SPECTRA OF Of AND Be STARS IN THE NEAR INFRARED REGION UP TO 1.1μ

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ABSTRACT

The classification of Of stars presents a number of problems, in part due to the small interval of the spectrum explored up to now. With J.M. Vreux an extended study has been made in the infrared region, up to 1.1 μ. Be stars have been studied with L. Houziaux. The hydrogen Paschen lines and lines of helium I and II can be studied in the region and used to determine temperature class and luminosity.

1. Of STARS, INTRODUCTION

There are many observations of Of stars in the blue spectral region. In the red, Conti (1974) has published results concerning the spectra of 33 Of-type stars up to 6700 Å. Above this wavelength, there exist few observational data.

Four years ago, in collaboration with J.M. Vreux, we began the observation of Of stars in the near infrared up to 1.1μ. In the first study we had published spectra of 25 stars that we had observed in the spectral range 5850 - 8750 Å (Andrillat and Vreux 1974).

The spectral interval 0.8-1.1μ shows very few lines (Andrillat and Vreux 1975) but this one is very important because here one finds the helium lines: He I 10830 Å and He II 10124 Å.

The observation of these lines is extremely useful for the understanding of the helium lines formation in the O stars in general, and the data concerning them are necessary for the establishment of theoretical models.

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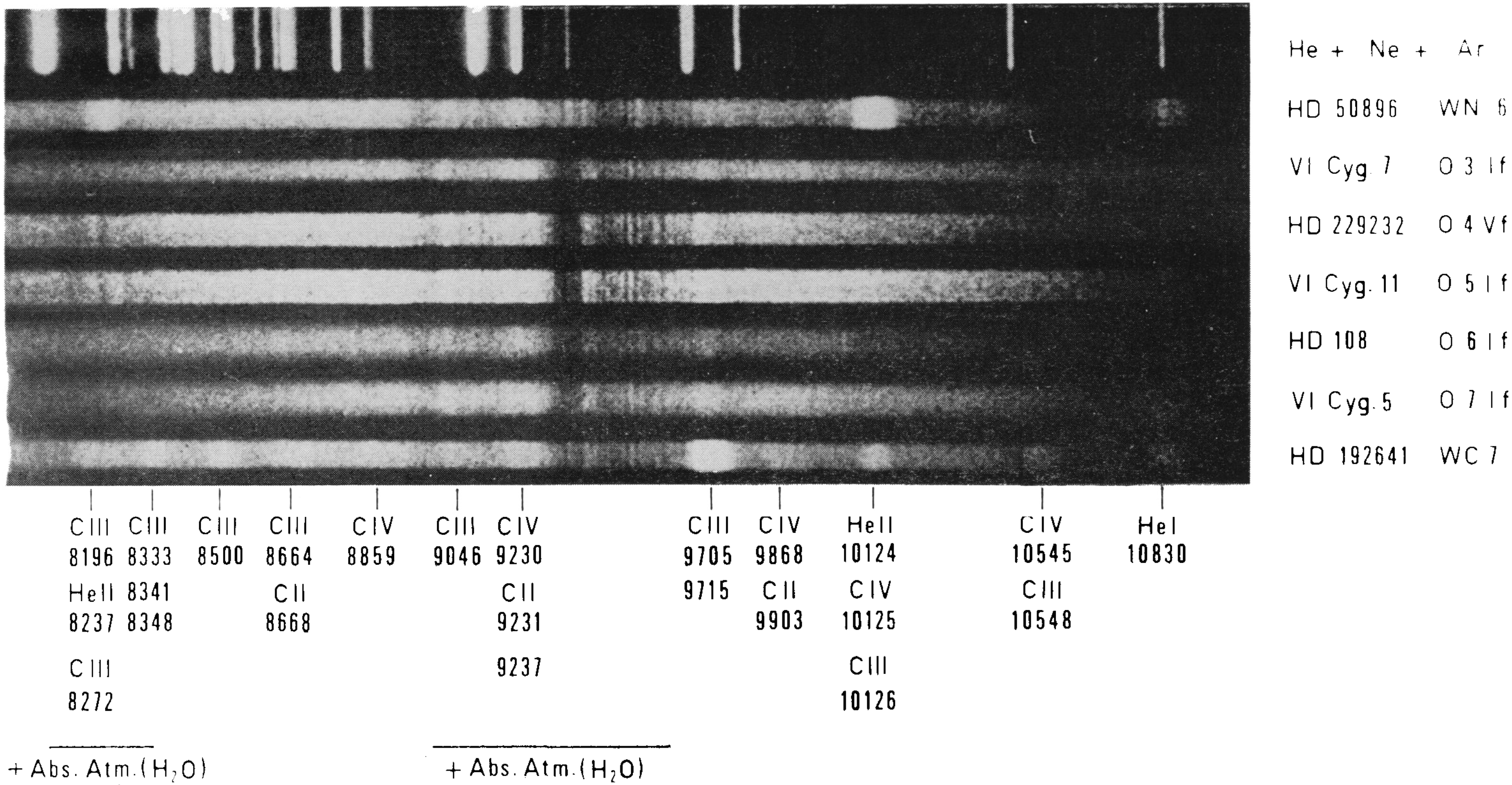

Fig. 1. Spectra of Of-type stars and of two Wolf-Rayet stars. For the Of-type stars, the spectral types are those given by Walborn. Original dispersion: 230 Å mm^{-1}. Receiver: image-tube with S1 photocathode.

Our observations were made with the 193 cm telescope of the Haute Provence Observatory with the spectrograph ROUCAS, specially built for the study of the 0.8-1.1μ region (Andrillat, Baranne and Duchesne 1973): the dispersion is 230 Å/mm. The receiver is a cooled ITT two stage image-tube equipped with an S1 photocathode; 103aD film is used behind the fiber optics output.

1.1. The Carbon Lines

We have observed 49 Of-type stars and 10 O-type stars. Spectra of 5 Of-type stars of different spectral types, and also, for comparison, those of 2 Wolf-Rayet stars, one of each sequence are shown in Fig. 1.

The spectra of Of stars are poor: the very intense C III emission lines of the WC7 star HD 192641 are not visible. Concerning the 9713 Å line, the strongest one, it is difficult to say if the line is present, because it is situated at the limit of a spectral range which is perturbed by an atmospheric absorption band of H_2O. It seems present in some stars. Nussbaumer (1971) has predicted this line in emission and has also suggested that the 4649 Å C III emission line is related to the 9713 Å emission line. So, in stars showing the 4649 and 5696 Å C III emission lines, 9713 Å should be in strong emission. In fact, on our spectra, when 9713 Å is suspected as present, it is not intense.

In the future, we intend to use a receiver which will permit us to take into account atmospheric absorption with accuracy, and so, to detect the presence and the intensity of this line.

1.2. The Paschen Lines

Beyond the atmospheric band, our spectra show the hydrogen line P_δ 10049 Å which is visible in about twenty stars. It appears in emission only in HD 108 (Fig. 1). In this star P_γ 10938 A is also in emission.

1.3. The Helium Lines

Previous observations of the He II 10124 Å line are due to Mihalas and Lockwood (1972). This line was found in absorption except in the spectra of ξPup where it is in strong emission and in the spectra of λCep where it is missing (absorption filled in by emission). Interest in these observations have been raised again with the recent theoretical calculations of Klein and Castor (1978) concerning the intensity of He II and H emission produced by the envelope of Of-type stars. The value of the 10124 Å/ 4686 Å ratio derived from their model is higher than the value derived from the observations quoted above. Out of our large sample of Of-type stars, we have observed an emission line at 10124 Å in three other objects: HD 16691, HD 190429 and HD 228766. We have shown (Vreux and Andrillat 1978) that the first two lines confirm the rather low value (<1.4) of the "observed" ratio and given reasons why the higher value given by HD 228766 should not be considered as a "typical" result for O stars. We have used the observed ratio for normal O stars and the calculations of Auer and Mihalas (1972) to predict the intensity of the 10124 Å line in all the stars for which we had data both at 4686 Å and 10124 Å. The results are given in Table I. Except for HD 108 which has a P Cygni profile at 4686 Å, there is a good agreement between the equivalent widths of the predicted and the observed lines, the difference being of the order of estimated error: the accuracy of equivalent widths larger than 2 A is about ±25%. For the fainter features, the detection threshold is 1 A approximately as the sharp sensitivity drop off at $\lambda > 1\mu$ sometimes makes the definition of the continuum rather imprecise.

The observation of 10124 Å in emission is very important. This line is the first member of the Pickering series (4⟶5 transition). To explain the formation of the 4686 A (3→4) and 1640 Å (2→3) emissions, it has been suggested that a direct pumping of He II (2→4 transition at 1215) by hydrogen L_α emission with a consequent cascade 4→3→2. In the case of the 10124 Å emission, it is not possible to invoke a similar mechanism because there is no hydrogen line whose frequency is near that of the 4→5 transition. Mihalas and Lockwood suggest that the causes of the emission must involve chromospheric phenomena.

It is necessary to obtain good profiles of He II 10124 Å and also a better determination of the intensity to decide which theoretical model to choose. In the next few months, we intend to continue our observations in this sense, with a greater dispersion and a receiver with a linear response.

The He I 10830 Å line appears on several spectra in emission. Some examples have been given in Fig. 1. The profile and the width of this line are different from one star to another as can be seen in Fig. 2.

In order to try to find which physical conditions are required to produce the 10830 Å emission line, we have plotted the observed

TABLE I

COMPARISON BETWEEN OBSERVED AND PREDICTED He II 10124 Å INTENSITIES IN Of STARS

Star	Spectral type (Walborn 1972-1973)	W(A) 10124 Å	
		Predicted	Observed
HD 108	O6F?pe	1,4	4,0
HD 14442	O5n(f)p	1,5	2,5
HD 14947	O5If+	E 1,1	0
HD 16691	O4If+	E 6,1	E 3,0
			E 6,0
HD 57060	O7Iafp	0	0
HD 166734	O7Ib(f)	0,9	A or 0 ?
HD 167971	O8Ib(f)p	0,9	0 ?
HD 188001	O7,5Iaf	1,0	A ?
HD 190429	O4If+	E 3,0	E 3,5
			E 4,0
			E 3,5
HD 210839	O6I(n)fp	0,6	A or 0 ?
BD 60°2522	O6,5(n)(f)p	0,6	0

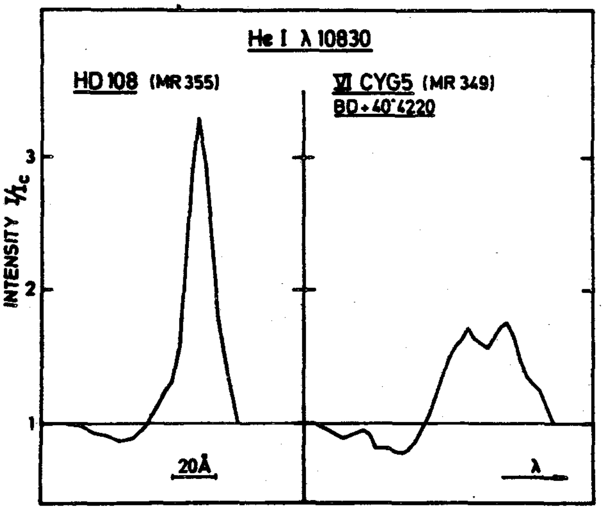

Fig. 2 P Cygni profile of the HeI 10830 Å in HD 108 (O6If) and VI Cyg 5 (O7If).

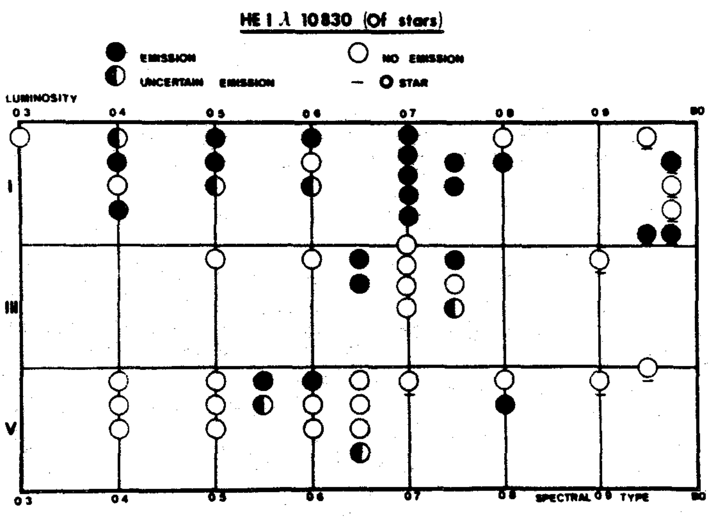

Fig. 3 Behavior of the HeI 10830 Å as a function of the spectral type and the luminosity class (given by Walborn).

behavior of this line as a function of the spectral type and the luminosity class given by Walborn (1971-1972) (Fig. 3): black filled circles are used when the emission is well visible, half filled circles when it is uncertain and empty circles when it is absent.

It appears that an emission line is observed at 10830 Å in 80% of the Of (from O3f) supergiants but only in 29% of the dwarfs, all the latter exhibiting some pecularities in their spectra: for example, the presence of an envelope with a rapid rotation or the presence of a companion.

Our observations are in good agreement with the theoretical results of Auer and Mihalas (1972) which predict the progressive appearance of the He I 10830 Å emission when the temperature is high (Te > 25000°K) and the gravity is low (log g ≤ 3). However it is important to note that in two very hot supergiants (O3f-O4f) there is no emission and in three others, the emission is uncertain.

The emission is not only related to T_{eff} and g: other parameters must be taken into account.

The problem of He I 10830 Å is associated to that of He I 5876 Å. There is no agreement between the observations of the latter line and theory, and it has been necessary to introduce a microturbulence effect to reduce the disagreement but the consequence is a marked increase of the 10830 Å absorption, a result in net disagreement with our observations.

We have determined the intensity of 10830 Å and a correlation between this intensity and the mass loss rate is shown in Fig. 4. The intensity increases with the mass loss. Moreover this effect is temperature dependant: it is strong in O5f-O9f stars and appears weakened among the O4f stars and also among the B stars (Andrillat and Vreux 1978).

In conclusion , it looks as an envelope with a sufficient amount of material and a temperature between 30000°K and 45000°K are the most favorable conditions to push the He I 10830 A line into emission. These He I observations undoubtedly put constraints on the ionization balance of helium in the theoretical models of the wind.

2. Be STARS, SPECTRA FROM Hα to 8750 Å.

About ten years ago, in collaboration with L. Houziaux

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we published the spectra of 53 bright Be stars (m < 6,6) in the near infrared photographic region from H_α to 8750 Å, obtained with dispersions of 19 and 39 Å/mm at the 193 cm telescope of the Haute Provence Observatory (Andrillat and Houziaux 1967).

In this spectral interval, the lines of hydrogen (Paschen series: P 12, P 13...) of helium (He I 6678-7065 Å), of oxygen (OI 7772-8446 Å), of calcium (CaII 8498-8542-8662 Å) and nitrogen are visible. The emission appears in the Paschen lines, the OI lines and the CaII triplet. It was interesting to determine in what spectral type the different emission lines appear. For this, it was necessary to have a greater sample of stars.

We have extended our observations to stars of 9th magnitude. We have obtained 65 classical spectra on IN hyper-sensitized plates with a dispersion of 230 A/mm from 5850 to 8750 Å at the 120 cm telescope of the Haute Provence Observatory.

Including these last observations, we have 118 spectra of Be stars. Almost all the stars of the B2e type show the Paschen lines and O I (8446 Å) in emission: the emissions are less abundant in the B3e type, and they are not present in the B7e B8e-B9e types.

On the basis of the statistics of the HD spectral type, we have determined the percentage of H_α emission stars with respect to stars classified Be in the Merrill and Burwell catalogues. Then, we have calculated the percentage of the different emission stars with respect to stars having H_α emission. The results are presented in Fig. 5.

It appears that emission in H_α, Paschen, O I 8446 Å and CaII lines are confined to spectral types earlier than B5, with a strong maximum at B2. For the spectral types latter than B3, the CaII variation is different. Peters and Poliden (Abell 1975) find also that the CaII triplet emission appears to be rare in Be stars

2.1. STAR SPECTRA UP TO 1.1μ.

We have observed 16 Be stars with the Roucas spectrograph. The spectra are poor. Only the part of the spectrum situated beyond the H_2O atmospheric band (9420 A) is interesting (Fig. 6).

The Paschen line P_δ is visible in emission in EW Lac and in 48 Lib, which are both stars with an envelope. It is also present in πAqr, P Cyg: the other spectra are over-exposed and it is not

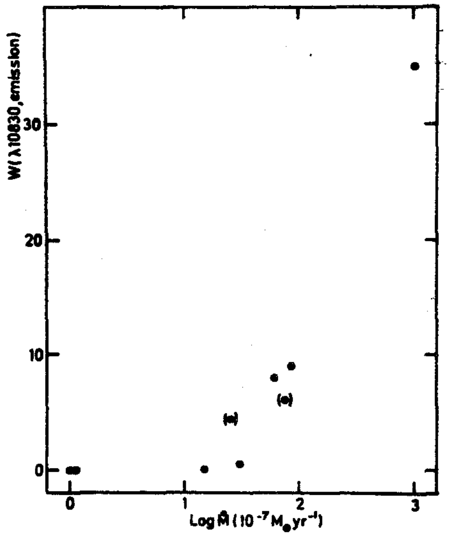

Fig. 4. Variation of the equivalent width of HeI 10830 Å with respect to the mass loss M. The indication ( ) corresponds to variable stars.

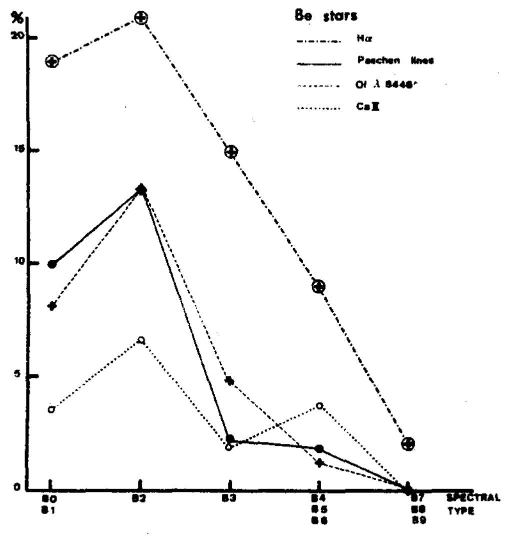

Fig. 5. Behavior of the emission lines of Hα, Paschen series, O I 8446 Å and Ca II in different spectral types.

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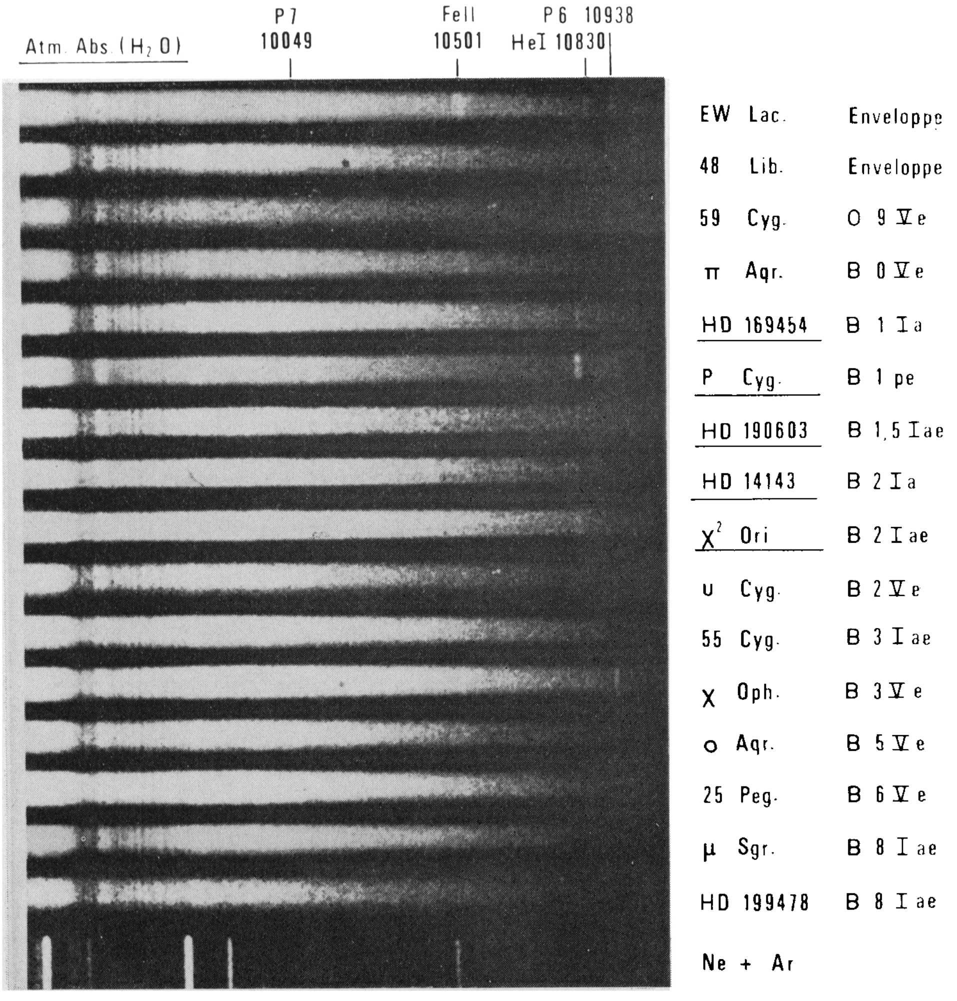

Fig. 6. Spectra of Be stars in the near infrared. We have underlined the stars having a great mass loss. Original dispersion 230 Å mm^{-1}. Receiver: image-tube with S1 photocathode.

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possible to see if the emission is present.

A strong emission due to Fe II 10501 Å is identified in EW Lac and in several other stars (48 Lib, πAqr, χOph...).

He I 10830 Å is visible in emission in the earlier types (B1, B2): EW Lac, πAqr (?), HD 169454, P Cyg, HD 190603, χ^2 Ori. It is interesting to note that the four last stars are characterized by a large amount of mass loss. However, HD 14143, in which this is also the case, does not show the He I 10830 Å emission.

These results were obtained only two weeks ago and there are not yet photometric measures: it is not possible to seek for a possible correlation between the intensity of this He I line and the amount of mass loss as we have done for the Of stars.

7. CONCLUSION

The aim of our further observations will be to study the possible variations of profile lines (Andrillat and Houziaux 1967-1972; Houziaux and Andrillat 1976), to determine the intensities of different emission lines: H I, O I, CaII, N I and to obtain quantitative data for the determination of oxygen and nitrogen abundances.

We intend to compare the behavior of homologous hydrogen lines in the two series of Balmer and Paschen lines to obtain the physical parameters of envlopes (Andrillat and Houziaux 1968). This research will be performed, using either a RETICON or a CCD receiver which are now tried on our spectrograph. These receivers, by their linear response, permit accurate spectrophotometry. Moreover, by a simple computer processing, it is possible to take into account the indesirable spectra of night sky emission and telluric absorption which strongly perturb stellar spectra in the near infrared region.

REFERENCES

Abell, C. (1975). Bull. Am. Astron. Soc. 7, 296.
Andrillat, Y., Baranne, A. and Duchesne, M. (1973). Mem. Soc. Roy. Liege V, 51.
Andrillat, Y. and Houziaux, L. (1967). Publ. OHP 8 n°11.
Andrillat, Y. and Houziaux, L. (1967a). Publ. OHP 9 n°32 = 1967, Journal des Observateurs 50, fasc. 4.

Andrillat, Y. and Houziaux, L. (1968). Publ. OHP 10 n°1 = 1968, Journal des Observateurs 51, fasc. 3.
Andrillat, Y. and Houziaux, L. (1972). Astrophys. Space Science 18, 324.
Andrillat, Y. and Vreux, J.M. (1974). Acad. R. de Belgique - Bull. classe des Sciences LX 53 série, 430.
Andrillat, Y. and Vreux, J.M. (1975). Astron. Astrophys. 41, 133.
Andrillat, Y. and Vreux, J.M. (1978). submitted for publication in Astron. Astrophys. in press
Auer, L.J. and Mihalas, D. (1972). Astrophys. J. Suppl. 24, 193.
Conti, P.S. (1974). Astrophys. J. 187, 539.
Houziaux, L. and Andrillat, Y. (1976). In IAU Symp. No. 70. Be and Shell Stars, A. Slettebak, ed., D Reidel, Dordrecht, p. 87.
Klein, R.I. and Castor, J.I. (1978). Astrophys. J. 220, 902.
Mihalas, D. and Lockwood, G.W. (1972). Astrophys. J. 175, 757.
Nussbaumer, H. (1971). Astrophys. J. 170, 93.
Vreux, J.M. and Andrillat, Y. (1975-6). Acad. R. Belgique - Bull. classe des Sciences, LXI 5e série, 577.
Vreux, J.M. and Andrillat, Y. (1978). submitted for publication in Astron. Astrophys. in press
Walborn, N.R. (1972). Astron. J. 77, 312.
Walborn, N.R. (1973). Astron. J. 78, 1067.

DISCUSSION

Mendoza: Photometric measurements at 7774 Å in Be type stars indicate three groups: (1) either faint or no absorptions; (2) faint emission; (3) strong absorption. Have you found something similar?

Andrillat: Most of our spectra were obtained with too low a dispersion (230 A mm^{-1}) for a precise study of the OI 7774 Å line.

Houziaux: About the measurement of Paschen continuum emission, it is well known that the (B-V) index for stars showing Paschen lines in emission is too "red", showing that there is some Paschen continuum emission. This effect is also observed in the Balmer continuum, the Balmer discontinuity being too small for the spectral type of the star.

Slettebak: The use of the OI infrared triplet for luminosity classification of B8 stars is dangerous because the lines arise from a metastable energy level and are therefore subject to dilution effects. How do you distinguish between stellar luminosity and shell effects?

Andrillat: We did not try to use the OI 8446 Å line as a criterion for the luminosity.

Code: Do you believe the difference between observed emission line strength and theoretically predicted intensities for HeII in Of stars is real?

Andrillat: I think the disagreement between the observed values and the theoretical values is real. The ratios found for two Of "normal" stars are approximately two times smaller than the theoretical ratios. This difference is too large to be due to measurement errors. In the present case the precision is about 25%.

Code: Is there any correlation between line profiles and difference between observation and theory?

Andrillat: Our profiles are too imprecise (mostly overexposed spectra for this region) and the dispersion is too small (230 Å/mm) to find any correlation. We plan to improve the photometric precision by the use of a Reticon receiver. Moreover for the line profiles we intend to use a larger dispersion.

Lesh: Do you have any observations of HeI 10830 Å in normal (non-emission line) B stars? Dr. David Meisel of the State University of New York has many scans of this line in various B stars; in general he finds that, although the theory predicts a strong absorption line, the observed line is almost absent or slightly in emission. Have you any results that would confirm or refute this effect?

Andrillat: Only a few normal B stars have been observed. The observation of HeI 10830 A in absorption is difficult, because in this region the spectrum is normally underexposed. The continuum is not easy to define because of the very large and rapid decrease in sensitivity beyond one micron.

Viotti: Your study of the infrared spectrum of OB emission stars is valuable in the investigation of extended envelopes, and I would be happy to have your line intensities for modelling. My comment is that since emission lines are variable, it is difficult to make a correlation with mass loss unless simultaneous observations in the ultraviolet, optical, near-infrared, and far-infrared are made. In measuring equivalent widths and comparing these with blue emission lines one has also to consider that, at least for some stars you have studied, the near-infrared continuum is partly "nebular" in origin. In this regard I would like to know if you have measured the Paschen discontinuity or Paschen excess since this would be important in the study of the continuum.

Andrillat: Telluric absorption prevents us from measuring at the Paschen limit. In the future we hope to do this by taking into account the atmospheric absorption and the emission lines of the night sky.

Fehrenbach: A typical example of the strong variation of the emission of HeI 10830 A is CI Cyg for which the very strong line disappeared in one night. The next day the star appeared as A8IA with HeI 10830 A in absorption, but with complex structures in the FeII lines.

Walborn: In the HeI 10830 A versus spectral type diagram, is the O3If point a definite absorption or a marginal detection? In the latter case may it be due to the high ionization? It would be worthwhile to extend the profiles further in wavelength with good signal to noise in the continuum and to correlate them with the general spectral morphology. For instance HD 39680 and 60848 are Oe stars which may show broad, shallow absorption on both sides of the emission. On the other hand HD 14947 which showed the P Cyg profile is a normal Of supergiant.

Andrillat: In the O3If type star no emission has been seen at 10830 A. It is difficult to study the absorption in this spectral region due to the plate graininess.