A GROUP OF PECULIAR SHELL STARS*

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ABSTRACT

Spectrographic observations of the stars AX Mon, HD 50138, HD 31648, HD 218393, and HD 236031, made in 1952 and 1953, are described. The various features which these stars have in common are discussed. These are principally the occasional appearance and rapid variations of displaced absorption components in the hydrogen lines. It is suggested that the infall of material from the shell may occur, in addition to outward surges, like prominence activity, previously suggested by Struve.

There is a group of shell stars whose spectra exhibit remarkable changes in the structure of the lines of hydrogen and ionized calcium. Emission components may be present and may vary, but the most striking feature is the presence of sharp absorption cores and the occasional appearance of additional absorption components. The sharp cores may vary in position, but they are usually displaced to the violet, and the additional components are usually displaced much farther to the violet.

Some examples are AX Mon, 17 Lep, HD 31293, HD 31648, HD 190073, HD 163296, HD 218393, and HD 236031. Merrill *et al.*[1] have pointed out the similarity between HD 31293, HD 31648, HD 163296, and HD 236031. Swings and Struve[2] have pointed out the similarity between HD 31648, 17 Lep, and HD 190073. Both Struve[3] and Merrill[4] have pointed out the similarity between HD 218393 and AX Mon. Two other stars, studied by Merrill and by Swings and Struve, may also bear some resemblance to this group. They are HD 45677 and HD 50138. These stars resemble each other, not only in the variable structure of their hydrogen lines but also because each shows forbidden emission lines.

We have made observations on AX Mon, HD 50138, HD 31648, HD 218393, and HD 236031, and the spectrograms are described below. The observations were made mainly at the McDonald Observatory, but some were made at the Yerkes Observatory. The McDonald plates were taken with the Cassegrain quartz spectrograph (dispersion 40 A/mm at λ 3933) and will be designated "M"; the Yerkes plates were taken with the small spectrograph and 12-inch camera (dispersion 60 A/mm at $H\gamma$) and will be denoted by "Y."

AX MONOCEROTIS = HD 45910

The remarkable variations which this peculiar Be star undergoes have been discussed in several papers, the most recent being by Struve,[5] Merrill,[6] and Beals.[7] The appearance of violet-displaced H and Ca II absorption lines, in addition to the usual absorption cores, occurs at irregular intervals; the "α Cygni" spectrum, consisting of narrow absorption lines of ionized metals, varies irregularly; the emission lines of H vary in strength; and lines of Fe II sometimes appear in emission. These variations have been recorded at different times by the three authors mentioned above and previously by

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[1] *Pub. A.S.P.*, **60**, 68, 1948.

[2] *Ap. J.*, **98**, 91, 1943.

[3] *Ap. J.*, **99**, 75, 1944.

[4] *Ap. J.*, **110**, 420, 1949.

[5] *Ap. J.*, **98**, 212, 1943.

[6] *Ap. J.*, **108**, 481, 1948.

[7] *Pub. Dom. Ap. Obs. Victoria*, **9**, 1, 1951.

Plaskett,[8] and no permanent periodicity has been found. We describe below a set of variations recorded on ten plates (M) and one plate a year later (Y).

JANUARY 8, 1952

H.—P Cygni structure—single absorptions with emission on the red side. Emission is fairly strong at $H\beta$, weaker at $H\gamma$, and very weak at $H\delta$. Underlying broad absorptions are weak or absent, but the Balmer discontinuity is well marked and retains the same appearance on all plates. The last resolvable line is *H*26.

Ca II.—The K line is a strong, narrow, single absorption. There is a faint broad emission on the violet side of the absorption line and possibly on the red side also.

He I.—Fairly strong, fairly broad, single absorption lines.

Fe II.—λ 4233 shows weak, narrow emissions on both sides of a weak, narrow absorption line, with $V > R$. λ 4352 has a weak, narrow, violet-displaced emission line on the violet side of a very weak, sharp absorption. λ 4179 and λ 4173 both appear as single, narrow, weak, violet-displaced emission lines.

Si II.—Absorption lines of λ 4128 and λ 4131 are fairly narrow; λλ 3863, 3856, and 3854 are narrower.

Mg II.—λ 4481 is fairly strong, but weaker and somewhat narrower than *He* I 4471.

There are several sharp absorption lines in the ultraviolet. *Ni* II 3514 is the strongest (*Ni* II 4067 is present as a weak, sharp absorption). *Ti* II 3761 and 3759 are narrow absorptions, fairly strong. *N* II 3995 is strong and rather broad; the strength of this line and of *Mg* II 4481 give the spectrum almost the appearance of a B5 supergiant.

JANUARY 10, 1952 (TWO PLATES)

H.—The emission lines are the same. Violet-displaced weak absorption lines are just visible at $H\beta$, $H\gamma$, and $H\zeta$ (presumably due to *He* I 3889).

Fe II.—At λ 4233 the emission is weaker, the absorption stronger and sharp. At λ 4352 both emission and absorption are very weak.

JANUARY 12, 1952 (THREE PLATES)

H.—The violet-displaced components are stronger but are still weaker than the red components (as they remain on all plates). The relative strength of the two components varies along the series—the *V* component is strongest relative to the *R* at $H\beta$. The *V* component of $H\epsilon$ is suppressed, but there is a trace visible, having about the same strength relative to the *R* component as in *H*11 (the *V* components are not visible beyond *H*11). The *V* component due to *He* I 3889 is strong. The separation between the two components is about 230 km/sec.

Ca II.—K is still a strong single absorption and remains single on all plates.

Fe II, *Si II*, *Mg II*.—All weaker.

Ni II.—Lines in the ultraviolet remain strong.

JANUARY 13, 1952 (FOUR PLATES)

H.—The *V* components are still present, having about the same relative strengths as on January 12. $H\epsilon$ has the same appearance as on January 12.

JANUARY 12, 1953

H.—The emission lines are much stronger than they were the year before. $H\beta$ has P Cygni structure, with very strong emission; emission is strong at $H\gamma$ and visible at $H\delta$ and $H\epsilon$ (the plate is underexposed at $H\zeta$). The secondary, violet-displaced absorptions are not present, and underlying broad absorptions are not seen.

Fe II.—There are numerous emission lines in the region between $H\beta$ and $H\delta$. The α Cygni lines are not seen.

[8] *Pub. Dom. Ap. Obs. Victoria*, **4**, 1, 1927.

He I, Mg II, Si II 4128–4131, N II 3995.—These absorption lines appear with about the same intensity they had the year before.

Ca II.—Both H and K have a narrow emission on the violet side of the absorption, and the absorption line at K may be double.

A plate of the visual region, obtained on February 18, 1953 (Y), shows $H\alpha$ as a strong, overexposed emission line. The *Na* I ($D_1 + D_2$) line is fairly strong, about twice the strength of *He* I D_3. Interstellar λ 6284 is weak. The faint M2 absorption spectrum of neutral metals, observed by Merrill[6] in the visual region, does not appear on our low-dispersion plate.

It will be noted that several plates were taken, at intervals of a few hours, on three of the nights, in order to see if there were any very rapid changes occurring. However, no changes occupying only a few hours were observed.

The secondary, violet-displaced absorption components have been attributed by Struve to a phenomenon resembling prominence activity, i.e., localized outward surges of gas. The suppression of the violet-displaced absorption of $H\epsilon$, observed by us, was first observed and discussed by Struve,[5] and he has discussed the problem again in connection with other stars as well as AX Mon.[9] In the earlier paper he suggested two possible explanations; the second of these, in terms of a hydrogen layer expanding outward so that the atoms have a velocity of recession relative to *Ca* II atoms emitting the H line, seems to us to be a probable solution.

HD 50138

This shell star has been observed by Merrill and by Swings and Struve. The former author in his first paper[10] described a series of spectrograms covering the period 1920–1930. During this time the hydrogen lines showed large V/R variations; absorption lines of *He* I, *Mg* II, and *Fe* II were present. Velocities derived from these latter agreed with each other and were fairly constant, while velocities from the H cores were variable and usually algebraically less than those from the *He* I group. In 1940 Swings and Struve[11] recorded the appearance of *Fe* II in emission. Later[2] they described a plate taken in 1943 and remarked that an unusual feature of this star was that the *He* I absorption lines, although diffuse and presumably broadened by rotation, indicated a smaller rotational speed than that given by the over-all widths of the H emission lines. They suggested that the *He* I lines originated in the deeper strata of the shell.

Recently, Merrill[12] has described a series of thirteen coudé spectra covering the period 1943–1951. It is interesting to note that on four plates he recorded the appearance of additional violet-displaced, weaker absorption components, and on one plate there were red-displaced, weaker components. These observations suggest to us that this star may resemble AX Mon and the other stars described here.

Three plates of this star were obtained on January 12 and 13, 1952 (M). The appearance of the spectrum is similar to the description by Swings and Struve.[2] The last resolved shell line of H is $H25$. The mean separation of the emission components is 280 km/sec. The mean velocity given by the *He* I, *Mg* II, and *Si* II lines is +37 km/sec, and that given by the shell lines of H, *Ca* II, *Fe* II, and *Ti* II is +17 km/sec. Thus, whether the lines of the *He* I group arise in the star itself or in the deeper strata of the shell, the hydrogen and ionized-metal lines arise in a region with an outward velocity, relative to the *He* I region. No additional absorption components in the H lines were seen,

On our plates the R emission component at $H\beta$ is considerably stronger than the V, and the R edge of the R component is shaded slightly and is not as sharp as the V edge. The fact that the R component is usually the stronger has been discussed by Merrill in terms of absorption of the V component by outward-moving gas. He noted that, although

9 *Pub. A.S.P.*, **64**, 288, 1952.

10 *Ap. J.*, **73**, 348, 1931.

11 *Pub. A.S.P.*, **52**, 294, 1940.

12 *Ap. J.*, **116**, 501, 1952.

the relative strength of the R and V components in $H\gamma$ was correlated with that in $H\beta$, it differed in the sense that the ratio V/R was always larger in $H\gamma$. When $V/R = 0.5$ at $H\beta$, $V/R = 1$ at $H\gamma$; when $V/R = 0.07$ at $H\beta$, $V/R = 0.5$ at $H\gamma$; and so on. He remarked that this was a curious anomaly. We can understand qualitatively the reason for this phenomenon. The problem of the transfer of line radiation through a gas which is dense enough not to be considered transparent to the Balmer series leads to a Balmer decrement in which the strengths of $H\alpha$ and $H\beta$ are reduced much more than those of the higher Balmer members. When we are considering the absorption by moving gas, the problem is much more complicated, but the usual explanation of V/R variations, namely, the absorption of the emission lines by gas moving outward or inward, would be expected to lead to a progression in V/R along the Balmer series.

On our plates this progression is not so marked as it apparently has been in the past. However, a plate was obtained on January 12, 1953 (Y), and on this the V and R components at $H\beta$ are approximately equal, while $V \gg R$ in $H\gamma$, $H\delta$, $H\epsilon$, *Fe* II 4233, and *Ca* II H and K. We have the same phenomenon here, i.e., a slower Balmer decrement in the V than in the R component, but if we assume that this is due to self-absorption, then we need to assume that the "unabsorbed" V component is much stronger than the R, and this is hard to explain if we have a symmetrical ring or equatorial disk of gas. We suggest that the additional displaced absorption lines sometimes observed by Merrill[12] probably play a part and that they are caused by some kind of prominence activity, on a smaller scale than that occurring in AX Mon and consisting of motion both inward to and outward from the star.

A study of the problem of the transfer of line radiation in a moving atmosphere should in theory be able to determine the different regions responsible for the emission and absorption and their relative velocities, but would be very complicated.

Finally, since Merrill[10] observed [*O* I] lines in the spectrum, the total extent of the outer atmosphere of the star must be very large.

HD 31648

The hydrogen lines in the spectrum of this star have a variable and complicated structure. Merrill *et al.*[13] remarked that the wave lengths of the absorption cores of the hydrogen lines changed by 2 or 3 A and that the *Ca* II K line was sometimes double. Swings and Struve,[2] in a note describing a plate taken in 1943, said that the H lines had violet-displaced cores of considerable intensity, suggesting an expanding shell. The *Ca* II K line was double.

A plate was obtained on January 12, 1952 (M). On this the hydrogen lines $H\beta$–$H10$ are double, with a diffuse absorption on the red side and a sharp, stronger absorption on the violet side; the sharp absorptions have quite strong P Cygni emission lines bordering them on the red side. *Ca* II K has a similar structure. A metallic-line shell, or set of "α Cygni" lines, is present, with narrow absorption lines of the following elements: *Fe* II, *Fe* I, *Ti* II, *V* II, *Ca* I, and *Sr* II. Absorption lines of *Mg* II, *Si* II, and *Si* III are present and are more diffuse than the lines of the other elements. Besides the *Ca* II K line, only two other lines of the metallic-line shell show P Cygni structure, i.e., *Ti* II 3761 and 3759.

At first sight it would seem that the diffuse H absorptions arise in the reversing layer of the star itself, and the sharp absorptions in an expanding shell. However, the values given in Table 1 show that the diffuse components have very large recession velocities. The progression in velocity, from $H\beta$ to $H10$, suggests that we are dealing with a broad absorption line in which the emission and sharp absorption components are superposed on and blot out the violet wing. The H lines beyond $H10$ can be used to test this hypothesis. There is a steady weakening of the sharp absorptions relative to the diffuse absorptions along the series as n increases, and from $H11$ onward the lines appear as

[13] *Ap. J.*, **96**, 15, 1942.

single broad absorptions. Their mean velocity is +55 km/sec. This is a large value to be the radial velocity of the star itself. Correcting for the local solar motion, we get +46 km/sec. The distance of the star may be about 500 parsecs, and the galactic longitude is 141°; at this place the velocity due to galactic rotation is very small and negative. Thus the star would have a very large peculiar motion relative to its surroundings if the value given above represented its own radial velocity.

The mean velocity from the single absorption lines of *Fe* II, *Fe* I, *Ti* II (excluding λ 3761 and λ 3759), *V* II, *Ca* I, and *Sr* II is −5 km/sec. The mean velocity from the lines of *Mg* II, *Si* II, and *Si* III is +16 km/sec. This suggests stratification in which the outer level of the shell is expanding faster than the inner level, and the P Cygni lines arise at a higher level than the α Cygni lines (as suggested by Struve in the case of HD 218393). Possibly the star is a binary of the β Lyrae kind, with a common shell

TABLE 1

VELOCITIES GIVEN BY LINES OF *H*, *Ca* II, AND *Ti* II (KM/SEC)

	Diffuse Absorption Lines	Emission Lines	Sharp Absorption Lines
*H*β	+319	+73	−64
*H*γ	+216	+64	−67
*H*δ	+159	+49	−65
*H*ζ	+167	+48	−49
*H*9	+139	....	−50
*H*10	+196	+60	−45
Ca II K	+195	+46	−54
Ti II 3761	....	+46	−35
Ti II 3759	....	+42	−43

giving rise to the α Cygni lines. If this is the case, however, it is difficult to locate the gases giving rise to the P Cygni structure of *H*, *Ca* II, and the two *Ti* II lines and to explain why two lines alone of *Ti* II should show P Cygni structure.

Another possibility is that we are observing the sort of prominence activity postulated in HD 50138, HD 218393, and HD 236031 to account for the occasional appearance of diffuse, red-shifted absorption components. But in this star the diffuse lines are almost as strong as the sharp absorptions. Perhaps we have a combination of effects: the sharp absorption and emission lines overlie the violet wing of a broad stellar absorption line, and a weak, red-shifted absorption line, caused by material falling back toward the star, reinforces part of the red wing of the broad stellar line, causing it to be measured too far to the red. Alternatively, it is possible that the star really does have a very large peculiar velocity.

A plate taken on January 12, 1953 (Y), which could not be measured for radial velocities, shows that the emission lines are definitely weaker—emission is only visible at *H*β. The sharp cores appear to be superposed on broad absorptions, and the lines are not double. The α Cygni lines are the same, and *Mg* II 4481 is still the strongest except for *Ca* II K.

HD 218393

Two plates of this star, taken on September 30 and October 4, 1952 (Y), do not show the secondary, violet-displaced absorption components in the hydrogen lines, found by Struve[3] to appear irregularly at 11–18-day intervals. On our two plates *H*β, *H*γ, and *H*δ have emission components on the *R* side of sharp, narrow absorptions, superposed on broad underlying absorptions. Absorption lines of *Mg* II and *Si* II are fairly strong and intermediate in width between the *H* cores and the very diffuse lines of *He* I. *Ca* II K is a strong absorption line. There is a weak metallic-line shell present (Struve observed this to vary between invisibility and moderate strength and thus to resemble the α Cygni lines in AX Mon). *Fe* II 4233 has an emission border on the *R* side of the narrow absorption, and in this respect it resembles the two *Ti* II lines on our plate of HD 31648.

A plate taken in the visual region on September 16, 1952 (Y), shows that $H\alpha$ is a broad, very strong emission, not resolved on our dispersion into any structure. Absorption lines in this region are due mainly to *Fe* II, while the *Na* I D lines are very strong, *He* I D_3 is moderately strong, and the interstellar line at λ 6284 is visible but weak.

Struve[3] described in detail a remarkable sequence of rapid changes in the spectrum of this star and pointed out their similarity to those occurring in AX Mon. In this star also he suggested that outward surges of matter were the cause of the secondary, violet-displaced absorption lines.

Merrill[4] discussed a series of coudé spectrograms taken between 1943 and 1948. He described the "Balmer progression" (also noted by Struve), in which the velocities of the *H* lines had progressively larger positive values on going to higher Balmer members, and he concluded that this was due to the presence on most plates of a diffuse wing bordering the sharp absorption cores on the red side. This wing became stronger relative to the cores on going to higher Balmer lines. On a few of his plates this wing had the appearance of a separate, diffuse line, shifted to the red. It seems that here again we may have the falling downward into the star of material, giving rise to weak absorption components with large positive relative velocities, in addition to the strong, outward-moving prominence activity in which the velocities reach 200 km/sec or more.

HD 236031

Two spectrograms of this star were obtained on September 16, 1952 (visual region) and September 20, 1952 (photographic region) (both Y). The first shows very strong emission at $H\alpha$; the *Na* I D absorption lines and the interstellar line at λ 6284 are moderately strong. The second plate shows a strong emission line at $H\beta$, on the *R* side of an absorption core; both are superposed on a broad underlying absorption line. $H\gamma$ has a very sharp absorption core over a broad underlying absorption, and no emission line is visible. Thus the Balmer decrement is steep. Numerous narrow absorption lines are present, evidently arising in the shell: lines of *Fe* II, *Ti* II, *Mg* II, *Si* II, *Sc* II, and *Ca* II were identified, and *Cr* II and *Fe* I may also be present. *Mg* II 4481 is strong and very sharp and definitely arises in the shell; thus the effect of dilution is not very marked. Lines of *He* I are broad and diffuse.

The shell is variable: Merrill *et al.*[1] remarked that the HD spectral type was B3 and that shell lines of *H*, *Ca* II, *Fe* II, and *Mg* II were present at the time of their observations. The shell spectrum is apparently stronger on our plate than it was then.

Merrill *et al.* found that the *H* lines had variable negative displacements, and in addition there were weaker diffuse components which shifted from one side of the core to the other. Displaced components were not visible on our plate, but it may require higher dispersion to distinguish them from the broad underlying absorptions, which did appear to be stronger on the *R* side. Prominence activity probably occurs in this star also, in addition to the more stable shell.

CONCLUDING REMARKS

Further observations of these stars with high dispersion may elucidate the problem of the red-displaced absorption components which have been observed in some of them. However, the basic problem of the instability of stars of this sort is a difficult one. In the first place, one does not know how deep the instability arises. The stars probably all rotate rapidly, but there are many other fast-rotating shell stars which do not show this sort of violent prominence activity. The stars described here are probably all of main-sequence luminosity, or at least we are not dealing with highly luminous stars like P Cygni (as indicated by their apparent magnitudes and the appearance of the interstellar features).

In AX Mon[6] and in 17 Lep[14] (which was mentioned in the Introduction) traces of a weak M-type spectrum have been found, which might arise in a separate late-type companion. They are reminiscent of the still more peculiar stars with "combination" spectra such as, for example, Z And and AG Peg. AX Mon has been found in the past to have small light-fluctuations, and it would be interesting if these could be investigated further and compared with the spectral variations.

All the observational work was carried out while the authors were working at the Yerkes and McDonald Observatories. We are indebted to Professor R. O. Redman for the use of a measuring machine at the Observatories, University of Cambridge.

[14] A. Slettebak, *Ap. J.*, **112**, 559, 1950.