QUANTITATIVE SPECTRAL CLASSIFICATION OF Be STARS ON LOW DISPERSION SPECTRA [1]

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ABSTRACT

Two separate Balmer jumps are observed in some B_e stars. The first one, in absorption and unchanging, is attributed to the central star and gives its spectral type and luminosity class in the $\lambda_1 D$ system. The second one, occuring at shorter wavelengths, either in absorption or in emission, originates in layers at a low pressure. It is shown that these layers modify the colors of the central star on both sides of the Balmer jump and that they are not optically thin even in the continuum.

1. INTRODUCTION

Classification of B_e stars is rendered difficult by the presence of an emission and/or a shell spectrum, and the effective temperature of the central star is often underestimated when the line spectrum is considered at medium or low dispersion. Effects of rotation also render visual classification somewhat uncertain as B_e stars are often rapid rotators. Photometric classifications are generally affected because, as will be shown, emission or absorption is often present in the Balmer continuum and strongly affects the ultraviolet magnitudes. H_β photometry is affected by emission in the Balmer lines. Reliable spectral types can be obtained from high dispersion spectra but only for bright stars and after a long and careful analysis of well calibrated plates.

[1] Observations done at the Haute Provence and La Silla Observatories.

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We describe here a method to obtain reliable spectral types and effective temperatures for B_e stars from low dispersion spectra. The method is thus applicable to faint stars (m = 11 with the photographic plate, more if new detectors are used).

2. BCD SPECTRAL CLASSIFICATION APPLIED TO B_e STARS

The parameters λ_1 and D used in the BCD system of classification are shown in Fig. 1. Naturally, the observed blue continuum AB is not extrapolated "by hand" from B to C as in Fig. 1 but by the use of correct spectrophotometric methods described by Chalonge and Divan (1952) and, for reddened stars, by Divan (1954). The parameters λ_1 and D depend on both spectral type and luminosity class but Chalonge and Divan (1973), using the calibration of the λ_1D plane into MK spectral type and luminosity class, derived two new continuous parameters, s depending only on spectral type and ℓ only on luminosity class. Later (Chalonge and Divan, 1976), s was calibrated with the empirical effective temperatures of Code et al. (1976).

With time it became clear that all these results could be extended to B_e stars. A first remark by Barbier and Chalonge (1939) that ζ Tau had two steps in the Balmer discontinuity, a first one A (Fig. 2) situated as in normal dwarf stars and a second one B at shorter wavelengths as in supergiants, enabled them to conclude that hydrogen was present both in a photosphere and in an envelope at a very low pressure. Following this idea, Chalonge and Divan (1952) derived the λ_1D spectral types of four B_e stars for which two separate Balmer jumps were observed, assuming that the longwavelength one characterized the central star. Later on, this hypothesis was rendered still more plausible by observations of variable B_e stars (see below).

The first Balmer jump, D_*, which is attributed to the central star (Fig. 3), is always in absorption but the second one, d, due to the envelope, can be either in emission as in α Ara or in absorption as in 48 Lib.

For some B_e stars, variations have been observed in the Balmer jump, but the most interesting point is that these variations occur only in d which can even disappear entirely as in 1 H Cam 1965 (Fig. 4) or 59 Cyg 1977 (Fig. 5). The longwavelength Balmer jump D_* is constant and defines, together with the corresponding λ_1 parameter, the spectral type (and luminosity class) of the central star. The variations of d are accompanied by variations in the first Balmer lines (see $H\beta$ on Fig. 4 and Fig. 5).

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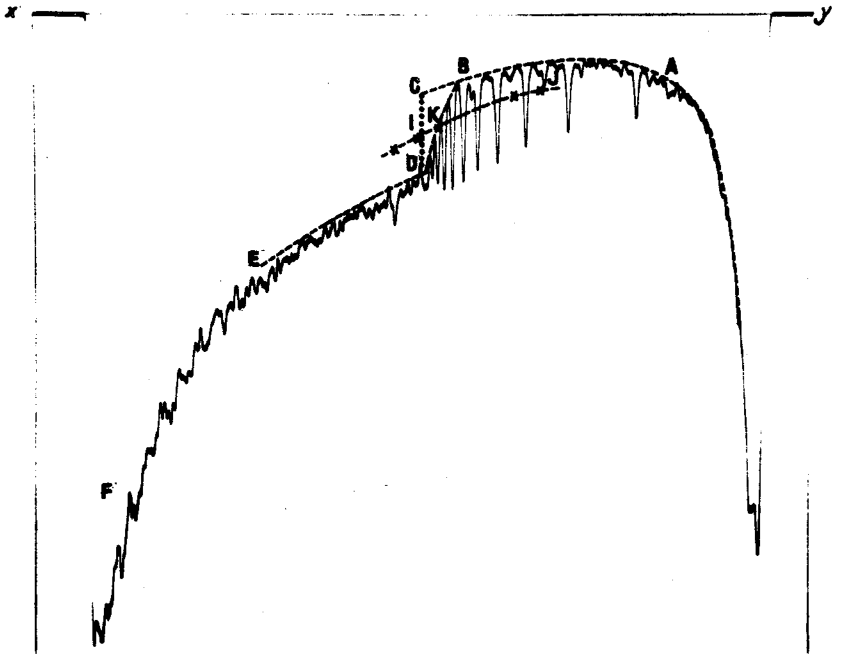

Fig. 1. Microphotometer tracing of a B star. D = log intensity in C - log intensity in D. IJ is the same curve as DE but shifted in intensity of + $\frac{D}{2}$ (violet side of the Balmer jump) or as AB shifted of - $\frac{D}{2}$ (red side of the Balmer Jump). The smooth curve BD joins the points of maximum density between the Balmer lines. The parameter λ_1 is the wavelength corresponding to point K.

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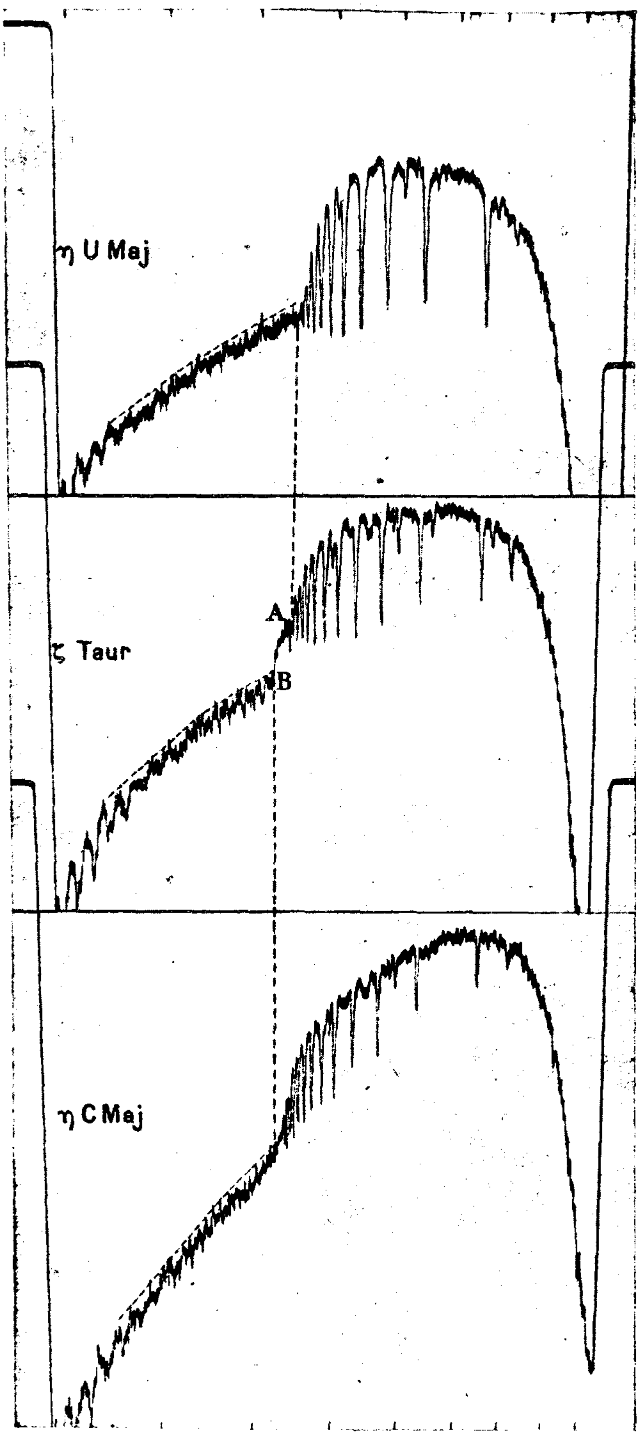

Fig. 2. The two steps in the Balmer discontinuity of ζ Tau (from Barbier and Chalonge, 1939).

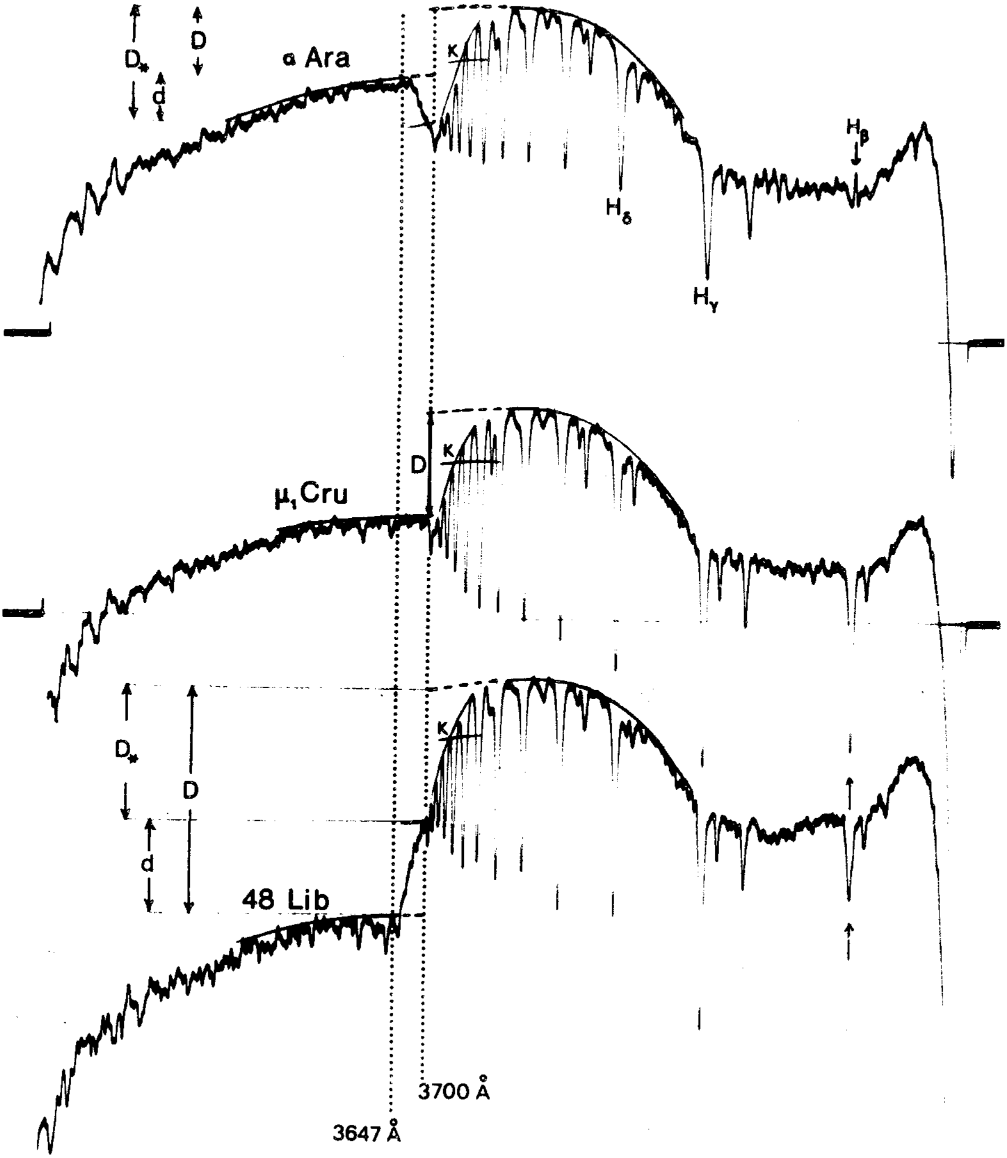

Fig. 3. Microphotometer tracings of α Ara, μ_1 Cru and 48 Lib. The normal star μ_1 Cru has an unique Balmer discontinuity, D. In α Ara and 48 Lib two Balmer discontinuities can be seen, a longwevelength one D_* due to the central star and a shortwavelength one d corresponding to the envelope. This second Balmer jump is in emission for α Ara ($d < 0$) and in absorption for 48 Lib ($d > 0$). In the two cases, $D = D_* + d$.

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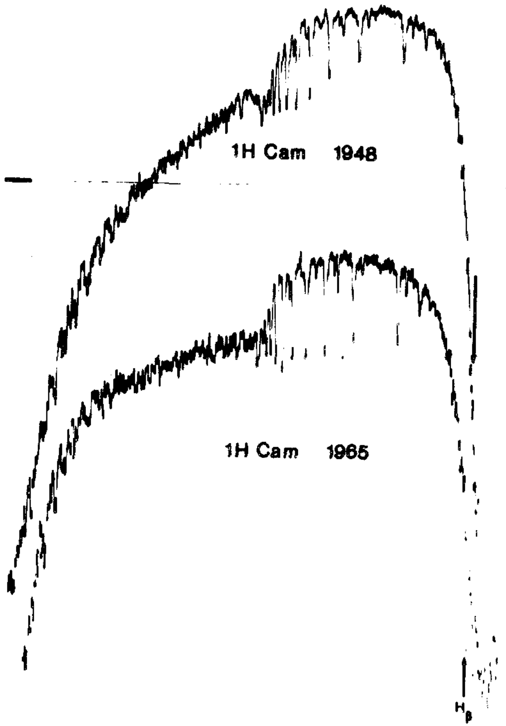

Fig. 4. Microphotometer tracings of 1 H Cam: emission clearly visible on the 1948 spectrum has disappeared in 1965. Note also the H line, absent in 1948 (filled in by emission) and normal in 1965.

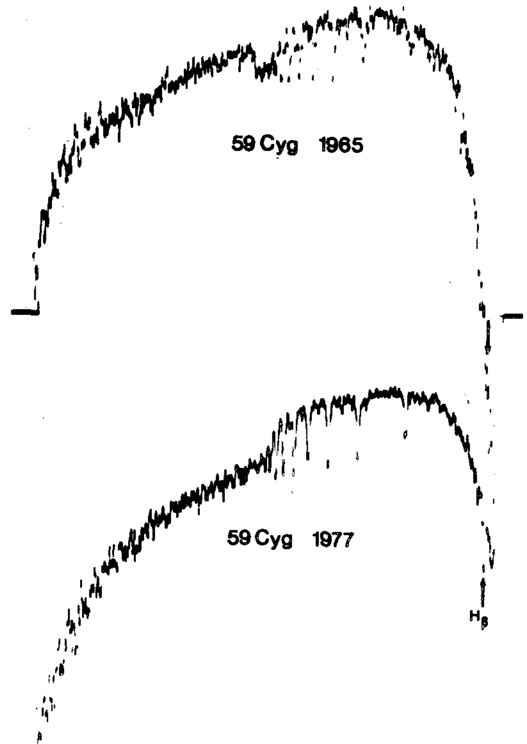

Fig. 5. Microphotometer tracings of 59 Cyg. Same remarks as for Fig. 4.

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It must be noted that the existence of two separate Balmer jumps is relatively rare and occurs only in stars having a small Balmer decrement. In a large number of B_e stars, the Balmer discontinuity is quite normal.

3. RESULTS

3.1 Spectral Types

The positions in the λ_1 D diagram of the B_e stars with d in emission (filled circles) or in absorption (open circles) are given in Fig. 6. The stars are in or near the luminosity class IV area, a result that is also often obtained from high-resolution spectra. However, the dispersion of the points in luminosity from class III to V is real and much larger than the apparent dispersion due to the uncertainty in λ_1. Since λ_1 depends only on the wings of the last Balmer lines, it is not affected by emission and very little by rotation. The effect of rotation if it exists is a small shift of the points to the right. When d is in emission, the measured values of D_* are somewhat smaller than the real ones because the two Balmer jumps have a small overlap. The corresponding error is about one subclass at B0 and B1, half a subclass at B2, and much less at B3 and later types. There is an indication that continuous emission occurs in the hotter stars and absorption in the cooler ones.

3.2 Colors

The colors of a B_e star can be affected by interstellar reddening and by a continuous absorption due to the envelope. Although the two phenomena certainly do not have the same wave-length dependence, their respective contributions to the observed colors cannot be determined unambiguously from the energy distribution only. The interstellar contribution could be estimated from the 2200 Å absorption feature but when the emission in the envelope is variable, more complete and precise results can be obtained from ground-based observations only. The gradients ϕ_{rb} (spectral range 6200 - 4000 Å) and ϕ_{uv} (3700 - 3130 Å) for X Per (=HD24534) as a function of $D = D_* + d$ are shown in Fig. 7. The Balmer jump D_* being constant, D varies as the emission d due to the envelope and can be measured without any ambiguity, even if D_* and d are somewhat uncertain because of the possible overlap of the two discontinuities. The dates of the observations are indicated.

As is well known, X Per undergoes irregular variations and in Fig. 7 it is shown that there is a close relation (practically

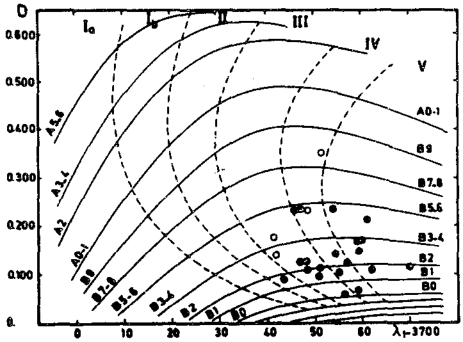

Fig. 6. Position in the $\lambda_1 D$ diagram of the B_e stars with two separate Balmer jumps. The stars are represented by filled circles if the second Balmer jump is in emission and by open circles if it is in absorption.

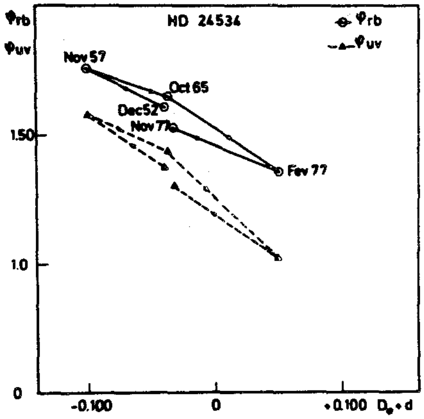

Fig. 7. Spectrophotometric gradients ϕ_{rb} (spectral range 6200 - 4000 Å) and ϕ_{uv} (3700 - 3130 Å) for HD 24534 (= X Per) as a function of $D = D_* + d$. The emission d in the Balmer continuum of X Per is variable and we can see here that the color temperatures on both sides of the Balmer Jump are strongly correlated with d. The normal color of X Per (spectral type B0) is $\phi_{orb} = 0.73$. In February 1977, the color of the star is $\phi_{rb} = 1.36$ and its spectrum shows practically no emission ($d = 0$, $D = D_*$); thus the color excess $\phi_{rb} - \phi_{orb} = 0.63$ is entirely interstellar. In all other cases the color excess is the sum of two terms, the interstellar color excess and a color excess due to the presence of the envelope. Observations of this type permit a clear separation of these two terms.

linear) between ϕ_{rb} and d or ϕ_{uv} and d, showing that the envelope is not optically thin even in the continuum on both sides of the Balmer jump.

In February, 1977, very little emission was seen in the lines and continuum of X Per and the observed color excess of the star was almost purely interstellar. This known interstellar absorption can then be subtracted from all the observations of X Per to obtain the color excesses due to the envelope alone.

Other stars show similar relations between the color temperatures (or gradients) and the emission d in the Balmer continuum. If these relations were the same for all stars or could be predicted from their spectra, the interstellar reddening could be obtained even if the envelope is always present, by an extrapolation from any observed point to d = 0. This possibility is being investigated.

The fact that variations in the Balmer continuum and lines are accompanied by changes in the color temperature of the star was first noted by Chalonge and Safir (1936) and by Barbier and Chalonge (1941) for γCas during its great outburst in 1936-1937. Now the star is undergoing much smaller changes but color variations are still observed. When no emission is present, the star has the normal colors for its spectral type on both sides of the Balmer jump and no interstellar reddening can be detected. All these observations will be extended to more stars. The variable part of the spectrum of the B_e stars is still a mystery: is it due to an extended atmosphere or perhaps to non-thermal phenomena in the stellar atmosphere? Simultaneous observations at high and low dispersion have been carried out at the Haute Provence and La Silla Observatories by V. Doazan, D. Briot, L. Divan and J. Zorec to measure all the parameters of the continuum (D_*, λ_1, d, ϕ_{rb}, ϕ_{uv}) and of the emission in the Balmer lines (W_X, W_β, ..., Balmer decrement...). In particular, correlations between

1. d and emission in Balmer lines
2. d and the color temperatures on both sides of the Balmer jump

will be searched in order to test new models.

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DISCUSSION

Mendoza: Is P Cyg plotted in your diagrams?

Divan: No, P Cyg is a very peculiar star and has not been plotted here.

Andrillat: Do you have intensity measurements of the Hα line for the stars that you have observed, and present variations of the Balmer discontinuity? If so, have you found a correlation between this intensity and the value of the Balmer discontinuity?

Divan: High resolution spectra have been obtained by V. Doazan at the Observatoire de Haute-Provence and by D. Briot at the ESO Observatory simultaneously with our own observations in order to investigate such correlations. But this program has been initiated only one year ago and the high resolution spectra are not yet completely analyzed. Chance coincidence between our older results and high dispersion observations are rare.

Houziaux: Is there an explanation for the fact that the two discontinuities do not seem to occur at the same wavelength? What is the wavelength of the continuous emission? There seems also to be a slope in the emission discontinuity. Is this a resolution effect? It would be most interesting to take spectra at the same time at high resolution.

Divan: The explanation for the fact that the two discontinuities do not occur at the same wavelength is that the merging of the last Balmer lines depends strongly on the gravity (this is the basis of our spectral classification and the reason why the parameter λ_1 is a good indicator of luminosity). Thus the two discontinuities are separated because the Be star is a dwarf or a subgiant and the envelope a very low gravity region.

Walborn: What is being observed in the case of the absorption discontinuities is not the Balmer edge but the confluence of the Balmer lines which depends upon atmospheric pressure. Have you observed Pleione through its current shell episode in which the emission-line spectrum has been replaced by a shell absorption spectrum?

Divan: We have not observed Pleione since its shell episode; however, even before this new shell episode Pleione has the second largest Balmer discontinuity in absorption. It would be very interesting to observe it again in the Balmer region.

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Lesh: I have classified Be stars on the MK system using the same method as for normal B stars but of course avoiding lines that are obviously affected by emission. I have also found that many of them are on the main sequence (luminosity class V). There are others of class IV and III, but main sequence Be stars do exist.

Divan: Yes, main sequence Be stars really do seem to exist and in our diagram about 25% of the Be stars with emission in the Balmer continuum are in the luminosity V domain.

Slettebak: Various evidence suggests that the Be stars are located somewhat above the main sequence. Does your classification scheme suggest that most Be stars are of luminosity class IV?

Divan: Yes, as can be seen on our diagram, Be stars are centered on the luminosity class IV but extend also to the nearby regions of the luminosity classes III and V domains.