An atlas of Be stars

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ERRATA

READ:

-p.13	HD 37657	Hα,...(Hγ) very variable emission;Hγ and Hδ sometimes exhibit a sharp dark core.
-p.26	HD 61224	;R_{1950}= 7h35.4m,...
-p.40	HD 218393	This star was observed from 1954 to 1976.
-id.(*last but one line*)		...;they are particularly strong toward the maximum of strength of the hydrogen shell,...

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PREFACE

We warmly thank all the people who by their help or interest contributed greatly to the production of this Atlas of Be stars, particularly the following :

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Automn 1978

Anne Marie HUBERT-DELPLACE
Henri HUBERT

INTRODUCTION

1 - PRESENTATION

The study gives the spectral variations of 148 northern hemisphere ($\delta > -20°$) emission line stars, of spectral type O8 to A2, brighter than seventh magnitude ($V \leq 7.0$).

From each of the 35 of them that were considered the most typical, the corresponding photographs are reproduced, illustrating the spectral variations.

Most of the 148 Be stars in this Atlas were observed regularly from 1953 at the Haute Provence Observatory (C.N.R.S.), at the Newton focus of the 120 cm telescope. This long campaign of observations was undertaken by Dr. R. HERMAN and followed by her research group. About sixty per cent of the observations were made by Dr. HERMAN and Mr. M. DUVAL ; thirty per cent, with equal participation, by Dr. M. LACOARRET, Dr. RAKOTOARIJIMY, and the authors, and ten per cent by various other observers. The program of observations of emission-line stars, developed by Dr. HERMAN, was based on the Merrill and Burwell catalogues (1933, 1943, 1949) ; some B stars whose Hα absorption was reported as particularly weak by Mohler (1940) were added, as well as some O and B stars pointed out as peculiar in the HD catalogue.

The program thus included a total of 204 stars that were for the most part observed annually or biannually except during the period 1965-1968. Excluded from the total for the purposes of this Atlas were the hotter O stars, the A stars latter than A2, the Wolf-Rayet stars, the supergiants whose frequency of variation of emission lines cannot be established from the periodicity of the observations, and the stars β Lyr and P Cyg, whose spectacular features do not fall within the interests of this study. Thus, 148 stars in the O8 to A2 range remain, all of which have or had definite emission features.

a) Scientific purpose

We have attempt to produce a basic document by using the approximately 10 000 spectrograms, spaced out over 23 years of observations, which were at our disposal. These were easily utilizable to study emission features, their variations, and the time scale of these variations, and to establish some comparisons between the behaviour of these objects, to try to draw up subgroups by analogy of variations, and, when appropriate, to relate these subgroups to spectral type, luminosity, and rotational velocity of the stars.

b) Method

The presentation of photographic plates of stellar spectra seemed to us the quickest and the most readable practice. The method of microphotometric tracing is very reliable, but it is not feasible to juxtapose on a limited surface a great many tracings, usually covering 23 years of observations, in order to give an overview of the evolution of a total phenomenon.

On the other hand, particularly in the case of spectra taken with a low dispersion, a narrow, weak line is usually, on a microphotometric tracing, lost in background noise. This noise is produced by the graininess of the photographic plate, which generates irregular fluctuations of the recording apparatus, the width of the analysing slit being optimized between the width of the narrowest line to be analyzed and the diameter of the silver clumps of the photographic plate.

To perceive the presence of a line in a spectrum, one must be able to distinguish a difference in density between a point of the line and a part of the neighbouring continuum. For this line to be visible, the variations in density must be larger than the statistical fluctuations due to the grain of the photographic plate. With our method of juxtaposing photographic prints, the same weak line, if it is reproduced on several spectra, becomes very readable. This method proves to be very practical in the case of metallic shell stars, whose lines are generally narrow and not very far apart, and also allows the doubtful traces caused by scratches or grains of dust to be ruled out.

2 - TECHNICAL DATA

a) Instrument

The spectra originated from observations at prism spectrograph C, attached at the Newton focus of the 120 cm telescope of the Haute Provence Observatory (C.N.R.S.). The main characteristics of this spectrograph, which were described by Boulon (1963), are as follows :

- collimator : $F \simeq 400$ mm opened at f/5.7, diaphragmed at f/6 (aperture ratio of the telescope)
- camera : $F \simeq 215$ mm
- prism : dense flint glass FDC 2036,
  $n = 1.6510$ ($\lambda = 4047$ Å)
  $n = 1.6424$ ($\lambda = 4358$ Å)
  angle $= 66°$ at the minimum of deviation
  $\lambda = 5100$ Å, $i = i' = 63°45'$.

The width of the entrance slit used for our observations was about 30 to 40μ (15 to 20μ on the plate) ; the height of the projected slit on the plates was 0.6 to 0.8 mm ; the spectral wavelength range studied was λλ3900-6600 ; and the dispersion was 52 Å/mm at Hε , 60 Å/mm at Hδ , 77 Å/mm at Hγ , 120 Å/mm at Hβ , and 300 Å/mm at Hα .

On the spectrograms, the sharpness and the dispersion at Hα is not sufficient to allow conclusions to be drawn about the profile of this line ; we have noticed that when emission is strong the line is often degraded on its violet wing but distinct on the red side.

Though the photographic plate is slanted with relation to the optical axis of the spectrograph in order to correspond to the focal curve (Fig. 1), there are some failures to bring into focus the uttermost ends, i.e. wavelengths below λ 3800 and above λ 6000. For this reason, we could draw from the examination of the Hα line information only about the presence or the absence of emission.

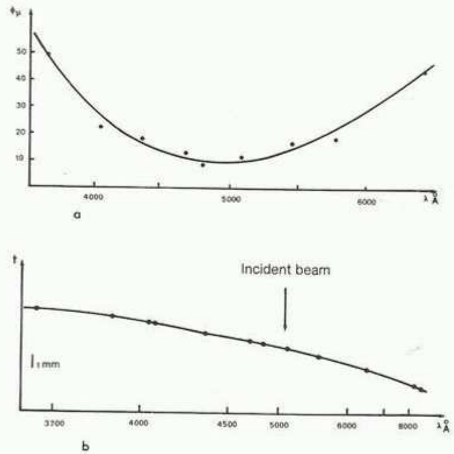

Fig. 1 Spectrograph C
a) Diameter of least aberration circle
b) Focal curve (t = focal length)

At the beginning of the observations, the exposure time was estimated by the observer. Greater regularity in the density of the spectrograms was obtained from 1969 on by the addition of an exposure meter.

The exposure times range, on an average, from 30 sec for a star of magnitude 3.0 to 45 min for a star of magnitude 7.0 ; the times vary around these average values according to the quality of the images.

b) Photographic material

Until 1960-1961, the spectrograms were obtained on Super-Panchro and Kodak 103a-F plates. The use of Super-Panchro plates was stopped because of their very low spectral sensitivity in the wavelength range λλ6450-6600, which did not allow accurate estimates of the behaviour of the Hα line. The 103a-F plates, of high contrast and average resolving power (80 lines/mm), were as often as possible replaced because of their strong graininess, by Kodak IIa-F plates, which are half as fast as former but which have average contrast, better resolving power (100 lines/mm), and less graininess in our conditions of use and development.

The two types of plates are both corrected for long exposures, i.e., for failure of the reciprocity law, and record the same spectral range. An illustration of inhomogeneity in the spectral sensitivity of the Kodak IIa-F and 103a-F is given in Fig. 2. These curves were obtained by exposing each sample, with the auxiliary spectrograph ETA of the Haute Provence Observatory, to the radiation of a tungsten lamp (grey body $\simeq 3200°$K) modulated by a rotating-sector which transmits the light in a geometric progression ratio : 1.33, $\Delta \log I = 0.125$.

These curves are cut off at wavelengths below λ 4200 because of the color temperature of the tungsten lamp, whose radiation fails in intensity in the short wavelength range, in contrast with the radiation of the hot stars studied here, whose temperature is much higher (Fig. 3). Except for that difference of temperature however, the curves of Fig. 2 exhibit the behaviour of the stellar continuum observable of the spectral plates as well as the lack of spectral sensitivity in the range λλ 5000-5500 and λλ 6500-6700, where Hα is situated.

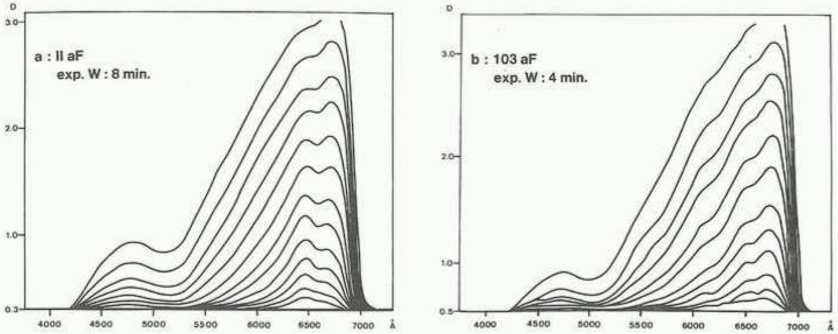

Fig. 2 Density curves, obtained with a tungsten lamp, versus wavelenth for illumination of steps with a ratio corresponding to $\Delta \log I = 0.125$
a) for a IIa-F plate, exposure 8 min.
b) for a 103a-F plate, exposure 4 min.

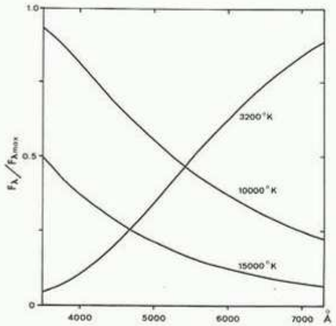

Fig. 3 Distribution of flux emitted by a black body, for temperatures of 3200°K, 10000°K, and 15000°K, in the spectral wavelength range 3500-7200 Å (fluxes are normalized to the maximum flux value $F\lambda$max).

Every plate was developed in Kodak D-19 or D-19b developer, and contains about 7 or 8 spectra, on an average, of different Be stars and a photometric calibration obtained with a « Soleillet » auxiliary spectrograph provided with a gradation apparatus described by Barbier (1944). The gradation of the light beam was done with a diaphragm limited by exponential curves. The calibration spectra were obtained by using a mercury-vapour lamp and a cadmium lamp. The usable wavelengths are the Hg lines $\lambda\lambda$ 3660, 4047, 4358 and 5460, and the Cd line λ 6438.

Each stellar spectrum was magnified without an intermediate negative in order to preserve the respective intensities of various stellar lines, both with regard to others of the same kind and from one spectrum to another one, for plates of the same type and of comparable density of the stellar continuum, which is important during the change from the Be star to the B star phase.

The final result submitted for printing is very close to the original document.

c) Caution to the reader

The shifting of lines which appears on the spectrogram plates signifies not stellar variations, but dimensional changes of the photographic paper arising during the drying, and tiny variations of the photographic enlargement over time.

There are some differences of contrast between the various spectrograms ; these are due to

a) changes in plate type (SP, 103a-F, IIa-F)

b) over or underexposure of the original spectrograms. In most cases such originals were set aside, except when a part of the information they contained was usable with the usual precautions, or when they represented the only information. We have obviously taken careful account of these parameters in the observational part of the Atlas.

Furthermore, the plates cannot be used to determine radial velocities because of the very frequent lack of appropriate reference lines.

3 - THE ATLAS

a) Description of the booklet

We give the nomenclature of each of the 148 Be stars accompanied by a description of spectral features and of their variations during the period of observations at the Haute Provence Observatory, in most cases from 1953 up to and including 1976. In the nomenclature we mention the HD number of the star in the Henry Draper catalogue, the name of the star, if need be its MWC number in the Mount Wilson catalogue, the coordinates right ascension and declination 1950.0, and the spectral type determined by Dr. M. Jaschek (ref. 1) using the criteria of the Morgan-Keenan classification ; in several cases we also give the spectral type determined by Dr. R. Herman (ref. 2) using the criteria of the Herman-Rojas classification (1955), based on the Hγ, Hδ, and Hϵ photospheric lines. The classifications given by Drs. Jaschek and Herman were made using the same observational material that we used. The standard stars were all observed in the same conditions. Then we give the v sin i value of the rotational velocity, from the catalogues of Uesugi and Fukuda (1970) and Uesugi (1978), and the photometric indices U, B-V, and U-B averaged by Nicolet (1978). When the V magnitude is known to be variable we mention the fact, and, finally, we mention if the star is known to be a binary and give the value of the period, as reported by Bidelman (1976).

In the description of spectral variations, we have taken care to specify the nature of the emission lines, their variations, and the temporary or permanent presence of a hydrogen shell (narrow, deep core on photospheric lines), sometimes accompanied by metals whose nature and ionization state are specified ; the strengthening of some absorption lines, such as the HeI, MgII, SiII, CaII, and NaI lines, is reported. The presence of the NaI and CaII interstellar lines is also mentioned. When the spectral variations are of the order of several decades, they are called « long-term » variations ; when they are of the order of several days, they are called rapid or « short-term » variations.

Illustrated in Fig. 4 are the various types of line profiles. There we give examples : 1) of hydrogen lines disturbed by emission, or by sharp dark core due to a shell, or by both at once ; 2) of variable absorption lines such as the hydrogen, HeI, and MgII lines, as they sometimes appear for certain stars ; 3) of shell lines disturbed by emission, as the FeII lines are often seen and very rarely the K line of CaII.

Several stars have often been studied in detail. We merely mention this fact, giving no reference to such studies because they are sometimes numerous and are beyond the scope of this Atlas. We refer readers to the bibliographical references in Merrill an Burwell (1933, 1943, 1949) Jaschek et al. (1971), and Cayrel et al. (1978), and to the I.A.U. Symposium n° 70, « Be and shell stars », edited by Slettebak (1976).

In the cases where the description of the star is accompanied by reproductions of photographic plates, we note « see illustration ». Finally a table summarizing the observations of the 148 Be stars is given (Table 2), but the number of annual observations of each object is not indicated. In this table, stars for which photographic plates are reproduced have been underlined.

b) Description of the photographic prints

The Atlas contains 51 reproductions of photographic spectra of 35 hot stars with emission lines. Some particularly interesting stars have been observed more frequently and therefore are represented by several plates.

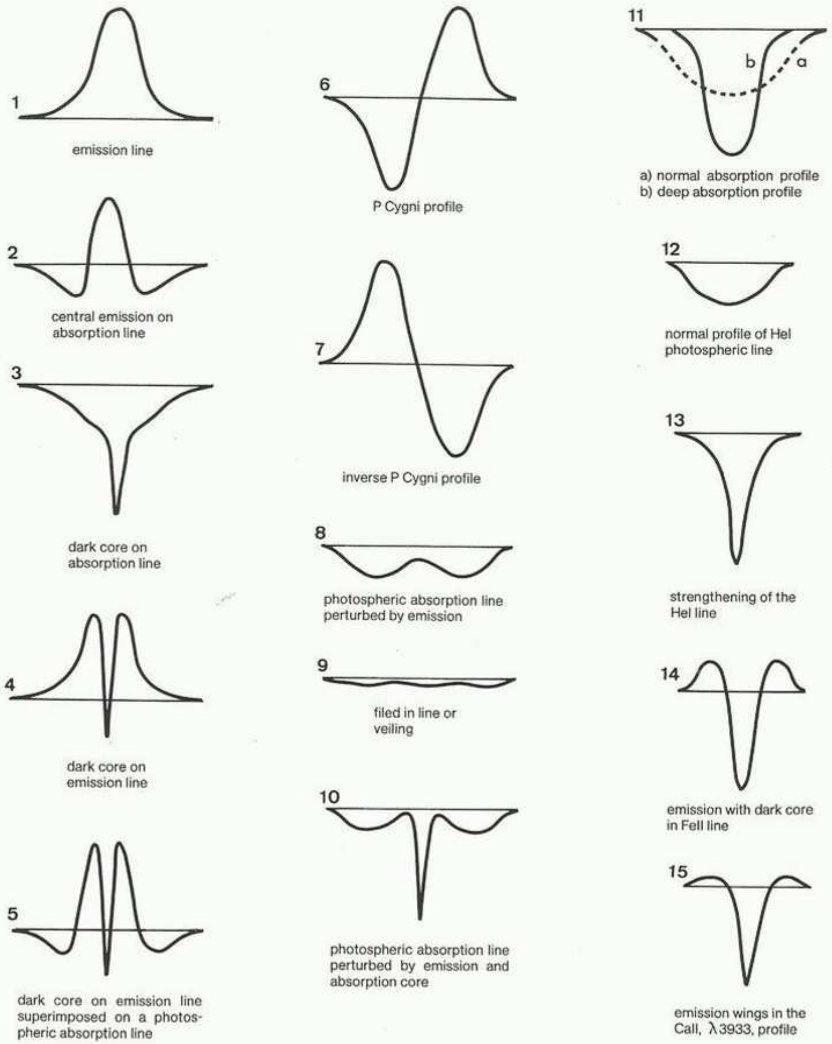

Fig. 4 Illustration of different types of observed profiles a) of the Balmer lines : 1-11 ; b) of the HeI and MgII lines : 12-13 ; c) of the FeII lines : 14 ; d) of the CaII K line : 15.

On each reproduction, the epochs of observation (day, month, year) are shown on the ordinate ; when several spectrograms were taken on the same day, there is no change of epoch. The wavelengths of the most important lines and the identification of the corresponding element and its ionization state are given.

Seitter's « Atlas for objective prism spectra I » (1970) was used as the reference for the location of stellar lines. For identification of circumstellar lines, we usually used microphotometric tracings referring to that of star HD 142983 (48 Lib), for which the identification of the lines is well known (Struve, 1943).

As the reproductions are negative of the plates used, emission lines appear as white, or « bright », lines, and absorption lines appear as black, or « dark », lines.

Table 1 groups the 35 stars whose spectral variations figure in the prints of this Atlas ; they are arranged in order to decreasing MK spectral type (ref. 1), and their spectral features are summarized. The Herman-Rojas classification (ref. 2) is also given for comparison.

The following explanations apply to Table 2. a) A question mark behind the Herman-Rojas classification indicates that the imprecision is related to the determination of spectral type and luminosity class. b) The notation $B_{\rightarrow}$ Be shows that the star, during these observations, is first in a « B star » and then in a « Be star » phase. c) The rotation B ⇄ Be shows that the star goes from a « B star » to a « Be star » phase and back. In addition every line affected by emission is noted. Of the hydrogen lines, $H\alpha$ is more often than not a simple emission line ; the other lines exhibit a central emission component superposed on a broad photospheric absorption, except in some cases when the $H\beta$ and more rarely $H\gamma$ lines are also simple emissions. When emission is not always visible on a line, this line is given in parentheses. When emission is only suspected, the designation of the line is followed by a question mark.

The prints of the Atlas illustrate : 1) Be stars which are in relatively « quiet » phases (e.g., HD 212571, HD 32343, HD 224559, and HD 21641) ; 2) Be stars in « very active » phases (e.g., HD 184279, HD 200120, and HD 23862) ; 3) stars which are sometimes in a « B star » phase, sometimes in a « Be star » phase (e.g., HD 33328, HD 171406, and HD 201733) ; 4) Be stars with permanent and relatively stable shells (e.g., HD 217050, HD 22192, and HD 195325) ; and 5) Be stars with temporary shells (e.g., HD 200120, HD 23862, and HD 162732).

For phases of the same nature, there is generally great similarity between emission features of stars of the same or similar spectral types (e.g., HD 202904 and HD 32343 ; HD 171406 and HD 171780 ; HD 199218 and HD 224544).

To separate Be stars from shell stars is difficult ; often a Be star exhibits a shell temporarily, as is the case for HD 200120, HD 201733, and HD 23862.

c) Table 1 - Summary of stars illustrated in the Atlas

Star HD	Classification MK, ref. 1	Classification Herman-Rojas ref. 2	Summary of description
203064	O8	O9	Oe → O ; during the « Oe phase » only $H\alpha$ is an emission line.
24534	O9.5 V	O9-B0	Strong emission lines ; $H\alpha$,... (H8), FeII, HeI λ 5876, HeI-FeII $\lambda\lambda$ 5016-5018 emission, strong « veiling » effect - variable emission features ; strong decrease of emission from 1971, when the HeI absorption lines, previously hardly visible, become very distinct.
45314	O9-B0?		$H\alpha$,...$H\gamma$, HeI 5876 Å variable emission ; hydrogen shell during the minimum of emission.
184279	B0.5		B → Be ; during the « Be phase », $H\alpha$ is in emission and the variable $H\beta$ profile is sometimes disturbed by emission ; a hydrogen and temporary HeI and FeIII shell is also observed ; at the maximum of the shell strength, $H\beta$ has a reversed P Cyg profile.
200120	B1V	O9V?	$H\alpha$, ...$H\gamma$, FeII emission lines. From 1971 to 1976, very large changes, spectacular strengthening of emission - all the H, HeI, MgII, SiII, and FeII lines are affected - followed by a phase with a very strong shell composed of H, HeI, MgII, SiII, FeII, NaI and CaII ; HeI λ 5876 remains in emission ; then gradual decrease of emission and disappearance of the shell. In 1976 $H\alpha$ is not visible.
212571	B1V	B0.5III?	$H\alpha$, ...($H\delta$), FeII emission, slow variation ; sometimes $H\gamma$ or $H\delta$ has a sharp dark core.
202904	B2V	B2V-IV	$H\alpha$, ...($H\delta$), FeII emission, slow variation with minimum.
212076	B2V	B2IV	$H\alpha$,...$H\delta$ variable emission ; at the minimum of emission, $H\beta$, $H\gamma$, and $H\delta$ exhibit a sharp dark core.
33328	B2IV	B2.5III-IV	B ⇄ Be ; $H\alpha$ is very variable ; $H\beta$ and $H\gamma$ sometimes exhibit a sharp dark core.
191610	B2.5IV-V	B3.5V	B → Be ; during the « Be star » phase, $H\alpha$ and $H\beta$ are variable emissions ; $H\beta$ and $H\gamma$ sometimes exihibit a sharp dark core.
32343	B3V	B3V	$H\alpha$,...H8?, FeII emission not very variable ; weak minimum in 1961.
37657	B3Vn	B3-4V	$H\alpha$,...($H\gamma$) very variable emission ; $H\beta$ sometimes exhibits a sharp dark core.
203025	B3III	B3III	$H\alpha$, ($H\beta$) variable emission ; $H\beta$ sometimes exhibits a sharp dark core.
217050	B3III	B2III	Hydrogen and metallic shell always observed, $H\alpha$,... $H\delta$? FeII emission. Hydrogen lines and emission FeII lines exhibit a sharp dark core. The strength of the shell lines, especially MgII, SiII, NaI, and CaII, fluctuates rapidly.
142983	B3III	B2.5III?	Hydrogen and metallic shell strongly variable, $H\alpha$,... $H\gamma$ emission ; the $H\beta$ profile is very complex, of P Cyg, symmetrical, or reversed P Cyg type ; hydrogen lines always exhibit a sharp dark core of variable strength, whereas metallic shell lines are not always seen ; the NaI and CaII absorption lines vary greatly.
22192	B4V	B5IV?	Hydrogen shell always present but of rather variable strength ; $H\alpha$,... $H\delta$, FeII emission, weak variation.
224559	B4Vn	B4V	$H\alpha$,...($H\gamma$) emission, slow variation ; at the maximum of emission some FeII emission traces are observed.
201732	B4IV		Be ⇄ B ; during the « Be phase », $H\alpha$, $H\beta$, and sometimes $H\gamma$ exhibit a very variable emission ; a hydrogen shell is often seen.
43285	B5V	B6V	$H\alpha$,...($H\gamma$) variable emission ; the absorption lines MgII and SiII $\lambda\lambda$ 4128-31 are variable.
171406	B5V	B5-B6V	Be ⇄ B ; during the « Be phases » only $H\alpha$ is in emission ; $H\beta$ and $H\gamma$ sometimes exhibit a sharp dark core.
698	B5III		Spectroscopic binary ; a hydrogen and (weak) metallic shell is always present ; $H\alpha$ is in emission and $H\beta$ is disturbed by emission ; the HeI, MgII, SiII, CaII and NaI absorption lines are narrow and strong.
171780	B6V	B7V	B ⇄ Be ; during the « Be phases », $H\alpha$ and ($H\beta$) are in variable emission ; $H\beta$ or $H\gamma$ sometimes exhibits a sharp dark core ; the MgII and some HeI absorption lines seem to vary.
224544	B6Vn	B7IV?	$H\alpha$,...($H\gamma$) emission, slow variation, at the maximum some FeII emission lines are observed ; $H\gamma$ and sometimes $H\delta$ exhibit a sharp dark core.
199218	B6Vn	B7V	$H\alpha$,$H\beta$ emission, no variation ; sometimes $H\gamma$ and $H\delta$ exhibit a sharp dark core.
162428	B7Vn	B7V	$H\alpha$,$H\beta$ emission, slow variation ; temporary and very variable hydrogen shell ; in 1954 metallic shell lines are observed ; the NaI and CaII absorption lines seem very variable.
22780	B7Vn		B ⇄ Be ; during the « Be phase », $H\alpha$, ($H\beta$) are variable emission, $H\gamma$ very sporadically exhibits a sharp dark core.
6811	B7III	B9III	$H\alpha$ emission, slow variation.
162732	B7	B6V?	Spectroscopic binary ; Be → B ; during the « Be phase », $H\alpha$ is an emission, $H\beta$ also seems disturbed, and hydrogen and metallic shell is always present ; the metallic shell lines disappear when $H\alpha$ becomes a weak emission, whereas the hydrogen shell lines disappear only when $H\alpha$ is a marked absorption ; the NaI and CaII absorption lines are always very strong during the emission phase.
142926	B7	B8V	B → Be ; during the « Be phase », $H\alpha$ is an emission, $H\beta$ also seems disturbed, and a hydrogen and metallic shell appears ; the NaI, CaII, MgII, and SiII absorption lines strengthen just before the appearance of emission.
23862	B8	B8IV	$H\alpha$,...$H\gamma$ variable emission ; FeII in emission to 1968 ; large decrease of emission in 1971 and appearance of a strong hydrogen and metallic shell, the NaI and CaII absorption lines become very strong.
193182	B8		Strong hydrogen and metallic shell always present and not very variable ; $H\alpha$ is an emission and $H\beta$ is also disturbed ; the NaI and CaII absorption lines are particularly strong.
21641	B9Vn	B9V	$H\alpha$, $H\beta$ emission, not many changes.
205551	B9III	B9III	$H\alpha$ weak emission, not many changes.
195325	A0	A0IV?	Very strong hydrogen and metallic shell (at this dispersion $H\alpha$ is an absorption) ; The NaI and CaII absorption lines are particularly strong.
41511	A2	A0III?	Spectroscopic binary ; very strong hydrogen and metallic shell ; $H\alpha$ is a weak emission ; the NaI and CaII absorption lines are very strong.

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