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SHORT-TERM SPECTRAL VARIABILITY IN AB AURIGAE: CLUES FOR ACTIVITY IN HERBIG Ae STARS. I. THE ULTRAVIOLET LINES OF Mg II AND Fe II[1]

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ABSTRACT

The Herbig Ae star AB Aur was monitored with the *IUE* satellite in the long-wavelength, high-resolution mode, first during 40 consecutive hours in 1982 and second intermittently over a span of 150 hr in 1984. The Mg II $\lambda2795$ wind profile and a number of Fe II ultraviolet lines were studied for variability during the two epochs.

We find temporal variations in the Mg II blue wing velocity by 30%–50% at both epochs. The intensity of the blue absorption wing is variable, but the redshifted emission part of the line is much less so. By contrast, the Fe II spectrum was constant in all respects in 1982, but variable in 1984. The Fe II absorption lines in 1982 show two narrow components displaced shortward of a main absorption. The location and intensity of the components is very stable in 1982, but the profiles are variable in 1984. There was no evidence that AB Aur varied photometrically at either epoch.

An analysis of the Mg II blue wing velocity versus time shows that the variability can be fitted with a sine curve of period 45 ± 6 hr, which we interpret to be the stellar rotation period. The period found is indeed very close to the rotation period of the star, as estimated from its projected rotation velocity and radius.

The observed rotational modulation of the blue wing velocity of Mg II $\lambda2795$ in the wind of AB Aur is the first direct evidence of a nonaxisymmetric wind in an A-type pre–main-sequence object. A qualitative model for the expanding envelope is proposed, with recurrent corotating fast and slow streams, a model analogous to the solar wind in the inner heliosphere. At variance with the Sun, the stellar wind is cool and dense enough in the portions of the envelope in which the observed variable parts of the Mg II line profile originate that optical and UV lines can trace its variable structure. The constancy of the Fe II spectrum in 1982 and its variability in 1984 are accounted for if these lines are formed farther out than the Mg II region, in a remote part of the envelope where the corotating streams in the wind have merged and pressure waves have interacted and dominate the structure.

As a consequence of our analysis, we argue that if rotation is the central parameter in explaining the observed short-term variations in the wind of AB Aur, the set of phenomena described could be magnetic in origin.

Subject headings: stars: emission-line — stars: individual — stars: winds — ultraviolet: spectra

I. INTRODUCTION

Among pre–main-sequence stars, those of intermediate mass (3–5 $M_\odot$) constitute the group of Herbig Ae–Be stars (Herbig 1960; Strom *et al.* 1972; Finkenzeller and Mundt 1984). The location of such stars in the Hertzsprung-Russell diagram has been established by Strom *et al.* (1972) and by Cohen and Kuhi (1979), whose work suggests that the Herbig stars represent a prolongation of T Tauri stars toward higher effective temperature. One of these stars, AB Aur (HD 31293, A0ep), was chosen for this study mainly because it is bright enough ($V = 7.2$) to be observed at high spectral resolution in the ultraviolet with *IUE*.

Like the T Tauri stars, the pre–main-sequence Ae–Be stars exhibit irregular variability in both visible light and line spectrum. Let us focus here on spectral variability. The characteristic time scales for the appearance and disappearance of both absorption and emission features in the hydrogen Balmer lines range from months to years (Merrill and Burwell 1933; Sanford and Merrill 1958; Finkenzeller 1983). These changes do not seem to be periodic. Similar long-term changes have been found in the Mg II and Fe II resonance lines of AB Aur (Praderie *et al.* 1984*a*). Changes of profile shape from day to day were also discovered in the Ca II K line (Praderie *et al.* 1982), which led us to suggest a flarelike activity in this star, as had already been proposed for T Tauri stars (Worden *et al.* 1981; Mundt and Giampapa 1982). Although Garrison and Anderson (1977) reported a P Cygni profile in Hα, which they attributed to a wind, it has been shown since then that AB Aur also exhibits definite signs of a chromosphere (Praderie *et al.* 1982; Felenbok, Praderie, and Talavera 1983; Catala, Kunasz, and Praderie 1984; Catala and Talavera 1984). Other stars of the same group also show spectroscopic evidence for winds and chromospheres, whether observed in the space ultraviolet (Talavera *et al.* 1982) or in the visible and near infrared (Catala *et al.* 1985*a*). Since chromospheric activity is variable with a primary time scale related to the star's rotation period in solar-type dwarfs (Vaughan *et al.* 1981; Boesgaard and Simon 1984), it also seemed promising to search for rotational modulation in Herbig stars. Such periodic variability, if present, would then provide a strong argument in favor of a common origin for chromospheric activity in pre–main-sequence stars and in stars on the main sequence; moreover, by analogy with the Sun, this

[1] Based on observations by the *International Ultraviolet Explorer* (*IUE*) collected at the Goddard Space Flight Center (NASA) and Villafranca del Castillo (ESA).

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TABLE 1

PROPERTIES OF THE HERBIG Ae STAR AB AURIGAE

$\log (L/L_\odot)$	$M/M_\odot$	$R/R_\odot$	T_{eff} (K)	$\log g$	v_{esc} (km s^{-1})	d (pc)
1.83[a]	2.5	2.7	10,000	4.4[a]	590	150[a]
2.0[b]	3.0	3.3	...	...	590	160[b]

NOTE.—T_{eff} = 11,000 K would give $R/R_\odot$ = 2.5, value used in Fig. 2.
[a] Strom *et al.* 1972.
[b] Cohen and Kuhi 1979.

would favor control of the observed activity by surface magnetic fields.

The characteristics of AB Aur are summarized in Table 1. AB Aur was chosen for this study also because an estimate of its projected rotational velocity $v \sin i$ was at hand: Praderie *et al.* (1982) obtained $v \sin i \leq 90$ km s^{-1}. If we adopt $R/R_\odot = 3 \pm 0.3$ from Table 1, then the photospheric rotation period is $P \geq 41 \pm 4$ hr for an inclination i of 90°. With more recent determinations of $v \sin i$ (75 km s^{-1}, Davis, Strom, and Strom 1983; 140 ± 30 km s^{-1}, Finkenzeller 1985), one obtains $P \leq 48 \pm 5$ hr and $P \leq 26 \pm 8$ hr respectively, irrespective of sin i. The rather discrepant values of $v \sin i$ can be explained first by the choice of the line used: the Ca II K line is not a bona fide photospheric line in AB Aur, and only an upper limit of $v \sin i$ could be reached by Praderie *et al.* (1982) in spite of spectra with 0.095 Å resolution. Other authors used the Mg II λ4481 line. The difference between Davis, Strom, and Strom (spectra with 0.3 Å resolution) and Finkenzeller (spectra with 0.8 Å resolution) is probably due to the differences in the analytical methods the authors used for deriving $v \sin i$. In any case, these short values of the rotation period make AB Aur well suited for a variability study with *IUE*.

In this paper we report the results of two observing programs in which we monitored AB Aur with the high-resolution, long-wave spectrographs of *IUE*. During the first, in 1982, we observed AB Aur with continuous coverage over one complete rotation cycle, and in the second, in 1984, we made observations at selected rotational phases in 3.5 cycles over a time span of 150 hr. Preliminary results for the 1982 observations have been presented by Simon, Boesgaard, and Praderie (1982), Praderie *et al.* (1983), Praderie *et al.* (1984*b*). The observations and data reduction are described in § II. The ultraviolet and visible continuum, the hourly spectral variability in Mg II, and the behavior of the Fe II resonance lines, are presented respectively in §§ III, IV, and V. The significance of Mg II short-term variability on the one hand, and of Fe II constancy or variability on the other hand, is discussed in § VI, as well as the consequences for the models of the envelope of AB Aur. The last section discusses various implications of our results for activity phenomena in Herbig stars.

II. OBSERVATIONS AND DATA REDUCTION

We obtained continuous phase coverage of AB Aur with the *IUE* satellite from 1982 October 25 to 27 in contiguous NASA and ESA shifts over a time span of 40 consecutive hours, then from 1984 November 5 to 11 we observed at selected rotational phases in several cycles involving again NASA and ESA time, over a total span of 150 hr. We observed in high-resolution (HR) mode (0.2 Å) with the LWR camera (2000–3500 Å) in 1982 and with the LWP camera in 1984. We obtained a total of 29 large-aperture spectra in 1982 and 22 spectra in 1984. A log of all the HR observations is given in Table 2. The exposure times were chosen to give well-exposed Mg II resonance line (λ2800) profiles, both in their absorption and in their emission parts. The spectra were also suitable for the study of Fe II UV multiplets 1, 2, 3, 62, 63, and 64, among others.

In alternating sequence with the HR spectra, we obtained large-aperture, low-resolution (~6 Å) SWP (1150–2000 Å) spectra, 28 in 1982 and 17 in 1984. The exposure time for these SWP images was 3 minutes.

TABLE 2

LOG OF HIGH-RESOLUTION *IUE* OBSERVATIONS OF AB AURIGAE

A. LWR

Number	Image[a]	1982 October UT (midexposure)	Exposure Time (minutes)
1.........	14485 G	25.944	30
2.........	14486 G	25.996	40
3.........	14487 G	26.050	45
4.........	14488 G	26.108	50
5.........	14489 G	26.166	45
6.........	14490 G	26.222	45
7.........	14491 G	26.278	45
8.........	14492 G	26.336	45
9.........	14493 G	26.392	45
10.........	14494 G	26.449	45
11.........	14495 G	26.505	45
12.........	14496 G	26.562	45
13.........	14497 V	26.625	45
14.........	14498 V	26.681	45
15.........	14499 V	26.747	45
16.........	14500 V	26.802	45
17.........	14501 V	26.859	45
18.........	14502 V	26.916	45
19.........	14503 G	26.975	45
20.........	14504 G	27.030	45
21.........	14505 G	27.088	45
22.........	14506 G	27.143	45
23.........	14507 G	27.200	45
24.........	14508 G	27.257	45
25.........	14509 G	27.313	45
26.........	14510 G	27.368	45
27.........	14511 G	27.429	45
28.........	14512 G	27.485	45
29.........	14513 G	27.541	45

B. LWP

Number	Image[a]	1984 November UT (midexposure)	Exposure Time (minutes)
1.........	4733 V	5.506	38
2.........	4736 V	6.509	33
3.........	4737 V	6.560	30
4.........	4747 V	7.723	30
5.........	4753 V	8.621	30
6.........	4754 V	8.668	30
7.........	4755 V	8.720	30
8.........	4757 G	9.197	30
9.........	4758 G	9.247	30
10.........	4759 G	9.288	30
11.........	4764 V	9.612	21
12.........	4765 V	9.664	30
13.........	4766 V	9.712	30
14.........	4768 G	10.172	30
15.........	4769 G	10.230	30
16.........	4770 G	10.206	30
17.........	4774 V	10.606	30
18.........	4775 V	10.654	30
19.........	4776 V	10.701	30
20.........	4784 V	11.682	30
21.........	4785 V	11.733	30
22.........	4786 V	11.774	25

[a] G, observations from Goddard; V, observations from Villafranca.

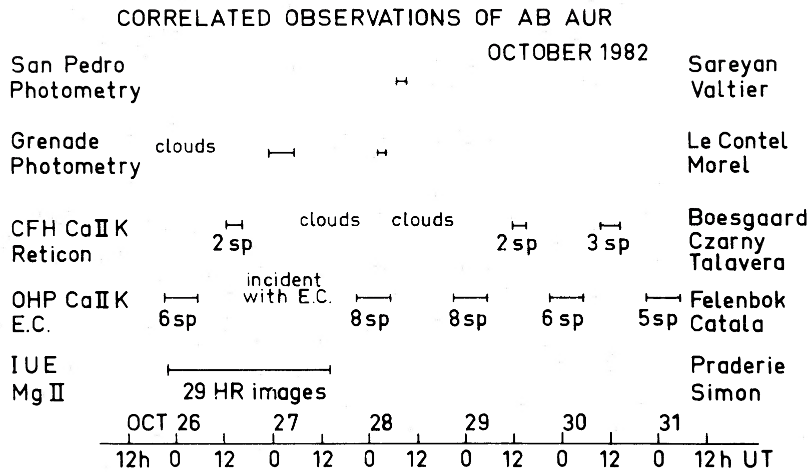

FIG. 1.—Time line of 1982 October observations. E.C., electronic camera; HR, high resolution.

A coordinated campaign of ground-based observations was organized in 1982 involving the Canada-France-Hawaii 3.60 m telescope (CFHT) and the 1.50 m at Observatoire de Haute-Provence; these instruments were used at coudé focus. Two photometric telescopes, the 0.6 m at Pico de la Veleta, near Granada (Spain), and the 1 m at San Pedro Martir (Mexico), also took part in the observations (see Fig. 1). Preliminary results of the whole campaign were presented by Praderie *et al.* (1983). During the 1984 observations, photometric observations were carried out at our request by W. Herbst at Van Vleck Observatory.

We reduced the *IUE* HR echelle spectra from the 3d file of the Guest Observer (G.O.) tape by means of software developed at the Paris-Meudon Observatory by J. Borsenberger. The ripple correction was performed following Ake (1982) for the LWR spectra and following Cassatella (1984) for the LWP spectra. In overlapping wavelength regions of adjacent orders of the echelle spectrum, a weighted average of intensity was formed (weighted by the relative photometric response of each order). The spectra were absolutely calibrated using the flux calibrations provided by Holm *et al.* (1982) for the LWR and by Cassatella (1984) for the LWP cameras. The spectra were also examined at the *IUE* regional data center of the NASA/Goddard Space Flight Center, using standard reduction software available there, and these independent reductions gave virtually identical results. For consistency we present here the reductions carried out at Meudon.

In the echelle spectra, the wavelength scale on the G.O. tape was adjusted to fit the Mg I presumably interstellar line present in the spectrum of AB Aur ($\lambda_0 = 2852.13$ Å). From a study of interstellar lines in the visible, Felenbok, Praderie, and Talavera (1983) showed that the interstellar lines have a LSR velocity of 6.3 ± 0.3 km s^{-1}, a value identical to within the uncertainties with the velocity of the associated molecular cloud. A similar result was obtained for other Herbig Ae–Be stars by Finkenzeller and Jankovics (1984), who also showed that there are no systematic motions of these stars relative to their associated molecular clouds.

The Mg II and Fe II line spectrum was studied both in absolute flux units and in reduced units (i.e., normalized to the continuum). In order to define the continuum level, we compared the HR spectra of AB Aur with an *IUE* spectrum (LWR 2915) of η Leo (A0 Ib), a star with narrow lines ($v \sin i = 20$ km s^{-1}), no detectable wind profiles (Praderie, Talavera, and Lamers 1980), and a well-developed Fe II spectrum. The continuum windows were chosen to represent high-intensity points in η Leo and to be fairly remote from regions where in AB Aur we suspect there are weak, variable Fe II emission lines (see § V below). The wavelengths of these continuum windows are given in Table 3. The continuum level at each window was fixed interactively by eye from examination of the spectra on a graphics terminal.

The low-resolution (LR) SWP spectra were analyzed at Paris-Meudon Observatory by means of software which corrects the data for halation effects and scattered light along the grating dispersion (Crivellari and Morossi 1982), and also with software available at the *IUE* GSFC regional data analysis facility.

III. THE ULTRAVIOLET AND VISIBLE CONTINUUM

As we noted earlier, AB Aur displays a number of characteristic time scales for variability. In this section and in the following ones, all our available data will be presented and analyzed. We first consider the continuum, then the UV Mg II and Fe II lines.

In 1982, we obtained 28 LR SWP spectra of AB Aur in intervals between HR long-wavelength spectra. We have coadded these spectra, and Figure 2 shows the resulting spectrum from 1250 to 2000 Å. In individual spectra we measured the integrated flux in 100 Å bins. No definite sign of photometric variability can be detected beyond what is expected for the photometric reproducibility of *IUE*. In particular, the spectral resolution is too low to discern subtle changes in the C IV resonance lines which Catala and Talavera (1984) noted from three HR images. In 1984, 17 *IUE* LR short-wavelength spectra were obtained, reduced, and averaged in the same

TABLE 3

LOCATION OF THE CONTINUUM WINDOWS IN THE ULTRAVIOLET SPECTRUM OF AB AURIGAE

Multiplets	Wavelengths (Å)
Mg II (1, 3)	2758.0, 2844.0
Fe II (2, 3)	2350.5, 2401.0
Fe II (64, 2)	2401.0, 2579.5
Fe II (1)	2579.5, 2678.0
Fe II (62, 63, 263, 283)	2678.0, 2758.0
Fe II (60, 78, 216, 217)	2844.0, 2975.0

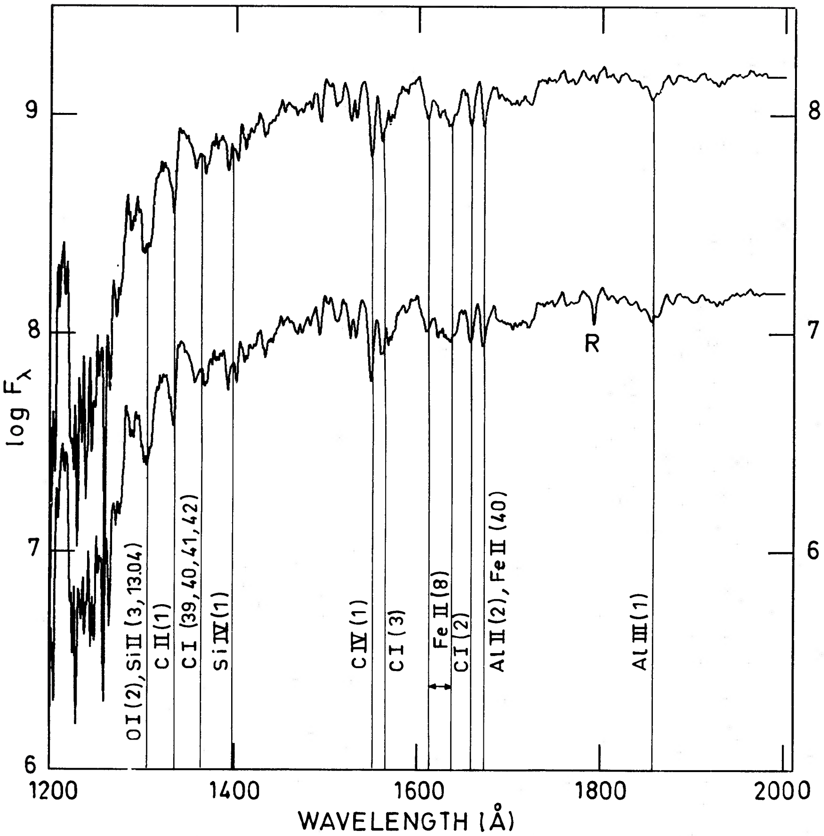

FIG. 2.—(*lower curve*) Average of 28 spectra obtained with the SWP camera of *IUE* in 1982 October. (*upper curve*) Average of 17 SWP spectra obtained in 1984 November. Plotted here is the flux F_λ at the surface of the star dereddened for $E(B-V) = 0.18$, as derived from the scaling factor $2\,R_*/d$, with $R_* = 2.5\,R_\odot$, $d = 160$ pc. F_λ is in ergs cm^{-2} s^{-1} Å^{-1}. "R" indicates a reseau mark. The 1984 November spectrum is shifted upward by one decade in log F_λ (*right-hand scale*).

manner as for 1982 October (Fig. 2). No difference exists between the two average curves (the standard deviation averaged between 1400 and 1900 Å is 0.004 mag).

We also searched for possible continuum variations in the vicinity of the Mg II λ2800 lines. From the 29 LWR images of 1982, we obtain a standard deviation for the continuum intensity of 3.5% for a $\sim$1 Å bin around 2758 Å and 4.6% for a $\sim$1 Å bin around 2844 Å. We attribute this scatter entirely to our procedure of visually locating the continuum. As for the short-wavelength region, a coadded spectrum was produced in the Mg II and Fe II region. Again, no variation of the continuum was detected above a limit of $\pm$8%, which is the photometric accuracy of *IUE* that was established through a careful study of the reproducibility of *IUE* spectra in HR, long-wavelength spectra by Franco *et al.* (1984).

The continuum in the vicinity of the Mg II resonance lines was also studied in the HR spectra of 1984. At 2758 Å, the continuum level is constant to within 3.8% (s.d.), while at 2844 Å, it does not vary by more than 3.7% (s.d.), these results being derived from the 18 images taken with the same exposure time (30 minutes) and the other images being excellently compatible with the quoted deviations.

The Balmer continuum ($\lambda \approx 3500$ Å, 100 Å width bandpass) did not vary by more than 0.02 mag during the sparse observations performed on 1982 October 26–28 (Praderie *et al.* 1983). A series of *IUE* measures of the FES (fine error sensor) counts was also available in 1982 October, from which the V magnitude of the star can be derived given its $B-V$ color ($B-V = 0.14$). Over the span of the observations, the color-corrected $V_{\rm FES}$ was stable to $\sigma = 0.02$ mag.

At our request, AB Aur was observed by W. Herbst at the 60 cm telescope at Van Vleck Observatory on 1984 November 3, 7, 8, and 15 in the Johnson/Cousins filters U, B, V, R, and I. The star was found to be constant relative to the comparison star BD +30°746 to within 0.02 mag in V. The $B-V$, $V-R$, and $R-I$ colors did not vary ($\sigma = 0.02$), while $U-B$ had a slightly larger dispersion ($\sigma = 0.03$ mag). In 1984 November the *IUE*–derived $V_{\rm FES}$ was stable to $\sigma = 0.02$ mag, except on November 8, where the average V increased by 0.08 mag relative to the value obtained on the other days. This fading of the star was not noticed by Herbst in his ground-based observations. However, Herbst did not observe at exactly the same time. Also, we did not see a change in the UV continuum in the SWP images on that day. Hence this departure might be instrumental in origin.

From this study we therefore conclude that the UV continuum, the Balmer continuum at 3500 Å (observed in 1982), and the Balmer and Paschen continua (observed in 1984) did not vary during our observing campaigns.

IV. THE Mg II RESONANCE LINES

The Mg II (λ2795.523 and λ2802.698) resonance lines of many Herbig Ae stars exhibit P Cygni type IV profiles (Beals 1951), which indicate the presence of a wind (Praderie *et al.* 1982; Catala 1984*b*). The blue-shifted absorption part of the profile is almost or totally saturated. The emission part of the line is intense. Since the broad lines of the doublet are blended together in AB Aur, it is preferable to study the absorption in Mg II λ2795 and the emission in Mg II λ2802. The blue wing velocity V_s(Mg II) measured at the level of the continuum in the λ2795 line corresponds to the largest velocity shift observed in the spectrum; it is larger than V_s(C IV) = 260 km s^{-1} (Catala and Talavera 1984), larger than or equal to the blue trough velocity in Hα, V_s(Hα) = 300 km s^{-1} (Felenbok, Praderie, and Talavera 1983), and larger than any blueshift observed in the Ca II K line profile (130 km s^{-1}). Note that one should strictly compare velocities measured at the same time, because all the lines mentioned vary in AB Aur. It therefore appears reasonable to call V_s a "terminal velocity" for the Mg II line-forming region, even though the wind may be decelerated at larger radial distances (Felenbok, Praderie, and Talavera 1983; Finkenzeller and Mundt 1984). The values measured for V_s were obtained from spectra plotted in reduced units, and V_s determined in the wavelength scale referred to the Mg II interstellar lines, as indicated in Figure 3. To extrapolate from the absorption part of the λ2795 profile up to the continuum, we gave more weight to the portion of the blue wing with reduced intensity between 0.2 and 0.6, since this segment of the λ2795 profile is equally well defined on all the available spectra. Since the definition of the Mg II interstellar lines is not equally clear on each image, we used several images having prominent features as templates. We then proceeded onward from these images by adjusting the other spectra so as to coincide along the steep portions of the line profile connecting the absorption and emission components.

It is worth pointing out here that the Mg II interstellar lines, as well as other similar lines originating from the 0 eV level in UV multiplets of Mn II and Fe II, have measured separations, as read from the routinely extracted wavelengths, equal to the laboratory values to within ±0.04 Å. However, these lines are blueshifted with respect to the Mg I λ2852.13 line, to which we have locked our wavelength scale, by 39 km s^{-1} in the 1982 October and 1984 November spectra. It is not possible without further study to decide which lines are interstellar in origin. This point does not really matter here, since our analysis depends only on *relative* variations of V_s.

We searched for variability in three spectral features: (1) V_s, (2) the intensity at wavelengths located in the blue wing of Mg II λ2795, and (3) the emission equivalent width W_{em}(λ2802).

a) Variability in Mg II *Terminal Velocity*

Inspection of the Mg II lines, either in absolute flux units or in reduced units, immediately reveals that V_s(Mg II) varies with time. Figures 4 and 5 illustrate this phenomenon, which is best seen in Mg II λ2795.

The variation of V_s versus time from our 1982 observations is presented in Figure 6*a*. The extreme values of V_s are 495 and 370 km s^{-1}. The measurement error in V_s, which includes positioning of the continuum and of the interstellar lines, is estimated to be ±20 km s^{-1}. The average value of the measured V_s during the 40 hr of observation is $\langle V_s \rangle$ = 418 ± 37 (s.d.) km s^{-1}.[4]

The variability exhibited in Figure 6*a* shows an increase in the blue wing velocity of 2795 Å to 500 km s^{-1}, then a decrease to 370 km s^{-1} with a monotonic trend of overall sinusoidal aspect. These data are therefore compatible with a cyclic variation with period ~45 hr, a value which is consistent with the estimated upper limits of the photospheric rotation period reported in § I.

Confirmation is indeed obtained from observations carried out over several rotation cycles, as is shown by our 1984 November data. Again the hourly variation of V_s(Mg II) is quite obvious (Fig. 6*b*). The extreme values are 315 and 495 km s^{-1}, which differ by 180 km s^{-1} or 57%. The average value of the measured V_s over the 150 hr of observation is $\langle V_s \rangle$ =

[4] The difference between those values and preliminary results published in Praderie *et al.* (1983, 1984*b*) is due to a different position of the continuum level once we realized that the previous continuum windows, chosen at 2770 and 2831 Å, are perturbed by weak emission lines, as explained in § V.

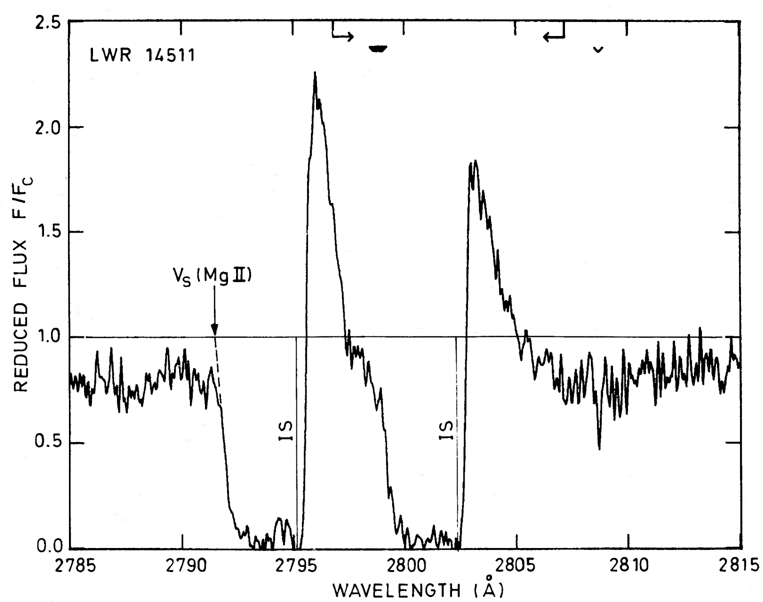

FIG. 3.—Mg II resonance lines plotted in reduced flux units (i.e., normalized to the continuum). The determination of the "blue wing" or "terminal" velocity V_s is depicted. The two arrows indicate the region of order overlap. The symbols V and ◇ denote respectively a reseau mark (or bright spot) and extrapolated intensity transfer function. The interstellar features are indicated by "IS."

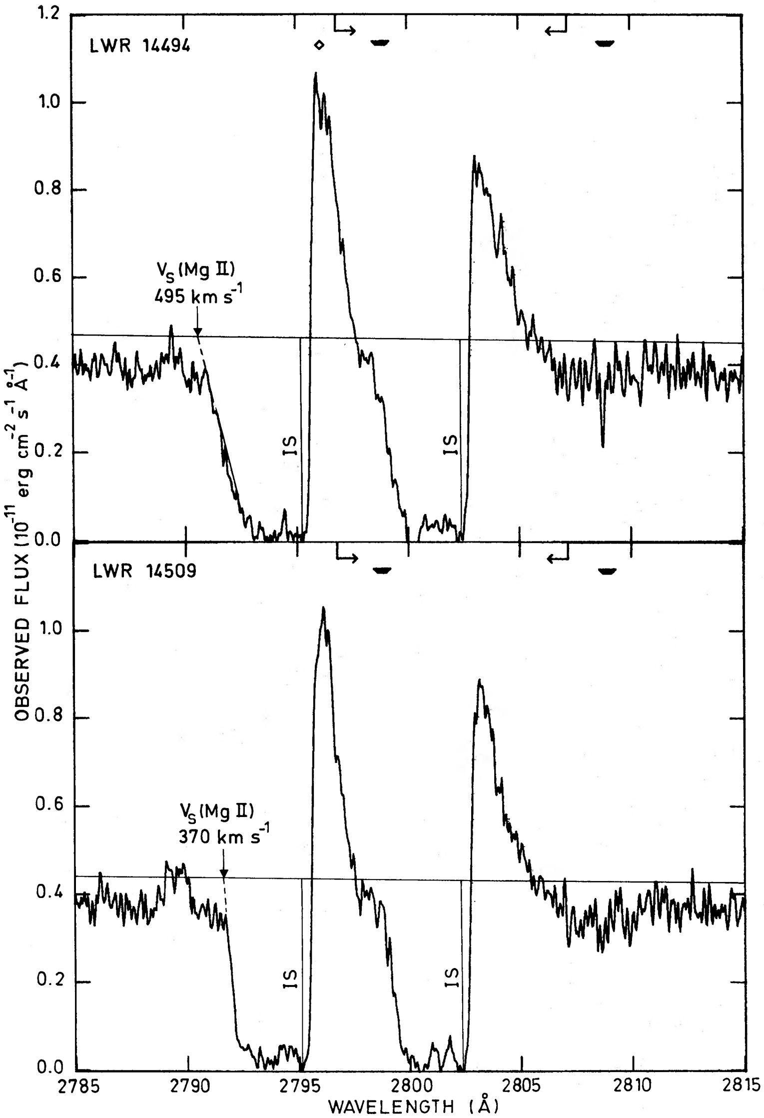

FIG. 4.—Echelle spectra of the Mg II resonance lines plotted in absolute flux units at Earth. Note the difference in V_s between the two images (LWR 14494 and 14509).

400 ± 63 (s.d.) km s^{-1}. One notes that the dispersion over the average of the measurements $\langle V_s \rangle$ is larger than in 1982 October, and that the average value is lower by 18 km s^{-1}. However, ignoring at this point the fact that V_s is variable with time, the 1982 and 1984 $\langle V_s \rangle$ values are perfectly compatible.

Figure 6*b* does not at first sight give clear proof of a cyclic variation such as is immediately apparent in Figure 6*a*. Therefore, a systematic procedure for period determination was applied to the 1984 November data. It is always a delicate matter to search for periods in data affected by gaps, which is the case of our 1984 November time series of observations. However, if a period exists, it should not only be obvious to the eye over one cycle, as is the case in 1982 October, but also should fit several cycles, as observed in 1984 November.

We therefore tried to fit the 1984 November data with a sine curve using the following procedure. The method followed was to fix the period of the sinusoid and to perform a least-squares fit to the data with the amplitude and the phase of the sinusoid as parameters, and then to let the period vary. For each trial period, we computed the residual $R = \sum_{i=1}^{N} [Y_i - F(x_i)]^2 / \sum_{i=1}^{N} Y_i^2$, where N is the number of observations, Y_i are the observed quantities (V_s), and $F(x_i)$ are the values of the fitting function at the points x_i which represent the midexposure times of our spectra. When applied to the whole set of data for 1984 November, this procedure did not yield any minimum for R. However, Figure 6*b* strongly suggests that the six largest values of V_s obtained on November 9 and 10 (LWP 4764–4770) might correspond to an isolated event that is superposed on a smoother variation. This event lasted for at least 15 hr, but less than 32 hr. Fifteen hours is the time needed for the wind to travel a distance of 12 R_*, so that we can interpret it as an outburst of short duration at its source that is observed all along its passage across the region of formation of the Mg II resonance lines. It can then be considered as a "flarelike" phenomenon of the kind we already observed in the Ca II K line and in the Balmer lines in 1980 October (Praderie *et al.* 1982). Consequently, in a second attempt we omitted these six points and tried again to fit the data with a

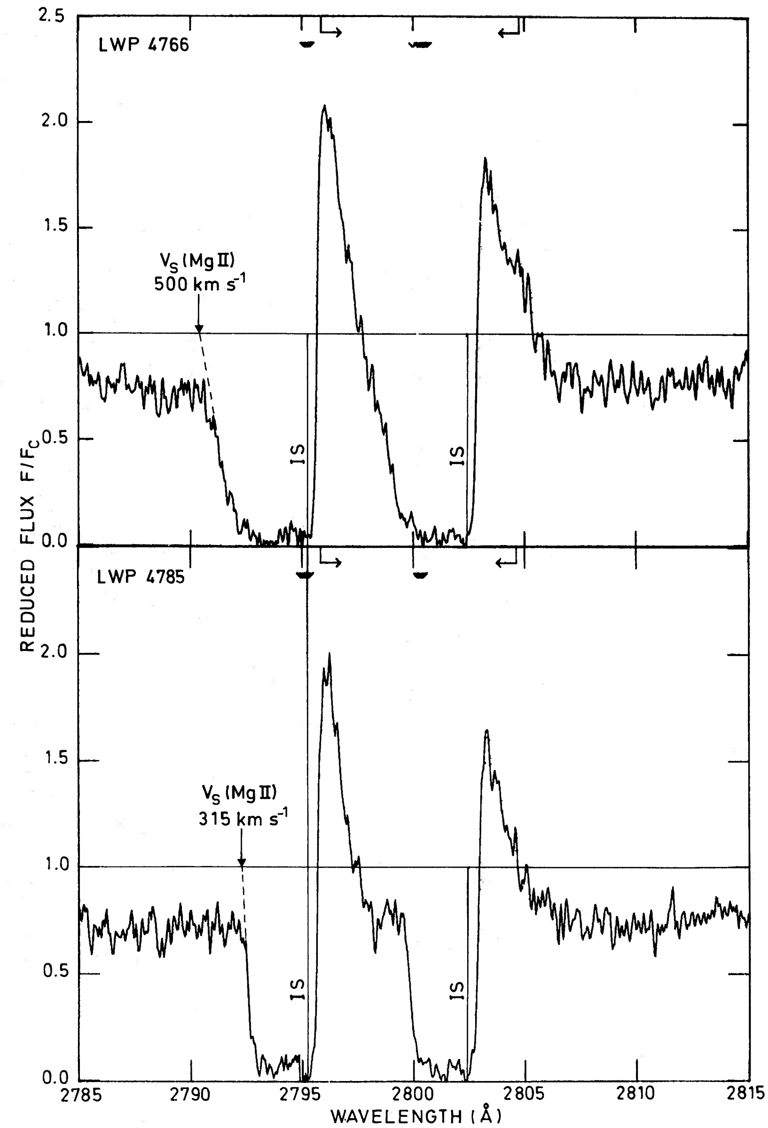

FIG. 5.—Mg II resonance lines spectral region in reduced flux units. The two images (LWP 4766 and 4785) show large differences in profiles and V_s values.

sinusoid. This procedure reduces the sample of available data points from 22 to 16. Figure 7 shows a plot of R as a function of the assumed period of the sinusoid; there is now a clear minimum, which gives confidence that the periodic time behavior of the observed values cannot be doubted. Figure 6*b* displays the result of the best fit. These two figures suggest that the 1984 data are consistent with a sinusoidal variation of period 45 ± 6 hr, plus an individual event that lasted for at least 15 hr.

The same fitting procedure was followed for the 1982 October data. For these data, we obtain a very wide minimum for R, simply because the total duration of the observations is of the order of the assumed period. Nevertheless, Figure 6*a*, which displays the result of fitting the sine curve with a period of 45 hr, shows that the 1982 October data are consistent with this period. In what follows, we explicitly assume that the period we have found is the rotation period P in the formation region of V_s(Mg II).

It is quite remarkable that we observed a stationary phenomenon, namely, that after 2 yr the spectroscopic tracer of the star's rotation, V_s(Mg II), exhibits the same time variability with the same period. As for the amplitude of the sine curve fit, it is not conserved, and is larger in 1984 November (142 km s^{-1} instead of 92 km s^{-1}). It is not possible with the available data to check the phase stability of the phenomenon; we are forced to conclude that there is a persistence over time of the existence of active sites or active longitudes, which, when they cross the visible disk, modulate some observable features.

b) *Variability of* Mg II λ2795 *Absorption Wing Intensity*

A general variability criterion has been used to search for variability in intensity. For each wavelength region, extending over about 100 Å, a point by point average of each set of spectra (separately for 1982 and 1984) was performed and the standard deviation $\sigma(\lambda)$ computed. An average of $\sigma(\lambda)$ over wavelength, $\langle\sigma\rangle$, was then obtained. We deduce that the spectrum is variable if, at a given λ, $\sigma(\lambda) \geq 3\langle\sigma\rangle$. The application of the criterion is subject to a careful analysis of the $\sigma(\lambda)$ curve in order to eliminate such camera artifacts as bright spots and reseau marks.

For the Mg II λ2795 line, the intensity in the absorption part

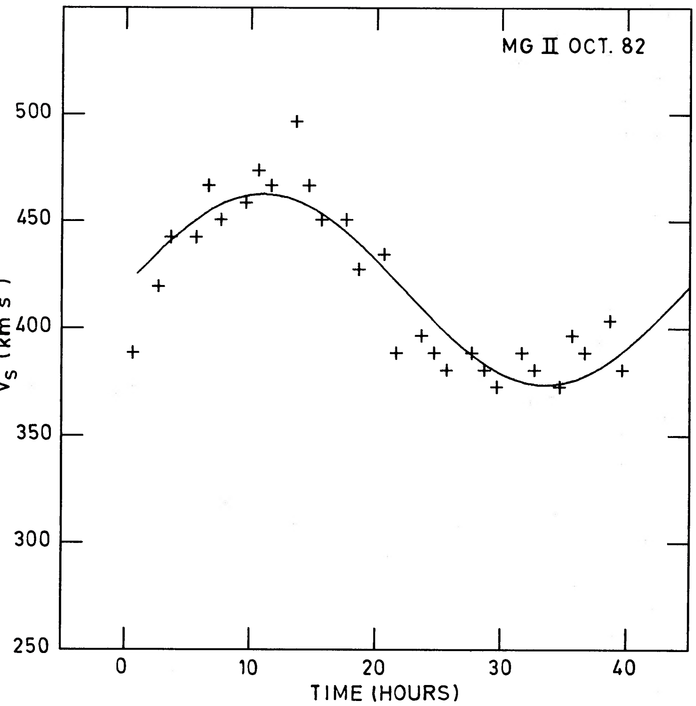

FIG. 6*a*

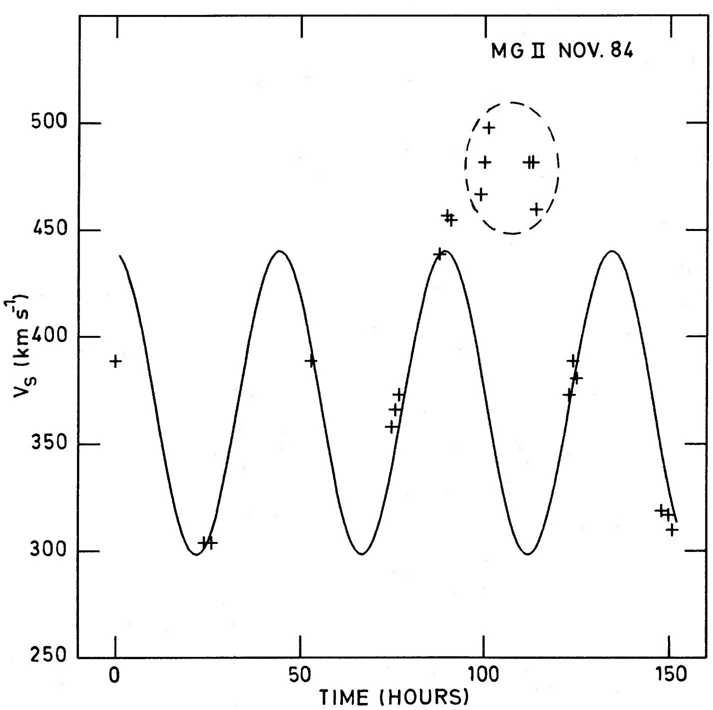

FIG. 6*b*

FIG. 6.—(*a*) Variations of the Mg II "terminal velocity" over 40 hr in 1982 October. A sine curve with a period of 45 hr is plotted for comparison with observations (*plusses*). (*b*) Variations of the Mg II "terminal velocity" over 150 hr in 1984 November. The sine curve fit excludes the six encircled points, which are attributed to a flarelike event. The measurement error for V_s is ± 20 km s^{-1}.

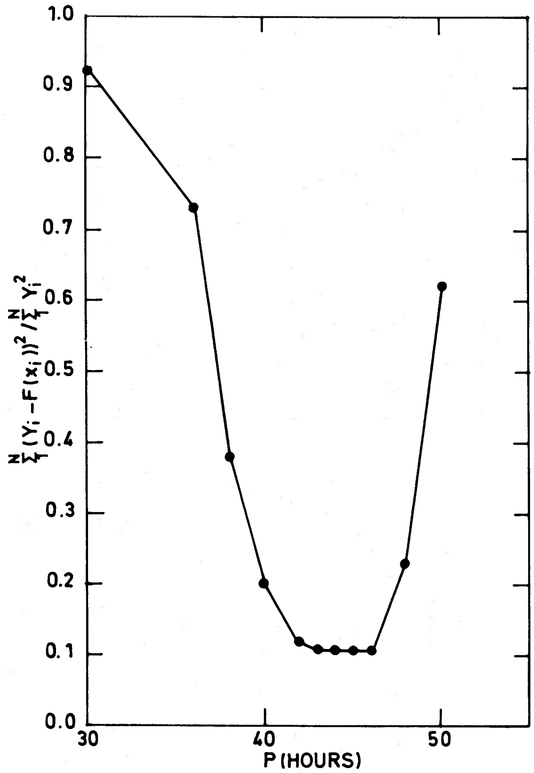

FIG. 7.—The residual of the sine fit to the observed set of data $V_s(t)$ for 1984 November vs. period *P*.

was studied in the blue wing, from about $V_s/2$ to larger values in Doppler shift up to V_s. This region is devoid of artifacts. On our 1982 spectra, we find $\sigma(\lambda) \geq 3\langle\sigma\rangle$ in this whole spectral region, $\langle\sigma\rangle$ being computed over a 100 Å wide region. The blue wing of the $\lambda 2795$ line is therefore variable in intensity for expansion velocities between $V_s/2$ and V_s. Other parts of the profile, though, do not vary in 1982. In 1984, the variations are so obvious that we did not perform the same analysis (see Fig. 5).

c) Search for Variability in the Emission Parts of the Mg II *Line Profiles*

Spectral variability could also be present in the emission equivalent width and in the peak emission intensity observed in Mg II $\lambda\lambda 2795$ and 2802. All four quantities vary in a random way over the 40 hr of observations in 1982 October; however, none satisfies the criterion that in a given image the deviation measured be larger than 3 σ. The most significant results are related to the emission part of Mg II $\lambda 2802$, which suffers no blending with the $\lambda 2795$ line. The average value of $W_{em}(\lambda 2802)$ is 980 ± 120 (s.d.) mÅ.[5] We note that inaccuracies in positioning the continuum and the effects of order averaging both affect $W_{em}(\lambda 2802)$, the error being estimated at 110 mÅ. A comparison of the spectra in absolute units confirms the lack of emission intensity variations, while the variations in V_s are quite obvious in the same visual examination.

The Mg II $\lambda 2802$ emission is more variable in 1984 November than in 1982 October. Over the 150 hours of observation, the peak to peak variation of $W_{em}(\lambda 2802)$ is a factor of 1.45, although the average value of 973 mÅ is very close to that of 1982 October. However, the standard deviation is now 216 mÅ, larger than the estimated error of measurement (110 mÅ). We find no correlation between $W_{em}(\lambda 2802)$ and V_s(Mg II); there is a tendency for the emission to be broader when $W_{em}(\lambda 2802)$ is larger, which occurs in particular for the eight images LWP 4764–4775.

To summarize this section on Mg II variability, we find that the blueshifted absorption part of the Mg II line profile varies systematically in terminal velocity and intensity over a time scale of 45 hr, which we interpret as the rotation period, while the redshifted emission component of the profile is less variable. In the first instance, the variability is the result of changes in the structure of the envelope localized on the line of sight to the stellar core, while most likely the variability in the emission part of Mg II lines, formed by a volume integration over the envelope, is smoothed out by uncorrelated (or correlated) local variations throughout the envelope.

V. THE Fe II SPECTRUM

The Fe II spectrum is intense in AB Aur. As already described (Praderie *et al.* 1982; Talavera *et al.* 1982), most of the Fe II lines are in absorption, and the resonance lines show no sign of P Cygni structure, i.e., no emission is located redward of the rest wavelengths. Some aspects of their long-term variability are presented in Praderie *et al.* (1984*a*).

In the 1982 October spectra, the strongest absorption lines of UV multiplets (1, 2, 3, 32, 33, 34, 35, 62, 63, and 64), when not too blended, are separated into three components. The most intense component is the shortward one, which is well separated from the others (Fig. 8), while the longward one is located at the rest wavelength in the Mg II/Fe II interstellar line system. The Doppler shifts of the two blueshifted components ($\Delta\lambda_1$, $\Delta\lambda_2$) relative to the undisplaced component have been measured on all possible unblended Fe II lines and on all 29 available spectra. The shifts remain constant over the 40 hr of observation and correspond to well-defined velocity shifts of $V_1 = 56$ km s^{-1} and $V_2 = 150$ km s^{-1}. Because of this constancy, we show in Figure 8 average spectra in the regions of UV multiplets 1, 62, and 63. Since the two extra blueshifted components appear in subordinate lines, as well as in resonance ones, at velocities very different from the interstellar one measured in other lines, these components must be intrinsic to the star rather than interstellar in origin.

The appearance of the Fe II spectrum in 1982 October is different from what we have observed at other epochs (Praderie *et al.* 1984*a*), when one could find either simple asymmetric lines (in 1981 January) or broad but unsplit, almost square line profiles (in 1983 January). In 1984 January the Fe II lines are again split into three components of nearly equal intensity, and their shapes evolve still more in 1984 November. Significantly, the velocities determined for the Fe II components are smaller than V_s(Mg II), and this is the case in all other images examined in the long-term variability study of Praderie *et al.* (1984*a*).

That the Fe II resonance lines exhibit no P Cygni structure, while the Mg II resonance lines and Hα do, can be attributed to one or several of the following reasons. (1) The spectral region where the Fe II lines are located is crowded by absorption lines, and those suffice to prevent the Fe II scattered photons from producing emission. (2) The wind region where the Fe II lines originate is farther out than the Mg II– and Hα–forming layers. There, the spherically symmetric approximation for the shape

[5] The present value of $W_{em}(\lambda 2802)$ differs from a preliminary result (Praderie *et al.* 1983) which was determined from a different choice of the continuum normalization.

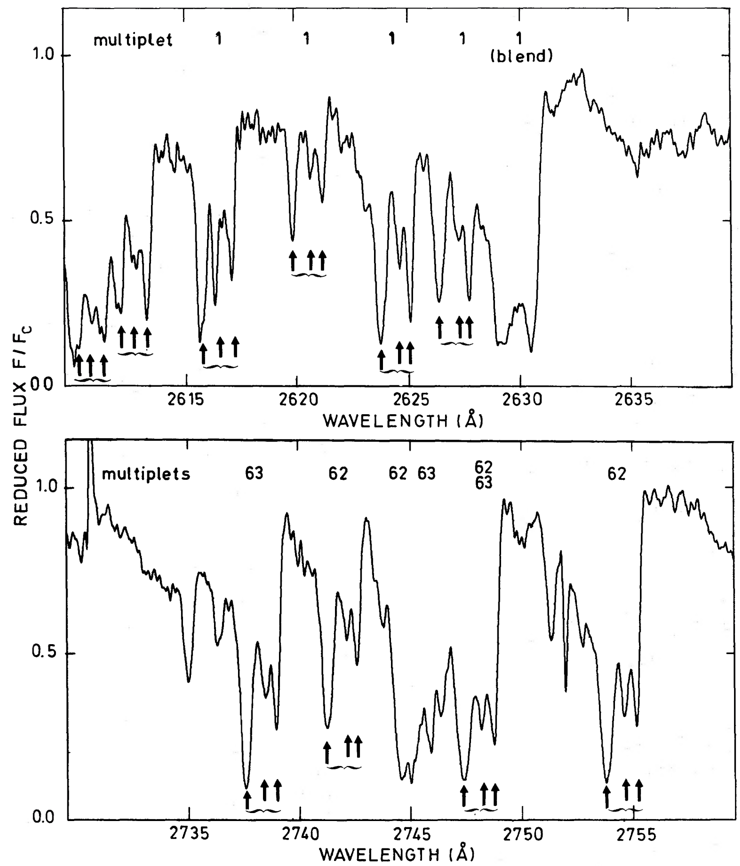

FIG. 8.—Average spectrum (29 spectra coadded) in two Fe II regions observed in 1982 October: Mult. UV 1 and Mult. UV 62–63. In this figure only, the wavelength scale is in the Mg II/Fe II interstellar lines system.

of the envelope is no longer valid. This latter assumption will be reinforced by the variability study which follows. (3) The scattered Fe II photons are destroyed by cold dust. This mechanism, already suggested by Kunasz and Praderie (1981) to explain the absence of emission in the Mg II wind profile in α Cyg (A2 Ib), is more efficient in a young star like AB Aur, where dust is indeed detected through an IR excess and through the 9.7 μm silicate emission (Allen 1973; Cohen 1980). Again it would suggest that Fe II is formed at large distances from the stellar photosphere, at places where the expanding gas envelope contains dust grains. However, the Fe II lines of the Herbig star HD 250550 exhibit the same shape (Talavera *et al.* 1982), while this star presents no silicate bump nor any $B-V$ excess. (4) The atomic structure of Fe II is very complex and could allow depopulation of the upper levels of the concerned lines via other transitions.

Isolated emission lines also occur in the Fe II spectrum of AB Aur, as was first noted by Talavera (private communication). These lines belong to UV multiplets 60, 61, 78, 216, 217, 234, 277, and 282. We have noted above that in our preliminary study (Praderie *et al.* 1983) the λ2831.56 line of multiplet 217 and λ2771.18 of multiplet 282 were identified as high-intensity points to locate the continuum. This explains the differences between values of V_s(Mg II) and W_{em}(λ2802) given here and those published earlier. A list of the Fe II emission lines in the spectrum of AB Aur appears in Table 4. Some of the multiplets are intercombination ones. All share the property that their lower energy level is not directly connected to the ground configuration (a^6D) of Fe II. Further work on these emission lines will be published elsewhere (Talavera, in preparation).

As we did for Mg II, we looked for evidence of variability in several features of the Fe II spectrum: (1) velocity in the least blended lines, (2) the intensity of the absorption components, (3) the peak intensity of the emission lines, and (4) the integrated strengths of the emission lines. All the spectra were treated in reduced units, with continuum windows located as indicated in Table 3.

TABLE 4

EMISSION LINES IN THE ULTRAVIOLET Fe II SPECTRUM OF AB AURIGAE

λ (Å)	Multiplet	Configuration
2771.184.........	282	$b^2G-y^4H^o$
2779.302.........	234	$b^2H-z^2G^o$
2783.690.........	234	$b^2H-z^2G^o$
2831.562.........	217	$b^2P-z^2D^o$
2835.716.........	216	$b^2P-z^4G^o$
2880.750.........	61	$a^4D-z^6P^o$
2926.584.........	60	$a^4D-z^6F^o$
2944.399.........	78	$a^4P-z^4P^o$
2947.658.........	78	$a^4P-z^4P^o$
2949.178.........	277	$b^2G-z^2F^o$
2953.774.........	60	$a^4D-z^6F^o$

In 1982, no detectable variation exists in the blue wing velocity. For instance, the average value of V_s for Fe II λ2727.5 is 210 km s^{-1}, with an rms dispersion of 6.5 km s^{-1}.

The intensity at maximum absorption of the pair of blueshifted components for Fe II $\lambda\lambda$2617.6, 2621.7 (mult. 1), 2714.4, 2727.5, 2739.5 (mult. 63), 2743.2, and 2755.7 (mult. 62) showed only a random pattern over the 40 hr of observation in 1982, although the variation often exceeds the $\pm 8\%$ statistical uncertainties established by Franco *et al.* (1984) in their study of the Mg II resonance lines of solar-type stars. However, no periodic variation can be recognized in the absorption intensity fluctuations of the Fe II lines in our 1982 spectra of AB Aur.

The general variability criterion discussed earlier was applied to three spectral regions containing the Fe II absorption lines (2340–2415, 2540–2640, and 2700–2980 Å). Namely, a $\sigma(\lambda)/\langle\sigma\rangle$ curve was produced for each region for the entire set of available images from 1982. An example is given in Figure 9. All details in this figure where $\sigma(\lambda) \geq 2\langle\sigma\rangle$ were analyzed, and all could be identified with artifacts due to the camera or exclusively to one of the images (radiation hits). In particular, we found no local maxima in $\sigma(\lambda)$ at the rest wavelengths of the Fe II absorption components, maxima which would have indicated variability in the intensity of the Fe II absorption components.

We therefore conclude that no short-term intensity variations in excess of *IUE*'s photometric precision are present in the Fe II UV absorption lines in the 29 images obtained over the 40 hr of observation in 1982.

The emission lines of multiplets 60 and 78 were also examined for variability by means of the variability criterion described above. No significant variation was found in the peak intensities in the 1982 spectra.

Fluctuations in the equivalent widths of Fe II emission lines W_{em} were detected. They are fairly intense in the case of the λ2926.6 line (mult. 60). However, we estimate the error $\Delta W_{em}/W_{em} \approx 0.30$, and so we find that in 1982 only five points of 29 lie outside the error range, which we judge to be totally insignificant.

It therefore appears that in 1982 the Fe II line spectrum in the star AB Aur behaves very differently from the Mg II spectrum. The Fe II absorption lines are very constant in blue wing velocity, in separation of the components, and in intensity. The Fe II emission lines do not exhibit conspicuous *organized*

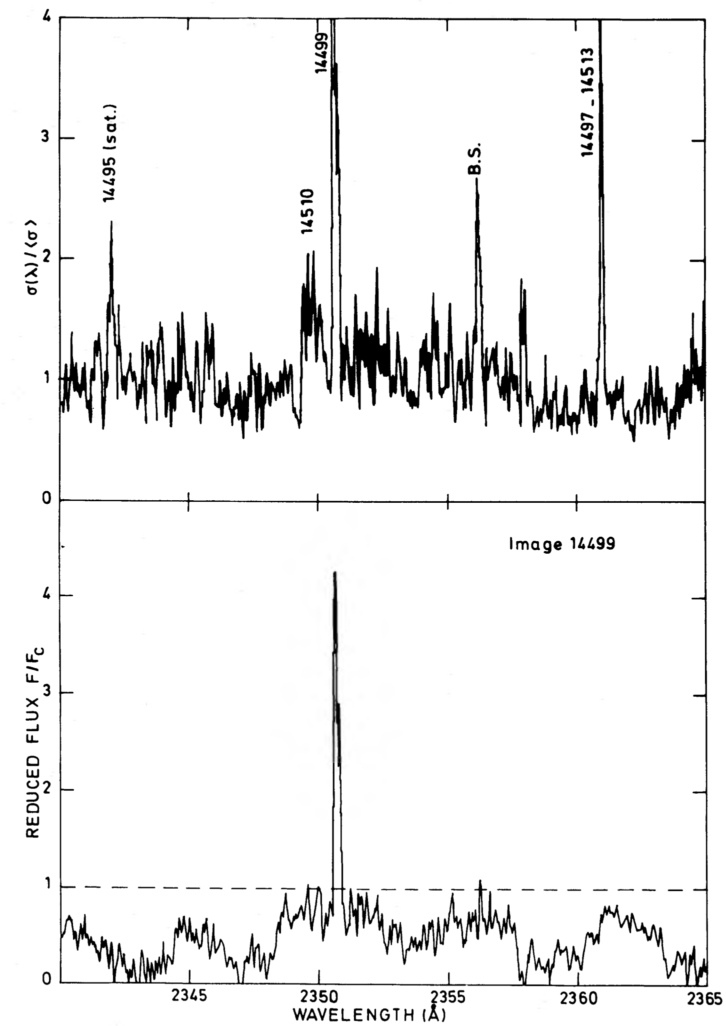

FIG. 9.—(*a*) An example of the standard deviation curve for 1982 October $\sigma(\lambda)$, referred to the wavelength average $\langle\sigma\rangle$. The $\sigma(\lambda)$ is computed for 29 individual images between 2340 and 2365 Å. Camera artifacts are identified by LWR image number, e.g., "B.S." denotes a bright pixel in the LWR camera. (*b*) An example of the effect of an artifact in image LWR 14499 on structure in the $\sigma(\lambda)/\langle\sigma\rangle$ curve. The other deviating points can all be similarly analyzed.

intensity variations either. By contrast, the blue absorption in the Mg II resonance lines exhibits periodic variations in velocity and intensity, while the Mg II emission is not distinctly variable.

In 1984, the aspect of the Fe II lines is very different from that observed in 1982. The lines are no longer split into three components; their absorption core is broad and deep. While we had to apply refined methods to finally conclude that the Fe II spectrum is not variable from the 1982 data, the variations in 1984 are so conspicuous over our series of 22 images that they were immediately obvious.

Figure 10 displays an example of this variability in the region of Fe II multiplets 62 and 63. The variations are particularly easy to see near Fe II λ2755.73 (mult. 62). On the upper panel of Figure 10, note that Fe II λ2753.29 (mult. 235) is clearly distinct from Fe II λ2755.73, and so is the case on images LWR 4733–4747. A detailed examination of the whole set of 1984 November data showed that a blueshifted absorption component appeared in all the lines of multiplets 1, 62, and 63 on LWP 4753. On Figure 10 (*lower panel*), for instance, this component in Fe II λ2755.73 has become mixed with Fe II λ2753.29. The width of this component increased continuously, then decreased from LWP 4774 on, and eventually the component disappeared on LWP 4784. In the region of Fe II λ2755.73, then, the multiplet 235 line is back to its well-separated state relative to Fe II λ2755.73. The total duration of this blue component was 3 days. No such variation was observed in the emission lines of multiplets 60, 61, and 78. Finally, there is no correlation at all between the "flarelike" phenomenon seen in the Mg II lines (§ IV*a*) and any feature in the Fe II lines.

VI. SIGNIFICANCE OF THE TIME VARIABILITY OF Mg II AND Fe II

The observations of AB Aur can be examined successively within the framework of two models. The first is a spherically symmetric representation of the wind of AB Aur, which is useful in studying the overall formation of various spectral characteristics. The second model is nonspherically symmetric and is suggested by new information deduced from variability studies. In such a laterally inhomogeneous model, the different aspects of the projected stellar disk seen by an observer, which result from the star's rotation, are responsible for the variability.

We first point out that no organized hourly profile variation, such as that which we have found for the Mg II "terminal velocity" V_s of AB Aur, has been reported in any other star of type A, whether dwarf or supergiant, pre–main-sequence or main-sequence. In hotter stars profile fluctuations have been observed in wind-sensitive lines: York *et al.* (1977) reported intensity variations in O VI in O-type stars on time scales of 1–6 hr; Slettebak and Snow (1978) found short-term irregular variability in the Si IV, Mg II, and Hα lines of the Be star γ Cas. These authors did not recognize the stellar rotation period nor

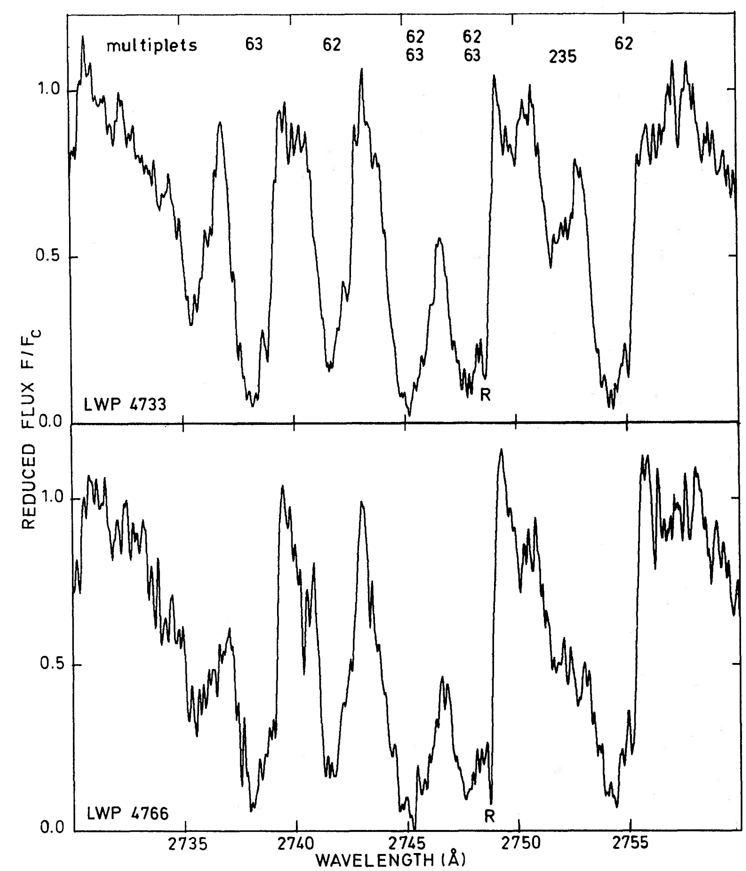

FIG. 10.—One of the Fe II regions of Fig. 8 (Mult. UV 62–63) at two different epochs within the 1984 November run, chosen to exhibit the short-term variability of Fe II as described in text.

any other period in their data.[6] High temporal resolution profile variability in B and Be stars (Smith *et al.* 1984; Baade 1984) constitutes a very new step in the study of pulsational motions of hot star atmospheres.

AB Aur is spectroscopically very different from an ordinary dwarf A star, as indicated by the P Cygni profile of Mg II. Since one cannot envisage on the basis of available data that AB Aur is a binary (Finkenzeller 1983), we are left with a variability phenomenon which may be restricted to pre–main-sequence stars, of which, among the hottest ones, only AB Aur has thus far been studied in sufficient detail. We found that a time scale very similar to the rotation period plays a role in modulating the terminal velocity of the Mg II λ2795 line, and this leads naturally to an interpretation in terms of rotation.

The Mg II line formation in AB Aur has been studied for a spherically symmetric expanding medium, with a monotonic velocity law increasing from small values at the photosphere to $V_\infty \approx 300$ km s^{-1} at $\sim 20\ R_*$ (Catala, Kunasz, and Praderie 1984). The Mg II line profile has been computed in a two-level atom NLTE approximation. In this representation of the envelope of AB Aur, the absorption part of the Mg II profile is sensitive to all velocities up to V_∞, and the strength of the emission intensity depends strongly on the presence of a chromosphere, which acts on the one hand to raise the line source function and on the other to fix the ionization fraction of Mg II in the lower portions of the expanding envelope. This chromosphere extends from 1 to 2.5 R_*, and its temperature reaches 15,000–18,000 K, a range of values confirmed by a recent study of the C IV resonance lines in this star (Catala and Talavera 1984; Catala 1984*a*).

The sinusoidal variation of V_s(Mg II) we have observed at two different epochs reflects a phenomenon that is best observed along the line of sight to the stellar core and one that is not averaged out by volume integration effects, as is the case of an emission feature such as $W_{\rm em}(\lambda 2802)$. Furthermore, the intensity in the blue absorption wing of the λ2795 line is variable for Doppler shifts ranging from $\sim V_s/2$ up to V_s. Therefore the variability in the envelope must extend over at least the corresponding radial distances if $V(r)$ is taken as a unique, monotonic function of distance. However, the mere existence of such variability, and of a periodic one, is incompatible with a spherically symmetric model of the star's envelope and suggests that the envelope of AB Aur needs to be represented by a nonuniform expanding model.

It is attractive to interpret the time variability of V_s(Mg II) shown in Figure 6 as the effect of large-scale perturbations in the stellar wind (Praderie *et al.* 1984*a*; Catala 1984*a*). As in the Sun, if the wind is structured in fast and slow streams of material, their passage across the line of sight produces for a remote observer a periodic pattern of variability as the star rotates and drives the envelope in corotation. In this picture, the envelope must be dense and cool enough that spectroscopically observable effects can be observed, unlike the case of the tenuous and hot solar wind. When fast streams (or one fast stream) face the observer, then V_s(Mg II) attains large values; when slow streams (or one slow stream) cross the visible disk, then V_s is at its smallest values. A similar, solar wind–inspired model has been elaborated by Mullan (1984) for the winds of hot stars, hybrid stars, and cool supergiants, but with a different purpose than to explain variability.

In the Sun, the origin of such streams is in the coronal holes for the fast ones, and in active regions (or at active longitudes) for the slow ones. Due to the solar rotation, the streams that emerge radially from the surface corotate and form a spiral structure; this structure keeps its individuality up to a large distance from the Sun in the interplanetary medium (10 AU). At greater distances, the streams are eroded and finally merge; hence, a more ordered configuration is restored (e.g., Burlaga 1984).

In Mullan's (1984) model, the fast streams overtake the slow ones in a region which corotates with the star. The radial distance to this "corotating interactive region" depends strongly on the longitude dependence of the velocity within the fast streams. Since we do not know anything about this dependence in AB Aur, we cannot determine at which distance the streams begin to merge. If this happens beyond the region contributing the most to the observed variations of V_s(Mg II), these variations give us a real measure of the velocity difference between fast and slow streams. If not, the bluest parts of the Mg II lines are formed in a region where the streams have begun to merge, and we see only smoothed variations. The azimuthal and latitudinal coverage of the stellar disk by the fast and slow streams must be substantial since we see (Fig. 6*a*) a continuous variation of V_s(Mg II), by contrast with short-lived but periodically distributed enhancements in V_s.

In the case of AB Aur, one then wonders if a structured expansion of the solar wind type extends throughout the wind or if it is characteristic of only a range of radial distances in the envelope. The observations of the UV Fe II lines are of interest here. In a spherical wind model, the expansion velocities in Fe II (either the blue wing velocity or the Doppler shifts of the components) can correspond either to the acceleration zone near the stellar surface or to the remote decelerating part of the wind, which gives rise to the blueshifted absorption in Na I D lines at $V = 130$ km s^{-1} (Felenbok, Praderie, and Talavera 1983; Finkenzeller and Mundt 1984). The first alternative can be eliminated, because otherwise we could not understand why the Mg II absorption lines are variable while at the same time the Fe II lines are so constant in all respects in 1982. Note that the blue wing velocity in Fe II at that epoch, 210 km s^{-1}, is only slightly larger than half of V_s(Mg II), namely $\sim$200 km s^{-1}. The difference is too small to support an overlap in the regions where Fe II and the variable parts of the Mg II profile, i.e., $V \geq V_s$(Mg II)/2, are formed. We believe it is more reasonable to assume that the Fe II lines originate in the cool decelerating part of the wind, above the Mg II–forming region. It cannot be assumed that the well-identified fast and slow streams existing in the Mg II–forming part of the wind keep their individuality in regions as remote as those where the Fe II lines form; otherwise again we should observe a periodic variability in the Fe II lines, and never a phase of constancy. These facts suggest that, as in the Sun, the fast and slow streams eventually merge, after a destruction of the ordered spiral configuration present at radial distances closer to the star.

How can we reconcile such a picture with the two contrasting characteristics of the Fe II lines in AB Aur as observed in 1982 and 1984, namely, (1) the existence of discrete velocity components, which are almost always present over several years (see Praderie *et al.* 1984*a*), and (2) the constancy of the Fe II spectrum in 1982 and its variability in 1984? The components correspond either to a velocity plateau at well-defined

[6] This work was completed when we received the paper by Brown, Shore, and Sonneborn (1985) on the helium-weak star HR 1063, in which the C IV resonance lines vary on the same time scale as the magnetic field, i.e., with the rotation period.

values of V or to a density enhancement (shell). The first occurrence seems unlikely, at least in the sense suggested by Mullan (1984): the velocity plateau which exists between consecutive fast and slow streams in a solar wind–type model would demand, if it existed in AB Aur, that a variability of Fe II accompany the Mg II variability in 1982 as the star rotates. This was not observed. The second alternative, i.e., the formation of shells at $r \geq 20\ R_*$ in the Fe II–forming region, would be compatible with the erosion of streams into pressure waves, directly observed in the heliosphere behind the region of corotating fast and slow streams (Burlaga 1984). In the case of AB Aur, to understand the time behavior of the Fe II lines one would need a stable configuration of such compression regions across the line of sight over 40 hr to interpret the 1982 data, while different "annuli" of these pressure waves would pass in front of the observer over 150 hr in 1984, accounting for the appearance and disappearance of components in the UV Fe II lines.

In the absence of the detailed radiative transfer computation of the Fe II lines, which should in particular explain why those UV lines do not show a classical P Cygni structure, we propose that the Fe II lines are formed in a nonuniform region 20 R_* or farther from the star, a region structured by pressure waves rather than by fast and slow streams, and contributing little to the formation of the bluest parts of the Mg II line.

Deeper in the envelope at radial distances corresponding to velocities smaller than about $V_s/2$, the lines which can be used to probe the wind include the Ca II and C IV resonance lines. The C IV lines have been analyzed by Catala and Talavera (1984), but the variability of C IV has not yet been studied in detail. The Ca II lines were observed in 1982 October. Their variability over five nights is pronounced, and a period can be extracted from the series of 39 available spectra (Catala *et al.* 1985*b*, Paper II of this series). The Ca II data are discussed in this forthcoming paper, and further properties of the wind model assessed.

If the structure of the wind of a very young star such as AB Aur shares some common characteristics with that of the solar wind, if rotation accounts for the variability observed in some of the lines, and if the large-scale structure present in the wind persists over several rotations, as suggested by the Mg II data, we may have indirect proof of the presence of a magnetic field. As in the Sun, the field may alternate between closed loop structures and open field configurations. The regions corresponding to closed loops would be the seat of the Ca II K emission component and of all other chromospheric lines (Ca II IR triplet, He I λ5876; see Felenbok, Praderie, and Talavera 1983). Consequently, we expect other chromospheric lines to be variable on a short time scale, as is the case for Ca II. "Coronal hole"–type regions with open magnetic field lines might extend into the envelope and be the source of the fast streams observed in the Mg II lines. Since short-term periodic variability in Mg II extends over at least 150 hr in 1984 November (Fig. 6*b*), this means that these regions, as in the Sun, persist on the stellar surface at the same location over more than three rotation periods. All these phenomena can be called "activity," whether present as rotational modulation in emission features or in radial velocities. Similarly, what we have called by extension "flarelike events" are shorter time scale ($\tau \ll P_{\rm rot}$) phenomena which manifest themselves either by a reinforcement in emission intensity, or by a sudden increase in velocity, or by the abrupt appearance of a short-lived absorption component.

The suggested model differs in one major respect from the solar wind: the temperature of the flow must be low (5000–10,000 K) in the region where the variable parts of the Mg II line profiles and the Fe II lines are formed. When we refer to "coronal hole"–type regions as the source of the recurrent fast streams in the wind, this designation is used only for the purpose of analogy, because no plasma at $T \approx 10^5$–10^6 K has yet been observed in AB Aur (Feigelson and De Campli 1981). Whether the star actually has a corona, and also what mechanism can accelerate the winds of Herbig stars in general, is unknown. Our proposed model is purely phenomenological.

The ultraviolet Fe II spectrum such as is observed in AB Aur has no counterpart in solar-type stars and makes this star more similar to hot stars, such as Be stars, or O and B stars. High-speed (Lamers, Gathier, and Snow 1982) and low-velocity (Gry, Lamers, and Vidal-Madjar 1984) absorption components are present in the resonance lines in a number of O and B stars where the origin of these components is still debated. In AB Aur, the short-term (this paper) and long-term (Praderie *et al.* 1984*a*) variability of Fe II can be qualitatively reconciled with a "remote heliosphere"–type model, as proposed here, implying the formation of pressure waves, but at densities large enough that optical and UV effects can be observed in the spectrum. We also point out that AB Aur shares some similarity with T Tauri stars, although not on the same time scale. Mundt (1984) reports that in a number of T Tauri stars, the blueshifted absorption components observed in the Na I D lines (but not in Fe II) seems to be constant in intensity and velocity, while Hα is variable. But these results refer to periods of order months or years; more closely spaced observations are needed in T Tauri stars before pushing a comparison further.

VII. CONCLUSIONS: ACTIVE PHENOMENA IN HERBIG Ae STARS?

The Herbig Ae stars are located at the junction of hot stars and of cool stars in the H-R diagram (Strom *et al.* 1972; Cohen and Kuhi 1979). One of them, AB Aur, better studied than the others, exhibits short-term spectral variability, which calls for an inhomogeneous structure of its expanding envelope. We have shown that, in AB Aur as in cool solar-type dwarfs, rotation modulates its observed features, here the Mg II terminal velocity. Also, like hot stars, AB Aur shows a prominent system of variable, narrow absorption components which are found not only in Fe II, but also in Ca II K (Simon, Boesgaard, and Praderie 1982; Praderie *et al.* 1983; Catala *et al.* 1985*b*).

In this paper, we have labeled as "activity" the rotationally modulated variability observed in AB Aur and presented a solar wind–inspired model, although cool, for its expanding envelope. We have also suggested that such a model can encompass the formation of Fe II components. Let us consider now whether such a model can be envisaged without posing difficulties for an intermediate-mass star as young as 10^6 yr (Cohen and Kuhi 1979).

As compared to many other young stars, AB Aur is a fairly rapid rotator: its $v \sin i$ of 75 km s^{-1} contrasts with those of T Tauri stars, which in the case where axial rotation rates have been determined are slow rotators ($v \sin i$ typically ≤ 25 km s^{-1}; see Vogel and Kuhi 1981), as well as three-fourths of the G stars in the young Orion Ic cluster ($v \sin i \approx 12$ km s^{-1}; Smith, Beckers, and Barden 1983). However, rotation rates have yet to be measured for the T Tauri stars with the most intense emission lines, and there exists a component of rapid rotators among the G stars in the Orion Ic cluster whose $v \sin i$ reaches 200 km s^{-1}.

The rotation/activity connection remains an open question in T Tauri stars. According to Vogel and Kuhi (1981), there is little correlation between activity level and rotation rate in T Tauri stars. Rotational modulation of chromospheric or coronal emission features has not been reported, except for fragmentary evidence in RU Lup (Boesgaard 1984). Periodic light variations have recently been discovered in some weak-emission T Tauri stars (Schaefer 1983; Rydgren and Vrba 1983; Vrba *et al.* 1985) and attributed to rotational modulation by large spots on stars which happen to be rapid rotators (e.g., $P = 1.9$ days for V410 Tau). In AB Aur, though, no light variations are observed simultaneous with the spectral variability we report here, to the level of 0.02 mag. For AB Aur we do not need spots such as those invoked (Rydgren and Vrba 1983; Herbst, Holtzman, and Klasky 1983) to account for the episodic variations observed in some cooler Ae irregular variables; or photometric techniques do not detect spots in hotter stars because of smaller contrast relative to the photosphere; or simply those spots do not develop in the hotter of the Herbig stars, as suggested by Finkenzeller and Mundt (1984, their Fig. 4).

The hypothesis that activity phenomena are of magnetic origin in T Tauri stars receives more and more attention. Their high levels of activity and the difficulty of providing the energy required to drive such activity, except by external causes such as accretion, led Gershberg (1982) to conjecture that strong magnetic fields in T Tauri stars on the one hand are responsible for the patchy aspect of the stellar surface ("spots," which at that time had not yet been observationally confirmed), and on the other hand modify the normal regime of radiation output over spots. For Gershberg, the magnetic field is most likely fossil, but it could also be dynamo-generated, thereby providing the common link between activity in T Tauri, UV Ceti, and other active stars.

Recently, Simon, Herbig, and Boesgaard (1985) have established the time decay of activity among main-sequence F–G stars with ages between $t = 10^8$ and $10^{9.5}$ yr. They find that ultraviolet activity "saturates" in a plateau for the youngest main-sequence stars, while the T Tauri stars lie one to three orders of magnitude above this plateau. Introducing the Rossby number ($\mathrm{Ro} = P/\tau_c$, with τ_c = turnover time for convective elements at a significant depth in the convective zone), they show that this parameter correlates well with all activity signatures, as was earlier demonstrated by Noyes *et al.* (1984) for Ca II, Mangeney and Praderie (1984) for X-rays, and by Vilhu (1984). They also note that T Tauri stars should be characterized by either long τ_c or very short P. This picture explicitly assumes that the magnetic field responsible for activity phenomena is generated with the stars' subphotospheric convective envelopes.

AB Aur brings a new element in this chain. Since the star is of type A and is located near the main sequence in the H-R diagram, the activity signatures have evolved relative to what they are in solar-type pre–main-sequence stars, but, as recalled above, one finds definite emission lines as well as wind profiles. As we stated earlier, there is no paradox in calling the observed variability of V_s(Mg II) an indication of activity, inasmuch as this variability is related to the rotation period, and we have conjectured that rotation, and hence a dynamo-generated magnetic field, controls the observed activity phenomena. However, a question arises of whether there exists a deep enough convective zone in the Ae stars to insure that an effective dynamo mechanism can operate. We argue (1) that the evolutionary tracks toward the main sequence are not in the ultimate state of refinement, especially for the massive and intermediate-mass pre–main-sequence stars; and (2) that if Mangeney and Praderie (1984) are right in their correlation between X-ray luminosity and the Rossby number all along the main sequence, then there is no fundamental distinction between the activity of solar-type and hot stars. An ad hoc and less appealing alternative is that the magnetic field is fossil in young pre–main-sequence A-type stars like AB Aur.

Let us point out that AB Aur, like the T Tauri stars studied by Vogel and Kuhi (1981) and the Orion Ic G stars (Smith, Beckers, and Barden 1983), does not obey the relationship for decay of activity (expressed, for instance, by the rotation rate Ω) versus age t established by Skumanich (1972). If this $t^{-1/2}$ relationship is applicable to stars as massive as 3 $M_{\odot}$, and if it applies to young stars, the rotation period of AB Aur should be $\sim$9 hr (assuming $t = 10^6$ yr), instead of 45 hr found here. This large discrepancy with Skumanich's relation points toward the Herbig stars belonging above the "saturated" plateau of activity versus age, as is the case for the T Tauri and Orion Ic stars. It most likely contains the key to the global problem of magnetic field generation and magnetic field plus wind braking in these very young stars.

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