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THE CHROMOSPHERE AND WIND OF THE HERBIG AE STAR, AB AURIGAE[1]

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ABSTRACT

The Herbig Ae variable, AB Aur, has been observed with the CFHT coudé spectrograph at 95 mÅ resolution for five consecutive nights in the blue spectral region and with the *IUE* satellite in the high resolution, long wavelength mode. The Ca II K line shows an asymmetric and variable profile and shows weak emission in the absorption core at least some of the time. An exceptional event, characterized by the appearance of blue components in Ca II K and Balmer lines, occurred on 1980 October 26. Other evidence of chromospheric emission is the presence of the He I λ5876, and that of Mg II *h* and *k* lines which have striking P Cygni profiles. The Mg II absorption is broader (up to -380 km s^{-1}) than in the A supergiant α Cyg, and shows strong redward emission; the line profiles indicate mass outflow. The Balmer lines (H_δ–H_{14}) are in absorption without emission components, in contrast to observations in the 1930s and 1940s. Their measured averaged velocity as well as the Ca II K velocity indicate global motions, variable with time, in the atmosphere. Variability in the line profile shapes and velocities for Ca II K and the Balmer lines occurs on time scales of less than a day. The narrow components of Mg II, Ca II, and Na I which were observed are thought to arise in the nebulosity in which AB Aur is embedded. The characteristic line emission and line positions, breadth, and variability show the presence of an active and variable chromosphere with mass outflow.

Subject headings: stars: chromospheres — stars: emission-line — stars: individual — stars: winds

I. INTRODUCTION

The irregular variable AB Aur (HD 31293) belongs to the group of Herbig Ae stars, which are associated with nebulosities (Herbig 1960; Strom *et al.* 1972). Its MK class is A0ep; Herbig classifies it as B9 IV–V. Its photographic magnitude is often 7.2, but it can reach 8.4. AB Aur is associated with the nebulosity Barnard 27 (also Lynds 1517; see Lynds 1962), which is in the Taurus-Auriga complex.

AB Aur is the brightest of Herbig Ae stars and can be observed at high spectral resolution. Through this type of observation, we want to characterize the properties of the outer layers: the structure of the chromosphere, the extent of the outer layers, and the origin of the wind. Moreover, we wish to establish the relation which prevails at early A spectral type, among main-sequence stars (which do not show any sign of a chromosphere or wind from the visible and UV spectrum; Freire 1979) but which have coronae (Vaiana *et al.* 1981), supergiants (which have an expanding atmosphere but probably no sign of chromosphere; Praderie, Talavera, and Lamers 1980; also Underhill 1980), and young more active objects, such as Ae stars.

II. OBSERVATIONS

We have observed AB Aur with the coudé spectrograph of the Canada-France-Hawaii 3.6 m Telescope (CFHT) at Mauna Kea on 1980 October 24–28. The available spectral range was 3820–4120 Å with a dispersion of 2.4 Å mm^{-1} and a spectral resolution of 95 mÅ at the Ca II K line. These spectra were recorded on IIIa-J plates backed in forming gas and calibrated by means of a rotating sector and tungsten lamps.

Two other spectra were obtained with the *IUE* satellite on 1981 January 26 at the European Space Agency tracking station near Madrid, Spain. The high resolution mode (0.2 Å) and long wavelength (1800–2300 Å) camera were used.

The complete log of observations is given in Table 1.

[1] Based on observations by the *International Ultraviolet Explorer* collected at the Villafranca Satellite Tracking Station of the European Space Agency.
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TABLE 1

SPECTROGRAPHIC OBSERVATIONS OF AB AUR

Date (UT)	Time (UT) (mid-exposure)	Exp. Time	Comments
1980 Oct 24	12hr 23min	1hr 40min	CFHT
1980 Oct 25	13hr 21min	2hr 24min	Mosaic grating 830 lines mm^{-1}
1980 Oct 26	13hr 27min	2hr 0min	Second order
1980 Oct 27	12hr 38min	3hr 04min	Image slicer
1980 Oct 28	13hr 57min	2hr 29min	IIIa-J backed
1981 Jan 26......	9hr 38min	1hr 30min	*IUE* LWR 9789
1981 Jan 26......	11hr 18min	0hr 30min	*IUE* LWR 9790

The CFHT spectrograms were scanned with a PDS microdensitometer at the C.D.S.I. (Orsay, France), and data reduction was made at the S.T.I.I. (INAG, Observatoire de Paris). The UV data have been reduced by the standard *IUE* routines.

III. THE Ca II K LINE

Figure 1 shows that at this resolution the Ca II K line (3933.66 Å) has a narrow unsaturated absorption component which has not been reported before. Its velocity relative to the local standard of rest is $V_R = 7 \pm 1$ km s^{-1}. Although the narrow component could be a shell line, we suspect that it is of interstellar origin. On spectrograms taken during a shell episode in 1928–1930, the Balmer lines showed narrow cores, according to Merrill and Burwell (1933). On only one of our spectrograms is there any evidence of a blueshifted component in the Balmer lines (cf. § IV), whereas the narrow component of the Ca II K line is stable in position on all five spectrograms. Seemingly, we see a narrow, stable ($V_R = 7$ km s^{-1}) component in the H line on three of our spectra (but the blend with Hϵ makes the measurement more difficult). The velocity of the sharp K line component agrees with that of CO (6.0 km s^{-1}) observed in the mm range from the Lynds 1517 nebulosity (Loren, Vanden Bout, and Davis 1973) and that of HCHO (5.5–5.9 km s^{-1}) in the direction of AB Aur (Nachman 1979). Furthermore, sharp absorption components, presumably of interstellar origin, are seen in our *IUE* high resolution spectra of Mg II *h* and *k* taken in 1981 January and in Reticon spectra of the Na D lines taken in 1981 January for us by G. Cayrel de Strobel with the CFHT spectrograph.[5]

The stellar K line exhibits an asymmetric profile variable in intensity and degree and sense of asymmetry, as can be seen in Figure 1. The spectrum of 1980 October 26 shows a blueshifted component with $\Delta V = -163 \pm 10$ km s^{-1} relative to the line bisector at residual intensity 0.8. This blue component must be short lived, and it is the most spectacular sign, in this set of observations, that the star is variable over a scale of less than one day. Spectra from 1980 October 25, 27, and 28 are characterized by a red asymmetry, i.e., a more extended red wing than blue. The asymmetry is reversed in the 1980 October 24 spectrum.

[5]Results from the Reticon spectra will be published separately.

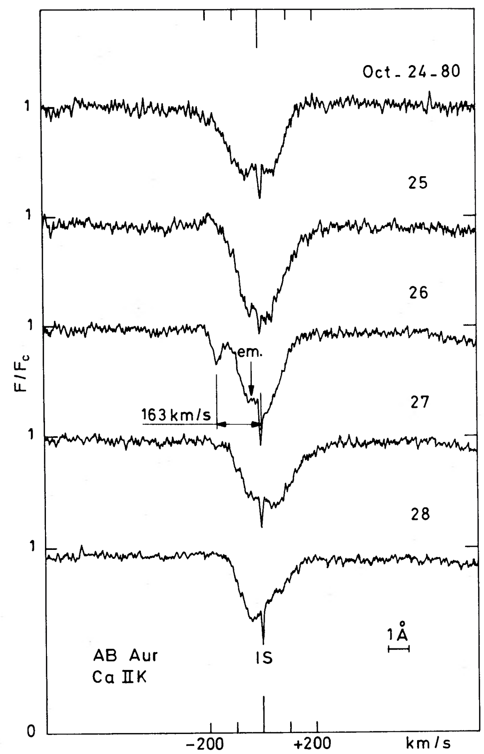

FIG. 1.—The Ca II K line in reduced flux units. A reference frame is provided by the interstellar component. The variability of the stellar profile is appreciable. The 1980 October 26 profile shows a blueshifted component at $V = -163$ km s^{-1}.

The line core is variable in intensity and radial velocity. The central residual flux for the deepest profile (1980 October 25) is 0.45; it reaches 0.62 on the 1980 October 24 and 27 spectra (Table 2). The point with deepest absorption in the profile varies in position relative to the narrow interstellar component.

Besides its blueshifted component, the 1980 October 26 profile has an increased intensity in the core to the

TABLE 2

THE Ca II K LINE

Date	F/F_c	V (bisector) at $F/F_c = 0.8$ (km/s)
1980 Oct 24 ...	0.62	+ 6
1980 Oct 25 ...	0.45	+43
1980 Oct 26 ...	0.53	+25
1980 Oct 27 ...	0.62	+50
1980 Oct 28 ...	0.60	+21

violet of the interstellar component, which we attribute to chromospheric emission. For this emission, $\Delta\lambda = -0.36$ Å relative to the interstellar component. Weak emission is possibly present on the other nights also as seen in the profile shapes (e.g., 1980 October 25, blue wing) or central depth. Table 2 also gives the heliocentric radial velocities (at residual intensity 0.8, supposedly formed in the photosphere) of the stellar K line. The variation between individual values exceeds the measuring error (± 10 km s^{-1}).

By comparison of the observed and computed wings of the Hδ profile, we determined that the photosphere of AB Aur can be represented by a radiative equilibrium (RE) model with $T_{\text{eff}} = 10{,}000$ K, $\log g = 4.0$, or $T_{\text{eff}} = 11{,}000$ K, $\log g = 4.5$; we adopted the first pair of values. The K line has been computed for a non-LTE, RE model atmosphere for a six level atom. Two values of the microturbulent velocity parameter ξ were used: $\xi = 3$ and $\xi = 10$ km s^{-1}, with Ca/H chosen such that the computed equivalent width for the K line equals that measured on the most symmetrical observed profile (1980 October 25), i.e., $W = 1.448$ Å. We found Ca/H $= 3.6 \times 10^{-6}$ (i.e., 1.8 solar value) for $\xi = 3$ km s^{-1}, Ca/H $= 2.9 \times 10^{-6}$ (i.e., 1.45 solar value) for $\xi = 10$ km s^{-1}.

The "deep chromosphere" models (with $\tau_{5000} = 10^{-3}$ at $T_{\min}$) of Freire *et al.* (1978) overlying a photosphere with $T_{\text{eff}} = 10{,}000$ K and $\log g = 4.0$ predict some K line emission at ± 0.06 Å from line center, but the emission would be unobservable when $v \sin i > 10$ km s^{-1}. Since AB Aur has a larger $v \sin i$ than 10 (but less than 90 km s^{-1} as we can deduce from the line computation) and K line emission is observed, an even deeper chromospheric model with a steeper temperature gradient is needed. Such a model would also predict excess Balmer continuum emission. An excess has been observed in other Ae stars although Garrison's (1978) observation of the Balmer discontinuity in AB Aur—at that phase—was close to that expected for a normal A0 star.

We have detected the He I λ4026 line in absorption on three plates; its equivalent width W is close to the detection threshold (100 mÅ due to the fairly high $V \sin i$). The Reticon spectrum taken for us by G. Cayrel de Strobel shows He I λ5876 quite strongly in emission. The presence of this line reinforces the evidence for a chromosphere which could be as hot as $\sim 2 \times 10^4$ K.

IV. THE VELOCITY FIELD

a) The Balmer Lines H$_\delta$–H$_{14}$

It is well known that Balmer lines display variations: their core is displaced, while the wings remain at the same velocity position; emission components appear and disappear, as well as cores arising in the shell (Merrill and Burwell 1933; Sanford and Merrill 1958).

We note the following phenomena:

1. On our plates, H$_\delta$ to H$_{14}$ are absorption lines. Asymmetries affect the line core, but no definite emission seems present. Swings and Struve (1943) reported strong diffuse Balmer emission through H$_{11}$ or H$_{12}$, while Merrill and Burwell (1933) and Sanford and Merrill (1958) measured both emission and absorption components in the Balmer lines. The shape of the line core varies from one day to the following on our plates.

2. Heliocentric radial velocities V measured at maximum absorption vary from one line to another (Table 3). Due to the intrinsic width of the line cores, the measuring error is as large as ± 20 km s^{-1}. No real trend can be seen for the variation of V along the Balmer series.

3. The radial velocities are in general positive, at variance with results for the absorption components, published by Sanford and Merrill (1958) and Merrill and Burwell (1933). For one and the same line, V varies irregularly by as much as 60 km s^{-1} from one day to the next one, but no period can be distinguished. The velocity averaged over the lines (last column of Table 3) varies along the observing period in quite a parallel way as V for Ca II K. This suggests a kind of variable ensemble motion of the atmosphere with time, on a one day scale.

4. Figure 2 shows that on the 1980 October 26 spectrum all Balmer lines up to H$_{10}$ are accompanied by a narrow blueshifted absorption component. Its average

TABLE 3

BALMER LINE HELIOCENTRIC VELOCITIES[a] AT MAXIMUM ABSORPTION

Date	H$_\delta$	H$_\epsilon$	H$_8$	H$_9$	H$_{10}$	H$_{11}$	H$_{12}$	H$_{13}$	H$_{14}$	$\langle V \rangle$[b]
1980 Oct 24 ...	−8	−30	1	5	24	2	0	45	23	7±21
1980 Oct 25 ...	44	2	20	8	44	45	28	50	49	32±18
1980 Oct 26 ...	35	33	12	13	25	29	24	10	0	20±12
1980 Oct 27 ...	57	48	59	75	49	66	30	47	36	52±14
1980 Oct 28 ...	16	13	−4	−3	13	4	−5	37	24	11±14

[a] Units: km s^{-1}.

[b] For $\langle V \rangle$, the error indicated is the standard deviation.

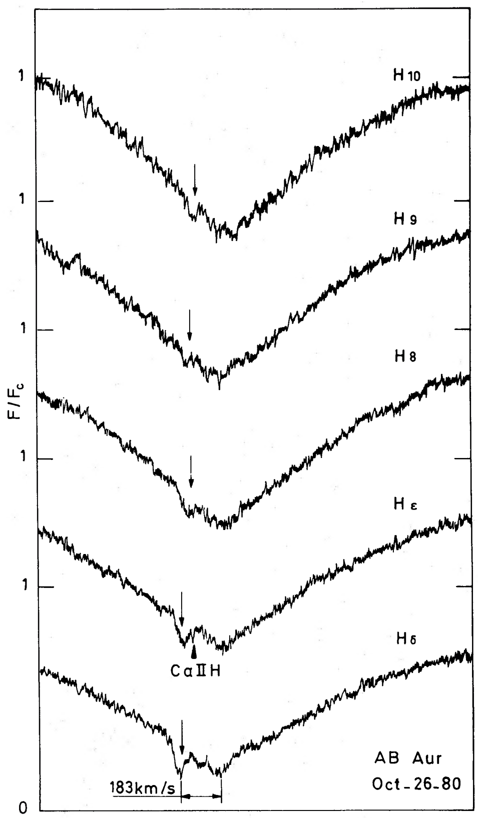

FIG. 2

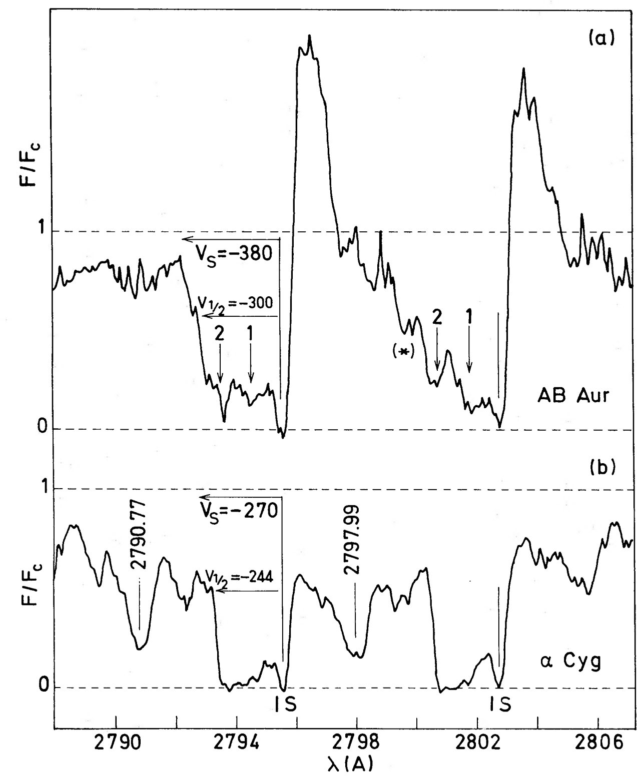

FIG. 3

FIG. 2.—The Balmer lines H_δ–H_{10} on 1980 October 26. All the lines have a blueshifted component, at $V=-183$ km s^{-1}, indicated by an arrow.

FIG. 3.—The Mg II resonance lines: (*a*) AB Aur; (*b*) α Cyg (A2 Ia). The blueshifted components are noted 1 and 2. The * shows an artifact due to microphone noise. Images are: (*a*) LWR 9790; (*b*) LWR 2926.

value is $\Delta V=-183$ km s^{-1} relative to the line bisector (taken at half intensity). On the same day, Ca II K also has a blueshifted component with equal velocity shift (within the measuring errors).

b) Mg II *Resonance Lines*

The *h* and *k* lines of Mg II 2795.53 and 2802.70 Å in AB Aur are shown in Figure 3*a*. The profiles are very similar to P Cygni profiles (compare with P Cygni itself in Cassatella *et al.* 1980) with intense emission shifted to the red ($\Delta\lambda=1.14$ Å). The subordinate lines (2790.77 Å and 2797.99 Å) are fairly diffuse. Interstellar components of both the *h* and *k* lines are present. For comparison, Figure 3*b* shows the Mg II lines of the A2 Ia supergiant α Cyg from Praderie *et al.* (1980).

The absorption part of the stellar *h* and *k* lines extends up to velocities of $V_s=-380$ km s^{-1} referred to the interstellar lines, while in α Cyg, $V_s=-270$ km s^{-1}. The absorption is less saturated than in α Cyg. Components are present; the most prominent is located at $\Delta V=-215$ km s^{-1} from the interstellar line, and the second is at $\Delta V=-104$ km s^{-1}. The short wavelength edge is less steep in AB Aur than in α Cyg. In the absence of a crisp edge, we take the terminal velocity, V_∞, equal to $V_{1/2}$, i.e., the velocity at half residual intensity; $V_\infty=V_{1/2}=300$ km s^{-1} (which is equal to 115 times the thermal velocity of Mg). Note that this value is smaller than the escape velocity at the photosphere, $V_{esc}=620$ km s^{-1}, for the stellar parameters given by Strom *et al.* (1972). To conclude that there is mass loss, one must assume that the Mg II absorption is formed at about four stellar radii.

If the Mg II profile is of the P Cygni type, then the dwarf AB Aur must have an expanding envelope with more rapid expansion than the supergiant α Cyg. If, however, the intense emission peaks in AB Aur are chromospheric and the absorption is formed in a cooler, expanding region beyond the chromosphere (and eventual corona), then the total emission must be even greater than that shown in Figure 3*a*. A combination of these two is possible: chromospheric emission (since we do see Ca II emission, a chromospheric signature but rare in A stars) plus emission and absorption in an expanding envelope.

c) Fe II *Lines*

Lines of the UV multiplets 1, 2, 3, 35, 62, 63, and 64 are observed in absorption on our *IUE* spectra. They are all asymmetric with the short wavelength wing extending up to -190 km s^{-1} relative to the absorption dip. The velocity at half-intensity, $V_{1/2}$, averaged over all lines, is -105 km s^{-1}. No variation of $V_{1/2}$ with excitation potential of the lower level of the lines was observed.

V. SUMMARY AND CONCLUSIONS

The Herbig Ae star AB Aur shows strong chromospheric features: (1) emission in the absorption core of Ca II K line which is weak, but remarkable in a star of this temperature; (2) very strong emission at Mg II *h* and *k*; and (3) emission at He I λ5876.

There is evidence for expansion, or a wind: (1) the breadth and large terminal velocity of the Mg II absorption indicate that it is formed over a velocity gradient—an expanding chromosphere and/or envelope; and (2) the asymmetries and extent of the blue wings of the Fe II absorption also imply expansion.

We have observed night-to-night variations in the shape of the Ca II line profiles and also in the position of the cores of the Balmer lines. Chromospheric variability thus occurs on time scales of less than a day as well as over periods of years (cf. Sanford and Merrill 1958). Spectral variations of this sort are well known in the less massive pre–main-sequence stars, T Tauri (e.g., see Kuhi 1978).

At the spectral resolution of our observations, we have found evidence of strong, sharp interstellar components of Ca II, Mg II, and Na I presumably arising in the nebulosity in which AB Aur is embedded.

The presence of the nebulosity, the chromosphere, the wind, and the chromospheric variability all identify AB Aur even more closely as a higher mass pre–main-sequence counterpart of the T Tauri stars.

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