1986ApJ...308..791C

THE ASTROPHYSICAL JOURNAL, 308:791–804, 1986 September 15

SHORT-TERM SPECTRAL VARIABILITY IN AB AURIGAE: CLUES FOR ACTIVITY IN HERBIG Ae STARS. II. THE Ca II K LINE

CLAUDE CATALA,[1,2] PAUL FELENBOK,[1,3] AND JEAN CZARNY[3,4]
Observatoire de Paris, Section de Meudon
ANTONIO TALAVERA[4]
Astronomy Division ESTEC, Villafranca Tracking Station
AND
ANN MERCHANT BOESGAARD[4]
Institute for Astronomy, University of Hawaii
Received 1985 October 28; accepted 1986 March 11

ABSTRACT

The Herbig Ae star AB Aur (A0ep) was monitored with the Canada-France-Hawaii 3.6 m and the Observatoire de Haute-Provence 1.52 m telescopes in the Ca II K line, for six nights in 1982 October. Some of the 39 recorded spectra were simultaneous with ultraviolet spectra obtained with *IUE* during a round-the-clock observation described in Paper I of this series.

We find that the Ca II K line is variable and modulated with a period of 32 ± 4 hours, corresponding to the estimated rotation period of the star. We also report the appearance on some of the spectra of blueshifted absorption components and of a small emission component near the core of the stellar line. In addition, a redshifted emission component appears on most of the spectra. The Ca II H line and the Hϵ line, observed at the Canada-France-Hawaii telescope, are also variable and their variations seem correlated with that of the Ca II K line.

We interpret the 32 hour period found in the Ca II K stellar line as due to a rotational modulation. The qualitative model of fast and slow streams alternating along the line of sight, presented in Paper I, is analyzed in more detail, and we interpret the difference between the 45 hour period found in the Mg II data (Paper I) and the 32 hour period in the Ca II data as due to a differential rotation in the envelope of the star. The existence of this differential rotation allows us to estimate upper limits for the magnetic field and the Alfvén radius in the envelope of AB Aur, as well as for the rate of angular-momentum loss. It is concluded that this angular-momentum loss might play a major role in the evolution of the star.

The blueshifted absorption components can be the results of puffs in some of the streams leaving the star's surface, or they can be formed in the so-called corotating interaction regions, where the fast and the slow streams merge. The core emission component is interpreted as due to motions near the stellar pole, and the redshifted emission component simply as due to the extension of the line emitting region.

Subject headings: stars: emission-line — stars: individual — stars: rotation — stars: spectrum variables

I. INTRODUCTION

In the 25 years since Herbig's pioneering work (Herbig 1960), his original conjectures that the Herbig Ae/Be stars are pre–main-sequence (PMS) objects of intermediate mass (2–7 $M_\odot$) and higher mass counterparts of T Tauri stars have been confirmed (Strom *et al.* 1972; Cohen and Kuhi 1979; Finkenzeller and Mundt 1984).

The Herbig Ae/Be stars can be divided into three subclasses, according to their Hα profiles: double-peak emission, single-peak emission, or P Cygni profile (Finkenzeller and Mundt 1984). It has been shown recently that the stars of the "P Cygni" subclass exhibit striking similarities in several other lines, which suggests a similar structure for their envelopes (Catala *et al.* 1986). Thanks to this similarity, AB Aur, the brightest member of the P Cygni subclass, can be considered as representative of the whole subclass. Quantitative interpretations of Mg II and C IV resonance lines in AB Aur (Catala, Kunasz, and Praderie 1984; Catala 1984; Catala and Talavera 1984) and of the first lines of the hydrogen Balmer series (Catala and Kunasz 1986) were carried out under the assumptions of spherical symmetry and stationarity and led to a model including a stellar wind and a deep expanding chromosphere at the base of the wind.

However, the short-term spectral line variability which has been observed for T Tauri stars (Schneeberger, Worden, and Wilkerson 1979; Mundt and Giampapa 1982; Boesgaard 1984) and for Herbig Ae/Be stars (Praderie *et al.* 1982; Finkenzeller 1983; Praderie *et al.* 1984; Thé *et al.* 1985) strongly suggests that their winds might be neither spherically symmetric nor stationary, but that strong inhomogeneities could be present in their envelopes. Understanding the causes of this variability is not only interesting in itself, but will also provide information about the physical processes at work in these atmospheres. It is then important to study in more detail the short-term variability in PMS stars.

Being the brightest Herbig Ae star of the northern hemisphere, AB Aur (HD 31293, A0ep, $m_V = 7.2$) has been chosen

---

[1] Visiting Astronomer, Observatoire de Haute-Provence, operated by the Centre National de la Recherche Scientifique of France.

[2] Unité de Recherche Associée au CNRS 264.

[3] Unité de Recherche Associée au CNRS 812.

[4] Visiting Astronomer, Canada-France-Hawaii Telescope, operated by the National Research Council of Canada, the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

for a detailed study of its short-term variability. An important observation campaign, involving the *International Ultraviolet Explorer* (*IUE*), the Canada-France-Hawaii 3.6 m telescope, the 1.52 m telescope at the Observatoire de Haute-Provence (OHP), France, and two photometric telescopes (0.6 m at Pico de la Veleta, Spain, and 1 m at San Pedro Martir, Mexico), was carried out in 1982 October. Its goal was to monitor the star for 40 hours in the ultraviolet range and for five nights in the Ca II line and photometrically, with a certain time interval of total simultaneity between the *IUE* and the ground-based observations. Preliminary results of the whole campaign have been presented in Praderie *et al.* (1984). In addition to the 1982 October campaign, the star has been observed intermittently in the UV range for 150 hours in 1984 November with *IUE*. The detailed results of the two sets of *IUE* observations have been presented and discussed in Praderie *et al.* (1986, hereafter Paper I), along with the results of the photometric monitoring. The striking conclusion of Paper I is that the maximum blueward shift of the Mg II resonance lines, called V_s(Mg II), varies periodically with a period of 45 hours, which can be interpreted as a rotational modulation, since available estimates of the projected rotation velocity ($v \sin i$), combined with estimates of the stellar radius, lead to a rotation period of the same order of magnitude.

In Paper I, a model involving an alternation of slow and fast streams rotating with the star has been suggested to account for such a modulation. The proposed model for AB Aur is directly inspired by the structures well known in the solar wind (Burlaga 1983, 1984). Indirect evidence of the presence of surface inhomogeneities can be seen in this alternation of slow and fast streams.

The present paper aims at describing and discussing the results of the Ca II K line observations during the 1982 October campaign. The total span of these observations was 130 hours, i.e., about three or four rotation cycles. We can then expect to derive valuable information from a careful analysis of these data. Moreover, since the Ca II line is formed in a very localized region, at the base of the wind (Catala *et al.* 1986), while the blue edge of the Mg II resonance lines is formed farther out (Paper I; Catala, Kunasz, and Praderie 1984), we can also expect to investigate a possible radial dependence of the modulation.

Section II describes the telescopes and the instrumentation used, as well as the reduction techniques. The procedure followed to analyze the line variations is detailed in § III. In § IV the results are discussed and compared with those derived from the Mg II data, in the framework of the model proposed in Paper I. A summary of the results and general conclusions are given in § V.

II. OBSERVATIONS

The observations of the Ca II K line of AB Aur during the 1982 October campaign were made using the coudé equipment of the Canada-France-Hawaii 3.6 m telescope at Mauna Kea and of the OHP 1.52 m telescope. The log of these observations is given in Table 1. Only six spectra were recorded at the Canada-France-Hawaii Telescope (CFHT) owing to poor weather, while 33 spectra have been obtained at OHP.

At the CFH 3.6 m telescope, the detector was a cooled RL 1872 f/30 Reticon with 15 μm × 750 μm pixels. Some special optical features of the coudé spectrograph include a specially coated blue-sensitive mirror train, an image slicer coated for the blue, and a mosaic grating consisting of four Bausch and Lomb 830 groove mm^{-1} gratings. A region of about 68 Å was covered with a spectral resolution of 0.12 Å. Three of the spectra obtained at CFHT are contaminated by a periodic pattern (4 pixel period) because of an inefficient operation of the Reticon cooling system. This pattern has been removed from the data by filtering the highest frequencies. This filtering results in a loss of resolution, and the filtered spectra are not as good as the unaffected ones, but their quality is still acceptable. All reduction techniques have been fully described in previous papers (Felenbok, Praderie, and Talavera 1983; Boesgaard and Tripicco 1986).

At the OHP 1.52 m telescope, the detector was an electronographic Lallemand camera, equipped with a S-11 photocathode. We used the echelle spectrograph in its multiorder configuration, with a Carpenter prism to separate the orders. Because of the smaller size of the telescope, the non-optimization of the optical surfaces to the blue wavelengths, the poor transmission of the OHP atmosphere at these wavelengths, and the lower sensitivity of the detector, the OHP spectra are considerably noisier than the CFH ones: the mean signal-to-noise ratio obtained at CFHT is 110, while the mean signal-to-noise ratio obtained at OHP is only 20. Moreover, in order to keep a good temporal resolution which was our main purpose, the exposure times could not be too much increased. For these reasons, only a small amount of information can be extracted from the OHP individual spectra. However, their interest lies in their great number, and, as will be shown below, many results can be obtained from this series. All the OHP spectra were scanned with a PDS microdensitometer at the Institut d'Optique (Orsay, France). This scanning resulted in a two-dimensional image for each spectrum, on which the order containing the Ca II K line covered several rows. After a correction for the curvature of the order, the different rows composing this order were averaged. Then the data reduction procedure was the same as the one used for the Reticon spectra. The scanned OHP spectra cover a region of about 48 Å, with a spectral resolution of 0.22 Å.

For the CFHT observations, comparison spectra obtained on the same night as the stellar spectra have been used to provide wavelength scale and reference points. At OHP, the comparison spectra were recorded on the same plates as the stellar spectra.

The hydrogen Balmer lines have very extended wings in AB Aur, and the Ca II K line lies in the blue edge of the wing of Hϵ. The fluxes of the Ca II K spectra have been divided by the local continuum flux, defined by two points close to the Ca II K line, at 3920 and 3950 Å. We have thus removed any influence of possible Hϵ variations on the Ca II line.

III. DATA ANALYSIS

a) Overview of Line Profiles Based on the CFHT Spectra

Since the three best CFHT spectra (those unaffected by the contamination described in § II) have higher spectral resolution and higher signal-to-noise ratios, we present those profiles and analysis and use them as guidance for the interpretation of the longer series from OHP. Figure 1 shows the complete spectral region of the three best CFHT Reticon spectra revealing the Ca II K line and the complex profile of the Hϵ and Ca II H lines. Variations are clearly present in the strength and shape of both Ca II and Hϵ. The presence of absorption and emission components can be seen clearly. Table 2 contains the information on the various measurements made on the spectra

1986ApJ...308..791C

TABLE 1

LOG OF THE Ca II K OBSERVATIONS OF AB AUR

Date 1982 October	UT Midexposure	Telescope (cm)	Exposure Time (minutes)	Sequence Number in Figs 3 and 4	Observers[a]
25	22	152	60	1	
25	2318	152	70	1	
26	0025	152	60	1	
26	0130	152	60	1	
26	0231	152	60	1	
26	0334	152	60	1	
26	1019	360	121	2	Boesgaard, Lavery
26	1440	360	100	2	Boesgaard, Lavery
27	2018	152	83	3	
27	2132	152	60	3	
27	2234	152	60	3	
27	2337	152	60	3	
28	0040	152	60	3	
28	0132	152	60	3	
28	0245	152	60	3	
28	0347	152	60	3	
28	2002	152	105	4	
28	2128	152	60	4	
28	2230	152	60	4	
28	2333	152	60	4	
29	0035	152	60	4	
29	0137	152	60	4	
29	0239	152	60	4	
29	0348	152	72	4	
29	1234	360	60	5	Czarny, Talavera
29	2054	152	70	6	
29	2202	152	76	6	
29	2303	152	75	6	
30	0038	152	73	6	
30	0155	152	76	6	
30	0321	152	90	6	
30	1026	360	84	7	Czarny, Talavera
30	1209	360	63	7	Czarny, Talavera
30	1325	360	64	7	Czarny, Talavera
30	2125	152	90	8	
30	2257	152	90	8	
31	0032	152	90	8	
31	0221	152	88	8	
31	0346	152	73	8	

[a] Where no names are listed, observers were Catala and Felenbok.

of equivalent widths (W_λ), residual intensity (F/F_c), full width at half-maximum intensity (FWHM), and radial velocity in the geocentric frame (V_r) as measured at FWHM. Corrections of 19 and 10 km s^{-1} must be applied to these V_r values to convert them into, respectively, the heliocentric frame and the local standard of rest.

A very narrow absorption feature appears on all the CFHT spectra, at the position of both Ca II K and Ca II H lines. The width of this component is not larger than the instrumental width, and it can then be considered as interstellar (IS). The presence of this IS component has already been reported by Praderie *et al.* (1982) and Felenbok, Praderie, and Talavera (1983).

The Ca II K stellar line shows a range of variations of a factor of 2.5 in W_λ with values in the range 0.180–0.470 Å; it is the weakest on 1982 October 30, where the core appears to be partly filled in with emission. The effect of the variation due to the amount of emission in the core can be seen also in the F/F_c measurement. Also affected is the apparent width of the feature when that measurement is made at the half-intensity point, inasmuch as the half-intensity level is controlled by the amount of core emission; therefore, when the Ca II K absorption is weakest, the FWHM is largest. In addition, the velocity of the line bisector at the half-intensity level (V_r) is also affected by the variations in the emission and is redshifted most when the emission is strongest, i.e., the absorption is weakest (October 30). Thus we see that the variations in the measurable parameters of the Ca II K line are strongly influenced by the difference in the emission in the core.

While the Ca II K line is primarily photospheric absorption seen against the continuum, the Ca II H line is seen as an emission feature against the deep phosospheric absorption wing of Hϵ. One convenient way to compare the amount of emission in the two Ca II lines is to measure the residual intensity of the stellar line at the wavelength position where the IS features are, ignoring the IS absorption components themselves. We note that these values of F/F_c vary in phase for the two Ca II lines (Fig. 2*a*). There is a caveat relevant to the measurements of the line residual intensities: the IS Ca II K feature should always absorb the same proportion of flux. In fact, this proportion is the same on October 26 and 29 spectra, but is 6% weaker on October 30 spectrum. This difference is

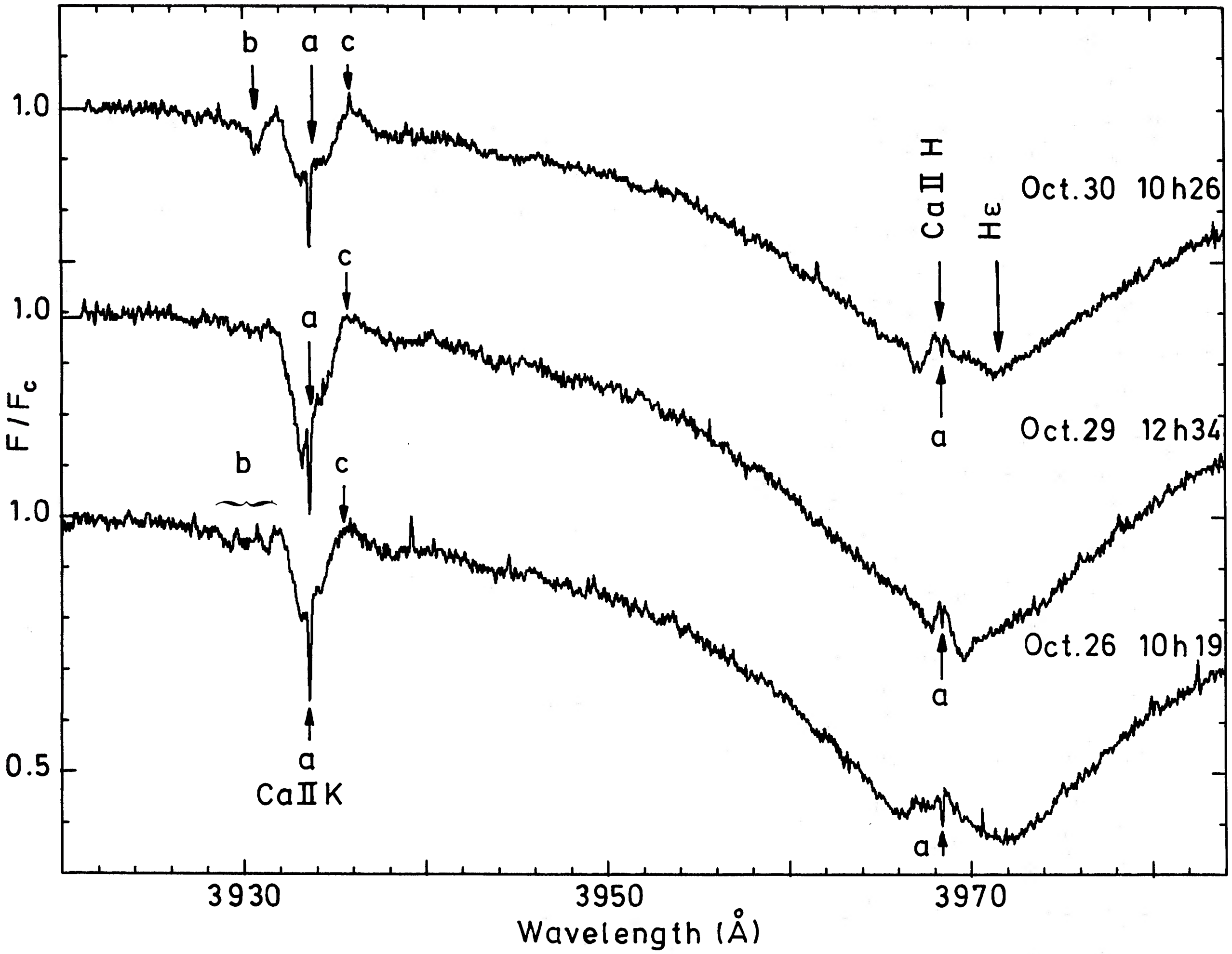

FIG. 1.—The three best CFHT spectra of the Ca II K, Ca II H, and Hε lines. The dates and universal times at midexposure are indicated. The spectra are in reduced units, and the wavelength scale is geocentric. (*a*) Interstellar component. (*b*) Blueshifted absorption components. (*c*) Redshifted emission.

TABLE 2

MEASURED PARAMETERS OF THE CFHT SPECTRA

		1982		
FEATURE	PARAMETER	Oct 26	Oct 29	Oct 30
Main Ca II K line absorption	W_λ (Å)	0.249	0.466	0.184
	FWHM (Å)	1.58	1.73	2.19
	F/F_c	0.83	0.73	0.89
	V_r (km s^{-1})	0	−4	+13
Redward Ca II K emission	W_λ (Å)	0.041	0.043	0.053
	FWHM (Å)	1.15	1.18	1.15
	F/F_c	1.04	1.04	1.05
	V_r (km s^{-1})	+189	+194	+192
Ca II K absorption components	W_λ (Å)	0.013, 0.013, 0.018	...	0.040
	FWHM (Å)	0.14, 0.24, 0.17	...	0.58
	F/F_c	0.97, 0.97, 0.96	...	0.94
	V_r (km s^{-1})	−170, −253, −330	...	−217
Ca II K core emission[a]	F/F_c	0.86	0.79	0.91
Ca II H core emission[a]	F/F_c	0.47	0.43	0.56
Hε at centerline[b]	F/F_c	0.40	0.37	0.51
Hε absorption component	V_r (km s^{-1})	−327	−196	−222

[a] Measured at the wavelength of the IS feature at the F/F_c level as if there were no IS absorption.

[b] Centerline found from reflecting the line profile around its bisector to achieve best match in the wing.

1986ApJ...308..791C

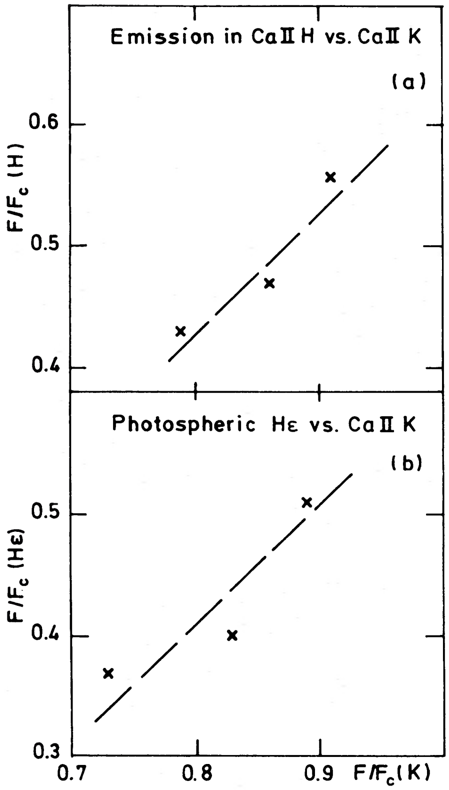

FIG. 2.—Residual intensity measurements in Ca II H and K and Hϵ for the three best CFHT spectra. (*a*) Comparison of the reduced intensity of the core emission component in Ca II H and Ca II K. The residuals are measured at the wavelength of the interstellar feature, ignoring the interstellar component itself; a smooth line has been drawn at the top of that feature in order to represent the stellar profile. (*b*) Photospheric Hϵ compared with Ca II K. The Hϵ residual was measured at the centerline determined by the best match of the Hϵ wings. The Ca II K residual corresponds to the deepest point in the K line absorption.

probably due to the Reticon temperature rise mentioned in § II, which could have begun at the end of the October 30 1026 UT exposure.

On all three CFHT spectra a redshifted emission feature is clearly visible. This feature is remarkably constant in strength and position. Individual measurements are given in Table 2. Such a feature was not present in another series of observations obtained in 1980 October (Praderie *et al.* 1982).

Three narrow blueshifted absorption components are present at Ca II K on 1982 October 26. The FWHM values are about 15 km s^{-1}, and the absorption is only about 3%–4% of the continuum, with equivalent widths of about 15 mÅ. These components have blueshifts of −170, −253, and −330 km s^{-1}. On that same spectrum, there is an absorption component at the highest Ca II K blueshift in the Hϵ profile. It has a V_r value of −327 km s^{-1} from the Hϵ centerline defined by matching the wings of the line. In the Hϵ profile, there is a hint of the middle component (−253 km s^{-1} at Ca II K) just shortward of the interstellar Ca II H narrow absorption in the Hϵ core. This is reminiscent of the 1980 October series, where on one night there was a strong blueshifted component appearing at Ca II K and in all the Balmer lines that were observed on those spectrograms.

The 1982 October 26 CFHT spectrum was taken simultaneously with two of the *IUE* spectra described in Paper I. We note that the maximum blueshift in the Ca II K components on this spectrum (−311 km s^{-1} in the heliocentric frame) is lower than the maximum blueshift in the Mg II resonance lines observed by *IUE* exactly at the same time (−450 km s^{-1} in the heliocentric frame). Since the Ca II K line is formed closer to the star than the blue edge of the Mg II lines (Catala *et al.* 1986), and since the problems of variability are overcome by the simultaneity of the observations, we have here a further proof that the wind of AB Aur is accelerated outward, at least up to the region where the blue edge of the Mg II lines is formed (> 5 stellar radii).

There are no obvious blueward absorption components at Ca II on October 29, but a single, stronger feature emerges on the October 30 spectrum. Its equivalent width of 40 mÅ is comparable to the sum of the three absorptions on October 26, as is its FWHM of 44 km s^{-1} similar to the sum of the earlier three. This feature has a velocity of −217 km s^{-1}, which is remarkably similar to that of the Hϵ component at −222 km s^{-1} on the same spectrum.

Finally, the amount of absorption in the main Ca II K feature and the Hϵ feature also seem to vary together, and both are weakest on the October 30 spectrum (Fig. 2*b*).

b) General Behavior of the Ca II K *Line*

In addition to the results described in the previous section, a great amount of information can be gained by the analysis of the long time series taken at both CFHT and OHP. Figure 3 gives a general view of the Ca II K line series, observed from October 26 to October 31. The three best CFHT spectra are presented in this figure. They correspond to three different nights. The OHP spectra have been added together on a one-night basis, so that each OHP spectrum displayed in Figure 3 represents an average over one night. The spectra are normalized to the continuum level. The difference in the Earth velocity with respect to the Sun, projected onto the line of sight, between the beginning and the end of the observation interval, is only 2 km s^{-1}. Several very interesting features appear on this figure.

The Ca II K line exhibits an asymmetric profile variable in several respects: intensity, shape, and position. The global position of the stellar line can be easily appreciated in Figure 3 thanks to the immobile IS component. Because of the low resolution and the low signal-to-noise ratio of the OHP spectra, this component does not appear clearly on some of them. The same type of Ca II K line variability in intensity, shape, and position was reported by Praderie *et al.* (1982), on the basis of five spectra obtained on five consecutive nights. We further note variations of larger amplitude on a longer time scale for the intensity in the line: the residual intensity at the bottom of the line was about 0.55 in 1980 October and about 0.85 in 1982 October.

The general behavior of the Ca II K line with time is better seen in Figure 4, which shows isointensity curves in the wavelength-time plane. The lower threshold has been taken as 0.89, i.e., the points where $F/F_c \leq 0.89$ are white in Figure 4. This threshold is the one leading to the most obvious contrast in the variations. The gaps in the observations are represented by white rows, but their real duration has not been taken into account. Figure 4 shows that the global position of the Ca II stellar line is moving back and forth in the geocentric frame all along the observation interval. We can also guess "by eye" a possible periodic behavior for this motion. However, it seems that the blue and the red boundaries of the line do not behave

1986ApJ...308..791C

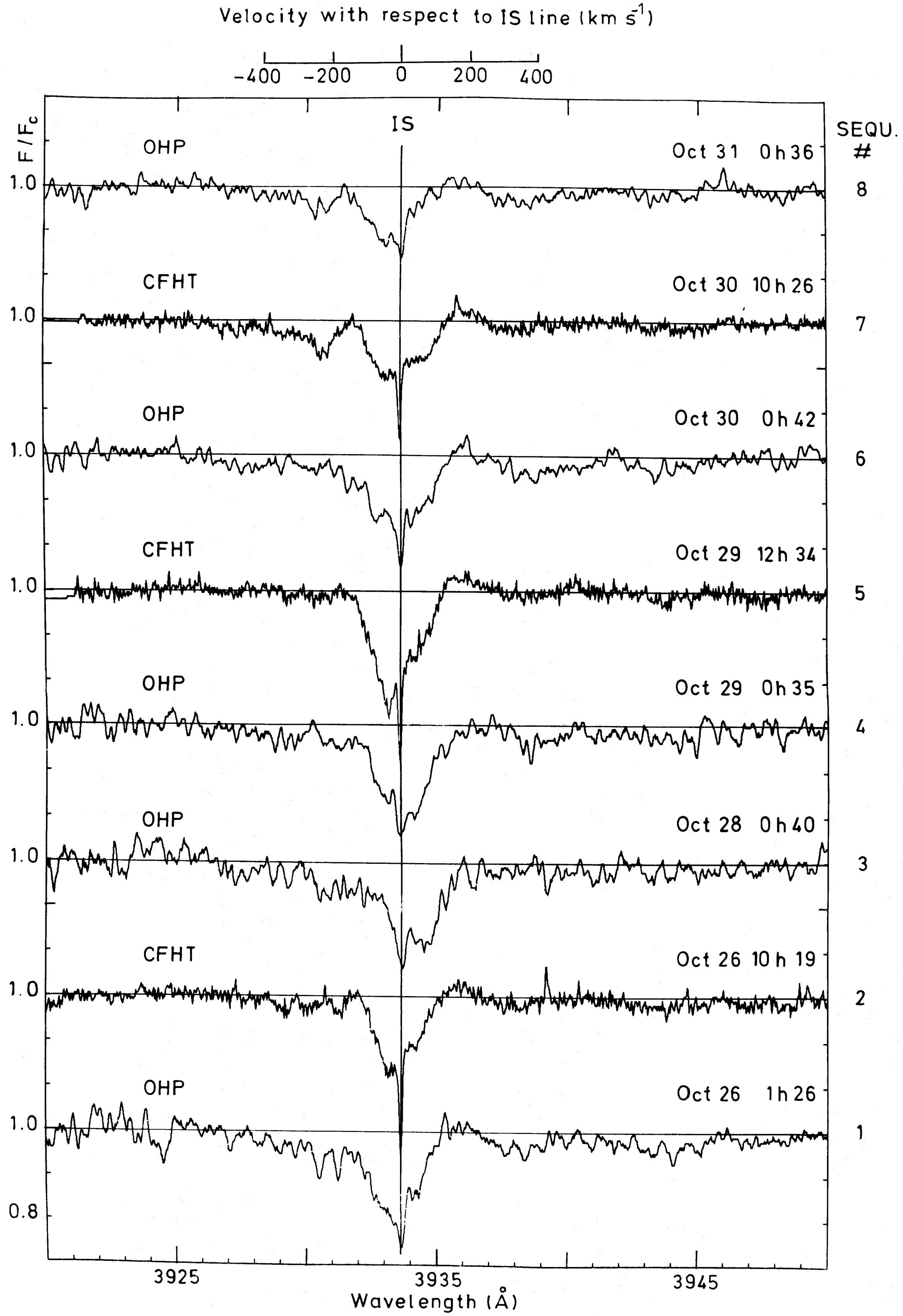

FIG. 3.—General view of the Ca II K line series. The OHP spectra have been co-added on a one-night basis. All the spectra are in reduced units, and the wavelength scale is geocentric. The date and universal time at midexposure are indicated for each spectrum. The interstellar component appears very clearly on the CFHT spectra. Note the asymmetry of the stellar line and its variations with respect to the interstellar component.

1986ApJ...308..791C

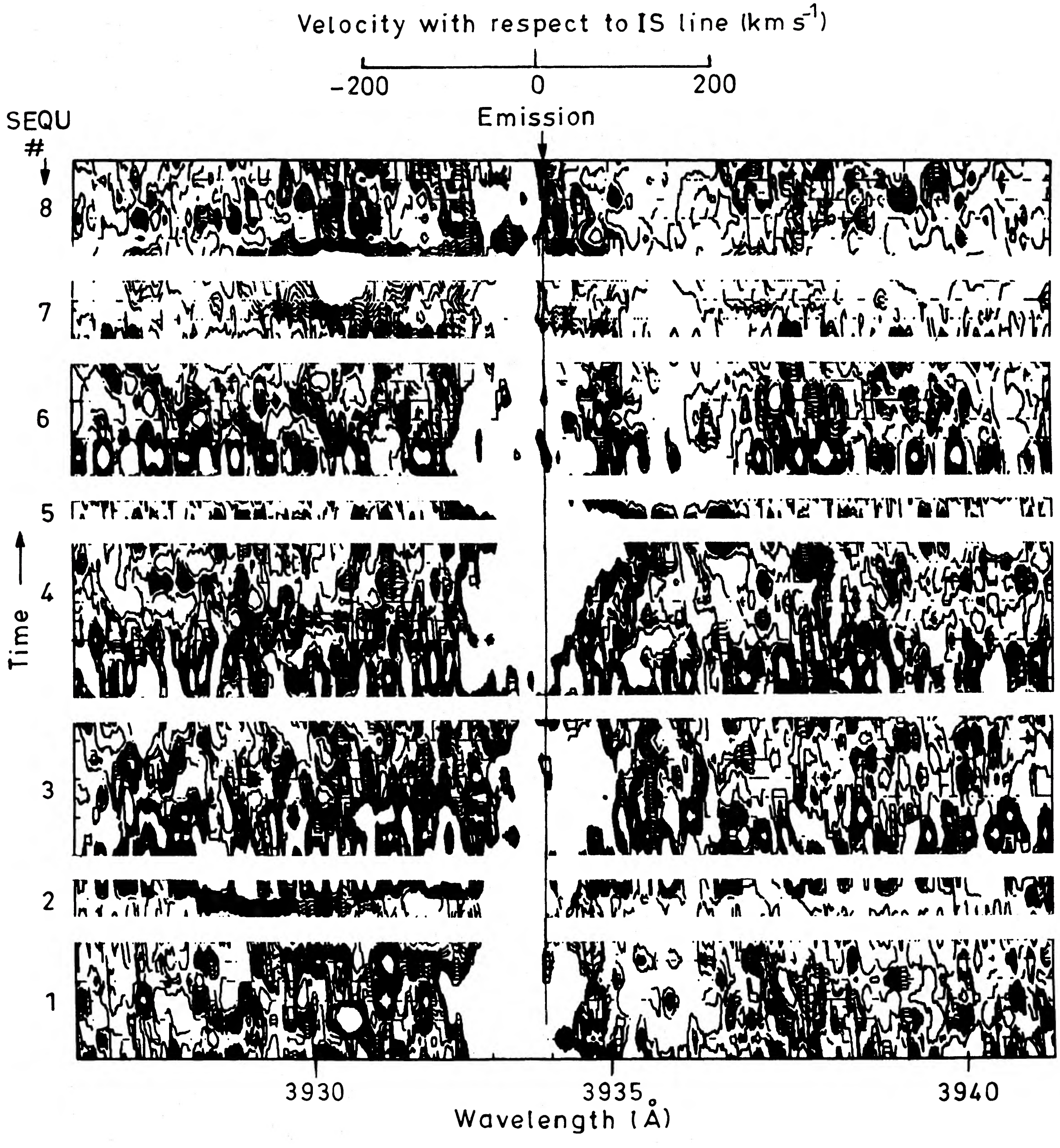

FIG. 4.—Time variation of the stellar Ca II K line. This figure represents isointensity curves in the wavelength-time plane. The lower threshold is 0.89, and the spectra are in reduced units. The wavelength scale is geocentric. On the time axis, no care has been taken to represent the real duration of the gaps between the observations. Note the striking variation of the stellar line, and its suggested periodicity. Note also the sporadic presence near the line core of an emission component, which does not seem to be affected by the general motion of the line.

exactly in the same way, i.e., that the line is not simply moving without changing shape. The variations of the blue and the red sides do not show the same characteristic. For example, between October 28 2002 UT and October 29 0348 UT (sequence 4), the blue side remains more or less at the same wavelength, while the red side is moving toward the red. This is not surprising, since the two sides are formed in different regions in the stellar atmosphere, because of the expansion. A more detailed analysis of these variations will be presented in § III*c*.

In addition to the blue absorption components appearing in the CFHT spectra described in § III*a*, one or several absorption components show up on some of the other spectra. These components are shown in Figure 5, where the corresponding individual spectra are displayed.

We also note the presence in 14 spectra of a small emission

1986ApJ...308..791C

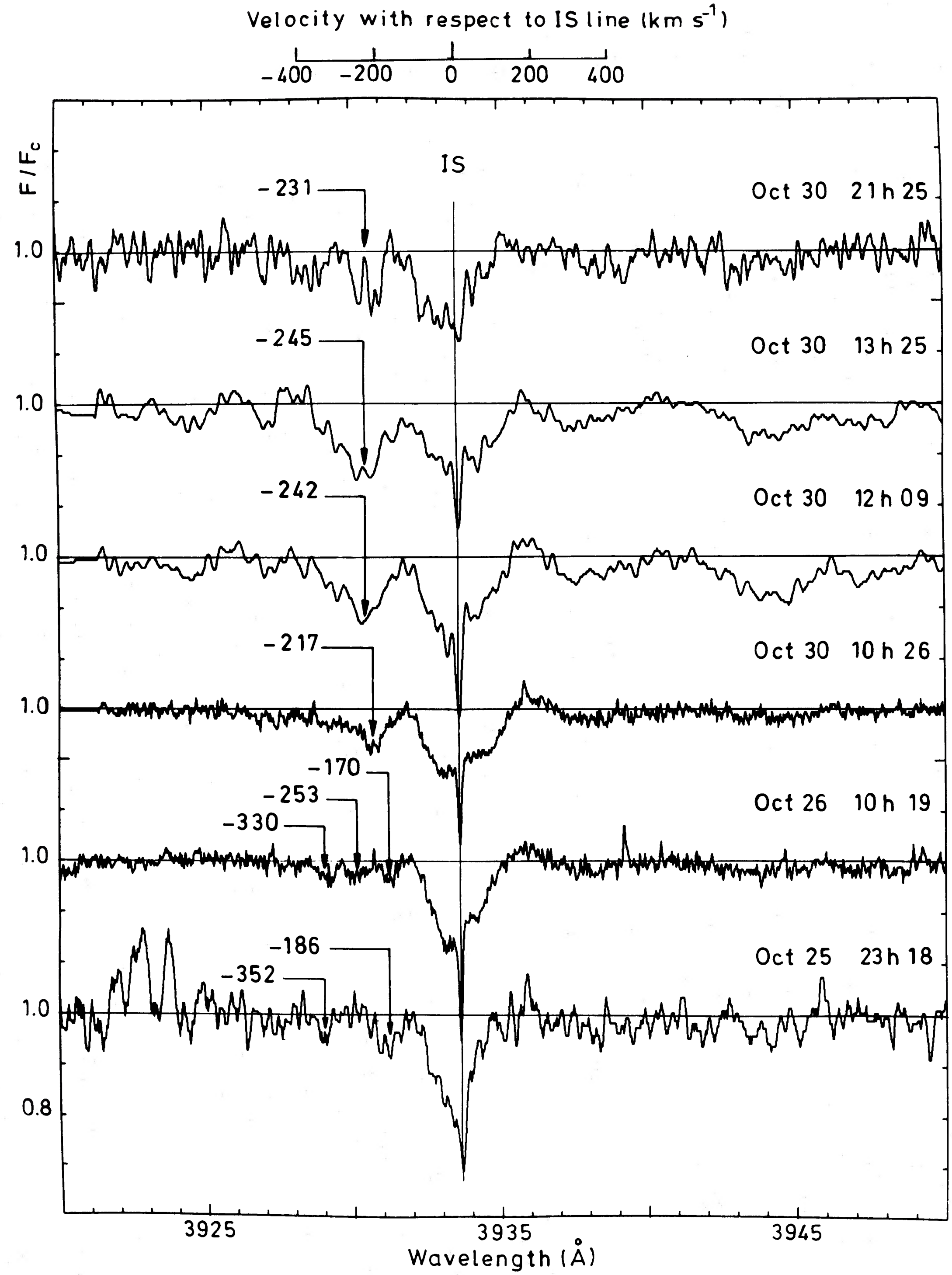

FIG. 5.—Individual spectra showing blueshifted absorption components. The spectra are in reduced units. The wavelength scale is geocentric, but the velocities indicated on the figure are with respect to the interstellar line.

component near the core of the stellar line, redshifted by 25 ± 4 km s^{-1} with respect to the interstellar component. This red emission component is easily seen in Figure 4. The striking feature is that it is not affected at all by the general motion of the stellar line: this emission component remains exactly at the same velocity all along the observation interval (to within 4 km s^{-1}). We have found no regularity in its appearance and disappearance. A similar emission component had also been noted in 1980 October by Praderie *et al.* (1982), but the latter was blueshifted. We will come back to the possible interpretation of this feature in § IV.

Finally, the red wing emission component described in § III*a*, located at about 190 km s^{-1}, appears in most of the spectra, always at the same velocity. We note that it appears in all the spectra with high signal-to-noise ratio and that the signal-to-noise ratio of some of the OHP spectra is too low for us to state unambiguously the absence or the presence of such a component. We are then tempted to say that it could be present at each time step in 1982 October. But clearly, further observations are needed to reinforce this conclusion.

c) Periodicity of the Ca II K *Line Variations*

Since Figure 4 suggests a possible periodic behavior of the data, we have carried out a quantitative treatment in order to extract a period, if there is one. This analysis has been performed over the whole set of individual spectra (39). We first had to choose a quantity characterizing the line at each time step. This quantity had to be sensitive to the variations that we can see in Figure 4. The residual intensity at the bottom of the line, for example, is a bad choice, because it is affected by the presence of the interstellar component, which is thought not to vary. Since the Ca II K line is probably formed at the base of the wind of AB Aur, the red boundary of the line can be affected by an emission component formed in the lateral parts of the envelope, possibly over a large solid angle. Thus, the red boundary of the line, formed in a region "integrating" the variations, is expected to show only smoothed variability. The blue boundary of the line is formed in the region of the atmosphere projected on the stellar disk. This region encompasses only a small solid angle, so it is expected to exhibit the most obvious variations. We have thus chosen to analyze in detail the blue boundary of the stellar line and have determined for each individual spectrum the wavelength in the blue wing of the line where the reduced intensity is 0.89 (this is the value corresponding to the lower threshold used in Fig. 4). This has given us a series of 39 values, $\lambda_b(t_i)$, for which we have carried out a Fourier analysis.

This analysis consisted of a deconvolution of the Fourier power spectrum of our data, $\lambda_b(t_i)$ with the Fourier power spectrum of the observation window (a function equal to unity when observations are available and to zero when they are not). The deconvolution was performed by an overrelaxed iterative procedure imposing at each step the positiveness of the resulting function. This method of deconvolution has been adapted by L. Celnikier (1985, private communication) from Jansson (1970), Jansson, Hunt, and Plyler (1970), and Schafer, Mersereau, and Richards (1981). The result of these computations is shown in Figure 6. A peak, corresponding to a period of 32 hours, clearly comes out from the noise. The error of ±8 hours on the period has been derived from the theoretical error in the frequency corresponding to the finiteness of the observation interval. This 32 hour peak also appears as the most intense one in the Fourier power spectrum of our data before deconvolution, and does not appear in the Fourier power spectrum of the observation window. The other peaks in the deconvolved power spectrum correspond to periods of 63, 13, and 10 hours. Although the 13 and 10 hour peaks are not very intense, they might correspond to a real behavior of the Ca II K line. However, they are very close to the 12 hour period obviously present in the observation window, and therefore highly suspect. As to the 63 hour peak, taking into account the fact that the total span of the monitoring was only about twice this value, and given the important noise in our data, we believe it not to be of stellar origin.

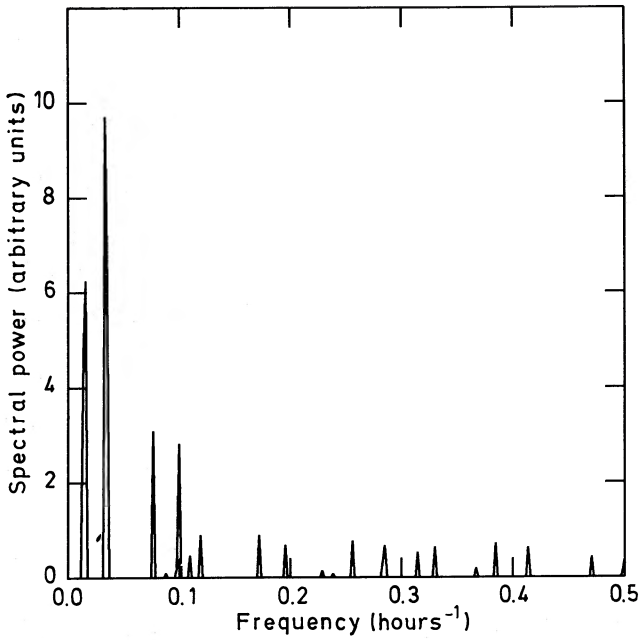

FIG. 6.—Power spectrum of the data $\lambda_b(t)$ (see text for a description of the analysis procedure). The highest peak corresponds to a period of 32 ± 8 hours.

In order to test the significance of this result, we have verified that mixing the observation dates and times in a random way within the observation window led to nothing but noise after the Fourier transform and the deconvolution. We have also verified that this procedure could properly recover the period of a sine wave function replacing the data within the observation window.

However, since the period found corresponds to a very low frequency, there is a risk that our Fourier power spectrum might be affected by aliasing problems. Therefore, we have also applied to our data $\lambda_b(t_i)$ the analysis used in the treatment of the Mg II lines in Paper I: we have fitted the data with a sine wave function of a given period, with the amplitude and the phase as parameters, and let the period vary. For each fit, we have computed the residual $R = \sum [\lambda_b(t_i) - F(t_i)]^2 / \sum \lambda_b^2(t_i)$, where the $F(t_i)$ are the values of the fitting function at the points t_i. A plot of these residuals R as a function of the period is shown in Figure 7. There is a clear minimum of R around the 32 hour period which has been found independently from the Fourier analysis. The position and the width of this minimum yield a period $P = 32 \pm 4$ hours, the error of ±4 hours being derived from the width of the minimum. Note that the two methods (Fourier transform and fitting) are different, and that it is not surprising that the errors in the period found by the two methods are not the same. We note that in neither of the two analyses is there any indication of the 45 hour period found in Paper I for the Mg II data. Figure 8 displays the result of the fitting for $P = 32$ hours.

As a very final test, we have applied the Fourier analysis described above to the difference between the data $\lambda_b(t_i)$ and the values of the sine wave function giving the best fit. As expected, the result no longer shows the peak at 32 hours. The close agreement of the results obtained by two independent methods proves beyond any doubt that the 32 hour modulation period of the Ca II K line is a real, stellar phenomenon.

IV. DISCUSSION: A NONSPHERICALLY SYMMETRIC MODEL WITH DIFFERENTIAL ROTATION

a) Periodic Variation of the Stellar Line

One explanation that could be given for the periodic variation of the Ca II K stellar line would be that AB Aur is a

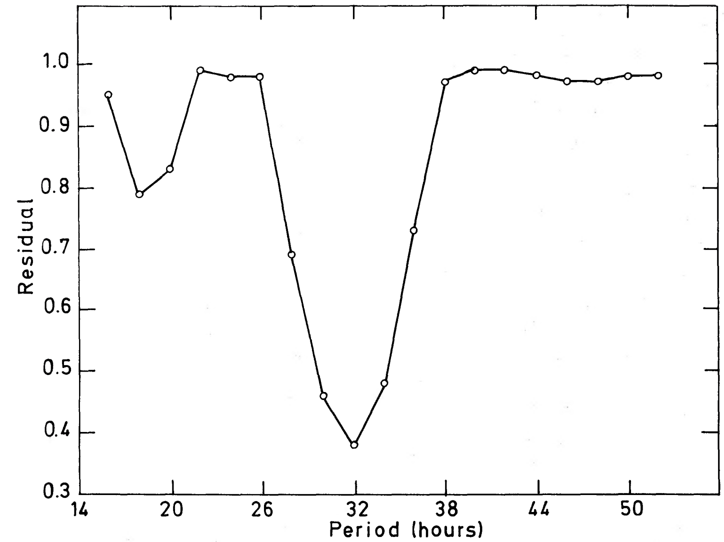

FIG. 7.—Residual of the sine wave fitting of the observed set of data $\lambda_b(t)$ for 1982 October plotted against period P

member of a binary system, and that the motion of the line corresponds to variations of the radial velocity of the star. However, Finkenzeller (1983) analyzed the system velocity of the star (computed from the Balmer lines) at different dates and did not find any change of more than ±10 km s^{-1}. Since the amplitude of the variations of the Ca II stellar line is higher (±20 km s^{-1}; see Fig. 8), and since 21 of the 39 points of our data lie outside ±10 km s^{-1} around the mean value, we can discard this explanation.

The second possible cause of such a periodic variation is the star's rotation. Estimates of the projected rotational velocity of AB Aur can be found in the literature. Davis, Strom, and Strom (1983) give 75 km s^{-1} from the Mg II λ4481 line, which corresponds to a period $P = 48 \sin i$ hours, assuming a stellar radius of 3 $R_\odot$. However, using the Mg II λ4481 and the He I λλ4388, 4471 lines, Finkenzeller (1985) finds a value of 140 ± 30 km s^{-1}, quite different from the previous one, and does not try to explain this discrepancy. In any case, the 32 hour period which we have found from our data is not too different from what is expected for the photospheric rotational period of AB Aur. The periodic variation of the Ca II stellar line could then be interpreted as a rotational modulation, as has been done in Paper I for the periodic behavior of the Mg II lines. The model proposed in Paper I is an alternation along the line of sight of slow and fast streams, similar to the streams observed in the solar wind. The same kind of model has also been proposed to explain several features observed in hot stars, hybrid stars, and cool supergiants (Mullan 1984). Such a model could be considered for the explanation of the 32 hour period observed in the Ca II K line, but we must carefully investigate all the implications of our results on this model. These implications are surveyed in the following sections of this paper. However, it is clear that at the present state, this model is only tentative and that additional quantitative analysis as well as further observations are needed to test several qualitative interpretations presented below.

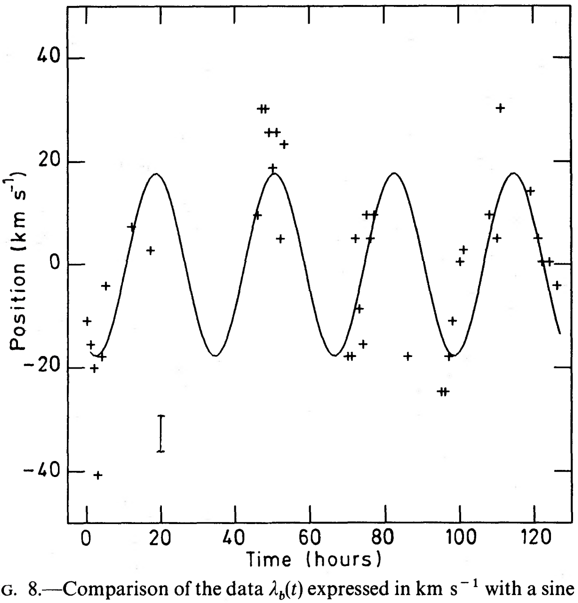

FIG. 8.—Comparison of the data $\lambda_b(t)$ expressed in km s^{-1} with a sine curve of 32 hour period. The average accuracy of the positions (taking the noise of the spectra into account) is given.

b) Stream Structure in the Stellar Wind

The variations of the Mg II resonance lines analyzed in Paper I have led to a qualitative model wherein these lines are modulated by the rotation of a stream structure originating from the inhomogeneous base of the wind. The observation of the Ca II K modulation, and most of all the difference between the 45 hour period in the Mg II data and the 32 hour period in the Ca II K data, allow us to take a second step in the building up of this qualitative model. In the following, we discuss this period difference and refine our view of the inhomogeneous wind of AB Aur. However, the model presented in Paper I and refined in the present paper remains qualitative.

The difference between the two periods is puzzling, because the stream structure must be rotating at the same angular velocity as the star itself, up to the distance where the streams merge. We must keep it very clear that the rotation of this stream structure is not a mass motion, but a kind of density wave rotating at the angular velocity of the stellar photosphere. As a consequence, any line formed in the region where the stream structure is stable should be modulated with the period of rotation of the stellar photosphere.

A first possibility to explain the period difference between the Mg II and Ca II data is to consider that the stream structure is not stationary. The nonstationarity of this structure would result in a distortion of the streams, which could lead to different apparent periods for lines formed in different regions of the wind, or observed at different times. The similarity of the periods found from the Mg II data of 1982 October and 1984 November (Paper I) argues against this explanation. However, the period of the 1982 October data is less well determined, because the observation spanned only one cycle. Therefore this explanation cannot be so simply discarded.

A second possibility is that the blue edges of the Mg II resonance lines form in a region where the streams have already merged, whereas the Ca II K line forms inside the stream structure. Let us first discuss the regions of formation of the two lines.

Line computations in spherically symmetric models are a good tool for determining the regions of formation of the lines. Catala, Kunasz, and Praderie (1984) have shown that the Mg II resonance lines of AB Aur are formed over a very extended region, from the photosphere up to radial distance $r = 50R_*$, where R_* is the stellar radius. However, their study and the one of Catala (1984) show that the blue edges of these lines, whose velocity has been denoted V_s(Mg II) in Paper I, form at more than $5R_*$. The 45 hour period derived in Paper I for V_s(Mg II) then has its origin in a region of the envelope relatively far from the stellar surface.

No detailed computation of the Ca II K line has yet been performed for that kind of envelope, but Catala *et al.* (1986) have shown that it is very likely to form in a more compact region, at the base of the wind. We then conclude that the 32 hour period derived from the Ca II data corresponds to a phenomenon occurring very close to the stellar surface. We should note at this point that the correlation found between the behavior of the Ca II and K lines and the Hϵ line cores (§ III*a*) indicates that these three line cores are formed in the same region of the star's envelope.

Since the regions of formation of the Mg II and the Ca II lines are different, it is possible that the Ca II K line is formed in the part of the wind where the stream structure is stable, while the Mg II lines are formed in the region where the streams have merged. In this case, the Ca II K line is modulated by the rotation of the structure (which is not a mass motion), i.e., with the period of rotation of the star, and V_s(Mg II) is modulated with the period of rotation of the envelope (which is a mass motion) at the distance of formation of the blue edges of the Mg II lines. Let us examine this second possibility in more detail.

First of all, we must wonder whether the streams can merge before the region of formation of the blue edges of the Mg II resonance lines. Following Mullan (1984), we can write that the structures begin to merge when the fast streams overtake their adjacent slow streams. Mullan (1984) has estimated the distance to these corotating interaction regions (CIRs) by assuming that the longitudinal dependence of the velocity at the base of a fast stream is a linear ramp. If we replace this assumption by a more general one involving a power-law dependence on the longitude ϕ, we can write

$$V_f(\phi) = V_0 + \frac{(V_{\rm max} - V_0)}{W}\,\phi^n\,, \tag{1}$$

where $V_f(\phi)$ is the velocity of the fast stream at longitude ϕ, V_0 the velocity of the adjacent slow stream, $V_{\rm max}$ the maximum velocity in the fast stream, W the longitudinal half-width of the fast stream, and n an exponent describing the longitudinal dependence of the velocity within the fast stream. We can calculate the distance r_i to the CIR, i.e., the region where the fast stream begins to overtake the slow one. We find

$$\begin{aligned} r_i &= R_* && \text{if } n < 1\,,\\ r_i &= R_*\left[1 + W\left(\frac{V_0}{V_{\rm rot}}\right)\left(\frac{V_0}{V_{\rm max} - V_0}\right)\right] && \text{if } n = 1\,,\\ r_i &= R_*\left\{1 + \frac{n}{n-1}\,W\left(\frac{V_0}{V_{\rm rot}}\right)\left[\frac{(n-1)V_0}{V_{\rm max} - V_0}\right]^{1/n}\right\} && \text{if } n > 1\,, \end{aligned} \tag{2}$$

where $V_{\rm rot}$ and R_* are respectively the rotation velocity and the radius of the star. These results show that the interaction regions can occur very close to the stellar surface. Assuming, for example, that $W = 10°$, and taking $V_0 = 300$ km s^{-1}, $V_{\rm max} - V_0 = 150$ km s^{-1}, $V_{\rm rot} = 100$ km s^{-1} (velocities consistent with Mg II data), we find that the maximum value for r_i (obtained for $n = 2$) is $2.5R_*$. Note that if the velocity rises sharply near the boundaries of the fast streams ($n < 1$), the CIRs start at the star's surface.

In the solar wind, a pair of forward and reverse shocks form at the beginning of the CIR and erode them (Burlaga 1984). We can easily extrapolate this phenomenon to the case of the wind of AB Aur. In order to obtain a crude estimate of the radial size of the CIRs, and to find the distance at which the streams have completely merged, we can write that the shocks are likely to destroy the structures after the time necessary for the sound to cross the interaction region, i.e., $t = r_i W/c_s$, where c_s is the sound velocity. Here we have assumed that the longitudinal width of a stream is the same all over the envelope. During that time, the wind has traveled a distance $r = V_{\rm exp}\,t$, where $V_{\rm exp}$ is the "mean" expansion velocity of the wind. The structure can then be destroyed at small distances from the star's surface if the longitudinal width of the streams is small and if the interaction regions start close to the stellar surface. By assuming, for example, that $r_i = R_*$ (which occurs if the longitudinal dependence of the velocity is very sharp at the boundary between fast and slow streams), a full width of 10° for the fast streams, a sound velocity of 10 km s^{-1} (corresponding to a temperature of 10,000 K), and a "mean" velocity in the stream of 450 km s^{-1}, we find that the streams have merged within $4R_*$, which is definitely closer to the star than the region where the variations of V_s(Mg II) originate. Even after the streams have merged, we can imagine the existence of longitudinal inhomogeneities in radial velocity, produced by the inhomogeneous feeding of the medium by the streams themselves, which could last for several stellar radii before being swept off by the differential rotation of the envelope. We can then interpret the modulation of the Mg II data as due to the rotation of these inhomogeneities, whereas the Ca II K line is modulated by the rotation of the stream structure in the inner region. The period of modulation of the Mg II data (45 hours) would then be the period of rotation of the envelope itself at $5R_*$, and the period of modulation of the Ca II data (32 hours) would be the period of rotation of the stream structure, equal to the photospheric rotation period of the star. The relatively small difference between the rotation at the star's surface and at $5R_*$ shows that the radial dependence of the rotation angular velocity in the envelope is indeed not very strong, so that the inhomogeneities modulating the Mg II lines can survive up to rather great distances. As a conclusion, if we accept this point of view, we must envisage that besides the rotation of the stream structure, the envelope itself is rotating, with a rotation angular velocity decreasing with increasing distance. The difference between the 32 hour period of the Ca II data and the 45 hour period of the Mg II data gives a rough measure of the radial dependence of the rotation in the envelope of AB Aur. Hence, the analysis of our Ca II K series has made more precise the qualitative model proposed in Paper I. However, the link between the different regions of the wind is still to be investigated from a theoretical point of view. In particular, it is not clear where pressure waves without streams, like those observed in the solar wind (Burlaga 1983, 1984), which have been considered in Paper I to explain the behavior of the Fe II lines, become the preponderant feature in the wind.

Given these values of the angular velocities (corresponding to a period of 32 hours at the photosphere and of 45 hours at 5 stellar radii), we notice that the rotational velocity $V_{\rm rot}$ increases with radial distance at least near the base of the envelope. From the 45 hour period, we find that the rotational velocity at $5R_*$ is about 300 km s^{-1}. This high value of the rotational velocity could explain the existence of a type III P Cygni profile for the Hα line of this star (Mihalas and Conti 1980; Catala *et al.* 1986).

If we keep following the analogy between the wind of AB Aur and the solar wind, the existence of a stream structure in its wind suggests the presence of a magnetic field at the surface of AB Aur. The latter must force the base of the envelope to corotate up to the Alfvén radius (the radius at which the flow velocity equals the Alfvén velocity). It is possible to derive from our data a rough upper limit for the magnetic field in the envelope of AB Aur. We first note that because the angular velocity of the envelope at $5R_*$ is lower than the angular velocity at the stellar surface, the flow velocity must become greater than the Alfvén velocity at a distance which is less than $5R_*$. Then, the Alfvén velocity is smaller than V_s(Mg II), which yields

$$B^2 \leq \dot{M} V_s(\text{Mg II})/r_{\rm A}^2 \,, \tag{3}$$

and, since $r_{\rm A} \geq R_*$,

$$B^2 \leq \dot{M} V_s(\text{Mg II})/R_*^2 \,. \tag{4}$$

Taking 10^{-7} $M_\odot$ yr^{-1} as a comfortable upper limit for $\dot{M}$ (Catala, Kunasz, and Praderie 1984), V_s(Mg II) = 450 km s^{-1}, and $R_* = 3.0\ R_\odot$, we find $B \leq 80$ G.

If we assume further that beyond the Alfvén radius the envelope rotates with a Keplerian rotation velocity, and again that the variations of the Mg II lines originate at $5R_*$ we obtain an estimate of the Alfvén radius $r_{\rm A}$ from the 45 hour period. We find $r_{\rm A} = 3.8R_*$. However, it is very likely that the kinematic viscosity and the magnetic field itself, even beyond the Alfvén radius, produce a speeding up of the rotation velocity with respect to a pure Keplerian law. Therefore, our estimate of the Alfvén radius is only an upper limit. However, we must keep in mind that the existence of a magnetic field at the surface of AB Aur is not definitely established, but only suggested by an analogy with the solar wind.

The upper limit for the Alfvén radius can lead to an upper limit for the angular-momentum loss in the envelope of AB Aur. The angular-momentum loss indeed can be estimated as

$$\dot{J} \sim \dot{M} r_{\rm A}^2 \Omega \,, \tag{5}$$

where Ω is the angular velocity at the Alfvén radius. If we take the same upper limit for $\dot{M}$ as previously (10^{-7} $M_\odot$ yr^{-1}), and $\Omega = 5 \times 10^{-5}$ radians s^{-1} (corresponding to a 32 hour period), we find $\dot{J} \leq 10^{38}$ g cm^2 s^{-2}. An estimate of the angular momentum of the star is given by

$$J \sim M R_*^2 \Omega \,, \tag{6}$$

where M is the stellar mass and R_* the photospheric radius. Assuming a stellar mass of 2.5 $M_\odot$, we find $J \sim 10^{52}$ g cm^2 s^{-1}. In order to estimate the effect of the angular momentum loss on the evolution of the star, we may compare J and $\dot{J}\tau$, where τ is the estimated age of the star, which is 10^6 years (Cohen and Kuhi 1979). We find that the corresponding upper limit $\dot{J}\tau \leq 10^{51}$ g cm^2 s^{-1} is not very different from J, which shows that the angular-momentum loss might play a decisive role in the evolution of the star.

An important question is raised by the relatively small amplitude of the Ca II variations ($\sim \pm 20$ km s^{-1}), when compared with the one of the Mg II variations ($\sim \pm 45$ km s^{-1} in 1982 and ± 70 km s^{-1} in 1984). This is difficult to understand in the framework of Mullan's (1984) model. If the Mg II variations originate beyond the beginning of the CIR, in a region where the streams have merged, the amplitude of the Mg II variations is necessarily smaller than the real velocity difference between fast and slow streams. Since the Ca II K line is formed closer to the star than the Mg II resonance lines, the amplitude of the Ca II variations should be at least equal to that of the Mg II variations, if the velocity difference between fast and slow streams was constant along with radial distance. Our observations then suggest that such is not the case, and that there must exist an important gradient of velocity difference between fast and slow streams (difference increasing with r), as well as a gradient of velocity within a single stream.

Finally, since the Ca II K line is formed close to the star surface, inside the stream structure, the 32 hour period that we have found is equal to the star's photospheric rotation period. It is then possible to give a rough estimate of the inclination angle of the rotation axis of the star with respect to the line of sight toward the Earth. If we assume again $R_* = 3.0\ R_\odot$ and if we adopt the value $v \sin i = 75$ km s^{-1} (Davis, Strom, and Strom 1983), we find $i = 41° \pm 6°$. If the value of Finkenzeller (1985) is adopted ($v \sin i = 140 \pm 30$ km s^{-1}), we find $i = 73° \pm 17°$.

c) *Blueshifted Absorption Components*

We have seen in §§ III*a* and III*b* that one or several discrete blueshifted absorption components appear in some of our Ca II spectra. What is the origin of these components?

One interpretation involves sporadic outbursts in the wind. In order to explain the high velocity of the observed components, we can envisage the occurrence of "puffs" in some of the streams, that is to say, strong enhancements of the wind density at the base of the streams, with short durations, which then travel through the envelope. Because of this high density, components could be formed in these particular streams at greater distances than the rest of the Ca II K line, and therefore at a higher velocity. The density enhancements would cross the region of formation of the Ca II K line in 2 or 3 hours: for example, at a velocity of 350 km s^{-1} (corresponding to the bluest component seen in Fig. 5), the wind travels more than 2 R_* during that time, which we believe can correspond to the size of the region of formation of the Ca II K line in presence of an enhanced density (its size in "normal" condition is likely to be smaller than this). Since the exposure times we have used are not very small compared with the time required for such density enhancements to cross the line formation region, and since there must exist a velocity gradient at the base of the wind, the components are likely to change their velocity during the exposure, which would explain the important width of some of them. An outburst has also been suggested in Paper I to explain a "flarelike" phenomenon seen in the Mg II lines.

However, two major difficulties arise with this interpretation. First, in order to understand the presence of several components on the same spectrum, we must imagine several outbursts very close in time within the same stream, or in different streams very close to one another. Such a situation could seem unlikely. Second, we should see from time to time components formed at the very base of the wind, therefore at very low velocities. They should then appear "inside" the stellar line, and this is not observed for the Ca II K line. One way to prevent their existence is to envisage a very strong velocity gradient at the base of the streams where the outbursts occur (which is almost equivalent to saying that the bursts themselves start at large ejection velocities), followed by a region of low velocity gradient. The outburst material would then spend very little time at low velocities, and we would see them only at high velocities. Another way to prevent the existence of components "inside" the Ca II K stellar line is to assume that the physical conditions at the base of the outbursts (temperature, density) are too different from those of the average medium for the Ca II K line to be formed.

Another interpretation of these absorption components involves the CIRs discussed in § IV*b*. Mullan (1984) has proposed that the narrow components observed in hot stars could be formed in the CIRs. Such an explanation could apply in our case. It is well known that the CIRs of the solar wind are bounded by a pair of forward and reverse shocks, that there is a broad velocity plateau between the shocks, and that the density can be considerably higher (5 times) in the CIRs than in the "average" wind (Burlaga 1983, 1984). If these CIRs are located beyond the region of formation of the stellar line, they could give rise to high-velocity absorption components, because of their high density. Since the radial distance at which a CIR begins depends on the velocity differential between fast and slow streams (see eq. [2]), and since we can imagine the existence of several fast streams of different velocities close to one another, there could exist several CIRs at different radial distances along the same line of sight. This could explain why we happened to observe several components on the same spectrum.

In this interpretation, the component should appear and disappear periodically, with the star rotation period, because the CIRs rotate at the same angular density as the star. Although our data are not sufficient to show such a periodic behavior, we note that there are exactly three rotational cycles between the spectrum of October 26 1019 UT, showing three absorption components, and the spectrum of October 30 1026 UT, exhibiting a single absorption component whose equivalent width and FWHM are the sum of the three absorption components in the October 26 spectrum, as if these three components had merged into one single component after 3 cycles. Since this absorption component still appears on the two following spectra, the passage of the corresponding CIR on the line of sight would have lasted for at least 3 hours, showing that its longitudinal extent should have been at least 25°. Here again, further observations are needed to analyze this interesting phenomenon.

d) The Sporadic Core Emission Component

The emission component appearing from time to time near the line core, without apparent regularity, is very puzzling. This emission component is without a doubt the sign of enhanced chromospheric activity, occurring very close to the photosphere. The sporadic and nonperiodic appearance, always at the same wavelength, of this emission component formed close to a rotating star, can be explained only by the existence of an intermittent phenomenon near the visible pole of the star, which is the only region of the stellar surface not affected by the rotation. In our 1982 October series, this component is redshifted, so it must be associated with sporadic accretion on to the stellar pole. This interesting feature then shows that, besides the longitudinal departures from spherical symmetry, which we can see from the rotational modulation of different lines, the atmosphere of AB Aur is also asymmetric in the latitudinal direction. A more detailed observational study of the time behavior of such a component would be of great interest. Moreover, an accretion of matter onto the stellar pole must lead to a shock at the stellar surface, and we can expect an X-ray emission from this shock. Assuming that the density at the stellar photosphere is 10^{-9} g cm^{-3} (typical for an A0 V star) and that most of the energy dissipated in the shock is used in the X-ray emission, and using the velocity of the core emission component with respect to the IS line as an estimate of the projected velocity of the infalling matter, we find that the corresponding X-ray luminosity is $L_X = \alpha \times 2.3 \times 10^{33}/\cos^2 i$ ergs s^{-1}, where α is the fraction of the stellar surface fed by the accretion. Our knowledge of the inclination angle i is poor, because of the poor determination of $v \sin i$. However, we have seen in § IV*b* that $35° \leq i \leq 90°$, so $L_X \geq \alpha \times 10^{33}$ ergs s^{-1}. The value of α is unknown, but reasonable values around 0.1–0.01 would definitely ensure detectability by the *Einstein* satellite. Feigelson and DeCampli (1981) give an upper limit of 3×10^{29} ergs s^{-1} for the soft X-ray luminosity of AB Aur. Sanders, Cassinelli, and Anderson (1982) also report nondetection of AB Aur's X-ray emission. These nondetections could be due to the sporadic aspect of the described phenomenon. In this context, an X-ray monitoring of this star, simultaneous with a monitoring of the Ca II K line, would be very useful.

e) The Red Wing Emission Component

As already stated, a broad and redward displaced emission component appears on most of our spectra and is possibly present in all of them. This red emission was not present in the 1980 October series (Praderie *et al.* 1982). This component could indicate high-velocity infalling material, but it could also simply be formed in the lateral parts of the Ca II K formation region. Catala, Kunasz, and Praderie (1984) indeed have shown that the emission part of a P Cygni profile must be redshifted if the line is optically thick. The amount of this redshift depends mainly on the broadening of the intrinsic line profile. The constancy of the position of this component (§§ III*a* and III*b*) would then indicate that this broadening does not vary at this time scale. Let us recall here that this broadening can be attributed to turbulent motions or to disorganized motions on small spatial scales (Catala, Kunasz, and Praderie 1984; Catala *et al.* 1986; Catala 1984). However, in the absence of a detailed computation of Ca II lines with spherically symmetric models, it is not possible to say whether such an explanation makes sense. In particular, it has to be shown that the extent of the region of formation of the Ca II K line is large enough to give rise to the observed emission component.

V. SUMMARY AND CONCLUSION

The basic results presented in this paper can be summarized as follows:

The Ca II K line of AB Aur presents a periodic behavior over 5 days in 1982 October, with a period of 32 hours. We propose to explain this behavior by a rotational modulation of the line. Besides this general behavior, absorption and emission components appear from time to time.

The periodicity of the stellar Ca II K line confirms the model proposed in Paper I from Mg II resonance line observations, consisting of an alternation of fast and slow streams in the wind of AB Aur. There is a clear difference between the 32 hour period derived from the Ca II data and the 45 hour period derived in Paper I from the Mg II resonance lines. This difference can be explained either by a nonstationary stream structure or by a model in which the Mg II variations originate in a region where the streams have merged, whereas the Ca II K line forms inside the stream structure. In the second model, the Mg II lines are modulated by the rotation of the envelope itself (which is a mass motion) and the Ca II K line is modulated by the rotation of the stream structure (which is not a mass motion). In the framework of this model, we are able to estimate the radial dependence of the rotation in the envelope. This would be the first evidence for a differential rotation observed in an expanding envelope.

We propose to interpret the blueshifted absorption components appearing on some of the spectra as due to sporadic outbursts, or to the presence of "corotating interaction regions," as has been proposed for the blueshifted components in hot stars (Mullan 1984). The core emission component can be explained by sporadic accretion onto the stellar pole.

The model presented in Paper I and refined in the present paper is still very qualitative; its exploration on a more quantitative basis is totally beyond the scope of the present paper.

Since in the solar wind the alternation of fast and slow streams is a consequence of the magnetic structure at the surface of the Sun, all the results presented in Paper I and in the present paper might also indicate the presence of magnetic fields in AB Aur. The study of spectral line variability would then appear as a very important step in the investigation of magnetic fields in PMS stars.

We can then speculate that there might be a relationship between the rotation and the existence of a magnetic field, such as is expected if the magnetic field is generated by a dynamo effect. Our knowledge of convection zones in PMS stars is too poor to allow us to speculate theoretically on the efficiency of the dynamo effect in such stars. The very existence of activity phenomena in PMS A stars might be an indirect indication of the presence of convection zones quite different from those of main-sequence A stars. An answer to this question would be found if we could observe the same kind of rotational modulation in other Herbig Ae stars. For example, a correlation between the level of activity or variability and the rotation velocity could be searched for. Such a correlation would tell us whether the magnetic field is of dynamo origin.

We are very grateful to F. Praderie, who assumed a leadership role in this program of observations. We acknowledge fruitful discussions with L. Celnikier, A. Mangeney, F. Praderie, T. Simon, and J. L. Steinberg. Special thanks are due to L. Celnikier and A. Mangeney for their help concerning the Fourier analysis of our data. This work is part of a joint effort to understand the variability of AB Aur, and we thank the people who participated in the 1982 October campaign: J. M. le Contel, P. Morel, F. Praderie, J. P. Sareyan, T. Simon, and J. C. Valtier. We are grateful to R. J. Lavery and to the staffs of CFHT and OHP for their assistance during the observations. Part of the work in Hawaii was supported by NSF grant AST82-16192 to A. M. B.

REFERENCES

Boesgaard, A. M. 1984, *A.J.*, **89**, 1635.
Boesgaard, A. M., and Tripicco, M. J. 1986, *Ap. J.*, **303**, 724.
Burlaga, L. F. 1983, *J. Geophys. Res.*, **88**, 6085.
———. 1984, *Space Sci. Rev.*, **39**, 255.
Catala, C. 1984, in *Proc. Fourth European IUE Conf.* (Rome) (ESA SP 218), p. 227.
Catala, C., Czarny, J., Felenbok, P., and Praderie, F. 1986, *Astr. Ap.*, **154**, 103.
Catala, C., and Kunasz, P. B. 1986, in preparation.
Catala, C., Kunasz, P. B., and Praderie, F. 1984, *Astr. Ap.*, **134**, 402.
Catala, C., and Talavera, A. 1984, *Astr. Ap.*, **140**, 421.
Cohen, M., and Kuhi, L. V. 1979, *Ap. J. Suppl.*, **41**, 743.
Davis, R., Strom, K. M., and Strom, S. E. 1983, *A.J.*, **88**, 1644.
Feigelson, E. D., and DeCampli, W. M. 1981, *Ap. J.* (*Letters*), **243**, L89.
Felenbok, P., Praderie, F., and Talavera, A. 1983, *Astr. Ap.*, **128**, 74.
Finkenzeller, U. 1983, *Astr. Ap.*, **124**, 157.
———. 1985, *Astr. Ap.*, **151**, 340.
Finkenzeller, U., and Mundt, R. 1984, *Astr. Ap. Suppl.*, **55**, 109.
Herbig, G. H. 1960, *Ap. J. Suppl.*, **4**, 337.
Jansson, P. A. 1970, *J. Opt. Soc. Am.*, **60**, 184.
Jansson, P. A., Hunt, R. H., and Plyler, E. K. 1970, *J. Opt. Soc. Am.*, **60**, 596.
Mihalas, D., and Conti, P. S. 1980, *Ap. J.*, **235**, 515.
Mullan, D. J. 1984, *Ap. J.*, **283**, 303.
Mundt, R., and Giampapa, M. S. 1982, *Ap. J.*, **256**, 156.
Praderie, F., *et al.* 1984, in *Proc. France-Japan Seminar on Active Phenomena in the Outer Atmosphere of the Sun and Stars*, ed. J.-C. Pecker and Y. Uchida (Meudon: Observatoire de Paris), p. 132.
Praderie, F., Simon, T., Catala, C., and Boesgaard, A. M. 1986, *Ap. J.*, **303**, 311 (Paper I).
Praderie, F., Talavera, A., Felenbok, P., Czarny, J., and Boesgaard, A. M. 1982, *Ap. J.*, **254**, 658.
Sanders, W. T., Cassinelli, J. P., and Anderson, C. M. 1982, *Bull. AAS*, **14**, 629.
Schafer, R. W., Mersereau, R. M., and Richards, M. A. 1981, *Proc. IEEE*, **69**, 432.
Schneeberger, J. T., Worden, S. P., and Wilkerson, M. S. 1979, *Ap. J. Suppl.*, **41**, 369.
Strom, S. E., Strom, K. M., Yost, J., Carrasco, L., and Grasdalen, G. 1972, *Ap. J.*, **173**, 353.
Thé, P. S., Tjin-A-Djie, H. R. E., Praderie, F., Catala, C., and Felenbok, P. 1985, *Messenger*, No. 41, p. 8.

A. MERCHANT BOESGAARD: Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu, HI 96822

C. CATALA, P. FELENBOK, and J. CZARNY: Observatoire de Paris, Section de Meudon, 92195 Meudon Principal Cédex, France

A. TALAVERA: Astronomy Division ESTEC, Villafranca Tracking Station, P.O. Box 54065, Madrid, Spain