. These values are given in Table III. McKellar *et al.* (1957) have pointed out that during the 1956-57 season the blue star entered totality about a month earlier than predicted and that the total duration of the eclipse was 40 days longer than those studied by Gaposchkin. Taken literally as a change in radius of the M star, this information implies a ten percent variation in diameter. This may seem large, but similar results have been derived quite independently for α Sco. Because of its proximity α Sco is a favorable case for the determination of its diameter by interferometric or lunar occultation techniques. A discussion of this type of investigation has been given by Evans (1957). He concludes that the size of the star is probably variable by as much as ten percent of its diameter and that the distribution of light across the disk appears to be irregular at times. Whether this could be due to the presence of some kind of giant prominences or a very close companion is uncertain. The irregularity of the radial velocities implies that the star may be pulsating.

The radius of AZ Cas has not been computed from the photometric observations, although it should be done.

V. Absolute Magnitudes and Galactic Distribution

The estimates of the absolute magnitudes of the M supergiants have been slowly climbing since the very early work on line ratios done at Mount Wilson. Most of these stars were estimated to have $M_v =$ about -1 to -2 in the 1920's. However, nearly all the available current data indicate that these stars have visual absolute magnitudes between -4 and -7 . Unfortunately none of the stars is close enough to have a reliably determined trigonometric parallax. Table IV presents what information is currently available for determining the absolute magnitudes. The values in Table IV are either given by the investigator who is referenced or a value has been derived from other information which he supplies. For example, in the case of VV Cep we have used Hiltner's (1951) polarization data. Both 13 Cep and ν Cep show the same amount and direction of polarization as VV Cep. We make the assumption that the three stars must be at roughly the same distance. Using Blaauw's (1963) calibration to derive the absolute magnitude of 13 and ν Cep we then are able to determine an absolute magnitude for VV Cep which is in good agreement with values obtained by other means.

The width of the Ca II emission (Wilson and Bappu 1957) can be used in α Sco since one can obtain the spectrum of the M star alone. The resulting M_v is -4^m9 . It might be possible to use this method for VV Cep and AZ Cas by obtaining plates during totality. In the other systems—the blue star dominates the spectrum in this region.

One of the most promising methods for the determination of absolute magnitudes is from their association with other stars either in visual binary systems or in clusters or associations. The most favorable is Boss 5481 which has a visual companion with a normal B3 V spectrum. With a Δm of 3^m7 and assuming $M_v = -1^m7$ for the B star we determine a visual absolute magnitude of -5.4 for the primary. This is about a half magnitude brighter than the value given by Blaauw's calibration of an M1 Ib star.

Another favorable case is HD 101712 which Thackeray and Weselink (1965) find to be in the cluster IC 2944. It is the only evolved star in the cluster, which starts at O6. All of the other stars lie on the zero-age main sequence. Taking into account the interstellar absorption they find $M_v = -4^m7$ which agrees very well with the accepted value for a Ib supergiant.

Miss Humphreys (1969*b*) finds that many of these stars can be considered members of associations or clusters on the basis of their radial velocities. The stellar group with which each star is likely associated is also listed in Table IV. In every case the absolute magnitude thus derived is in agreement with the star being brighter than -4 , although individual values are not given because of uncertainty in the amount of interstellar absorption.

The galactic concentration of these stars is very high, as for the normal M supergiants. The galactic coordinates are given in Table I. Further, the tendency to be found in associations implies that the stars are young, recently-evolved objects.

VI. Masses

Reliable masses have been determined for only two of the stars, VV Cep and Boss 1985. The orbits of both Boss 5481 and WY Gem are under investigation at Michigan, but both have very long periods and small radial velocity ranges which make it difficult to determine the spectroscopic orbits. Because it is an eclipsing

system, AZ Cas should be investigated spectroscopically. Its period of nine years is not an insurmountable obstacle. Information on the orbits, masses, and probable inclinations are given in Table III. Both VV Cep and Boss 1985 evidently contain stars of very large masses. If the blue star could be considered the more massive, the result would be to reduce the total mass of both stars (see for example Fig. 3, Cowley 1965). However the range in the radial velocity of the hydrogen emission which surrounds the B star in VV Cep leads us to believe that the M star is the more massive in that system. Further, unless considerable mass transfer has occurred we would expect the evolved star to be the primary.

Indirectly we can infer something about the mass of the primary star in HD 101712. Since it is the only evolved star in the cluster IC 2944 we assume that it is the most massive if all the stars are coeval. The earliest star on the main sequence is O6. According to Miss Underhill (1966, p. 140) a star of this type has a mass of about 32 solar masses. From this we conclude that the VV Cep stars (or at least HD 101712) are more massive than 32 solar masses. Thus the values derived by Peery for VV Cep are not unreasonable.

VII. Magnetic Fields

Several of the VV Cep stars were reported by Babcock and Cowling (1953) to have magnetic fields. However Babcock's (1958) later *Catalogue of Magnetic Stars* contained only VV Cep and WY Gem. The fields are not large; the maximum field measured in VV Cep is +850 gauss. Recent Lick observations of VV Cep (Conti 1969) show no measurable field.

VIII. Conclusion

It is plain that our understanding of the VV Cep systems is in a rudimentary state. Many important and interesting questions remain unanswered. For example, we might ask, what did these systems look like when they were on the main sequence, and can we recognize their unevolved counterparts? Has there been mass transferred to the hot component as the red star expanded to reach its inner Lagrangian surface? What is the current rate of mass loss or exchange? Are the masses which we measure for these stars comparable with the masses of single M supergiants, and do these high values present real difficulties for our theories of the stability

of massive stars? Are the present secondary stars unevolved? What is the role of the magnetic field? And finally, what will these systems look like in 100 million years?

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