HOW STRONG IS THE EVIDENCE OF SUPERIONIZATION AND LARGE MASS OUTFLOWS IN B/Be STARS?

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НАСКОЛЬКО СИЛЬНЫ ДОКАЗАТЕЛЬСТВА СУПЕРИОНИЗАЦИИ И БОЛЬШОЙ ПОТЕРИ МАССЫ В ЗВЕЗДАХ ТИПА В/Бе?

Изучается проблема спектроскопического диагностика суперрионизации и большой потери массы у звезд типа В, выведенных через ультрафиолетовые резонансные линии C IV, Si IV и N V. Эффекты перекрытия вблизи этих линий были оценены при помощи сети теоретических спектров, подсчитанных для моделей звезд главной последовательности и сверхгигантов в пределах температуры с 8000 до 40 000 К. Показывается, что спектры сверхгигантов могут для этой цели удовлетворительно симулировать спектры Be звезд. Основные результаты следующие: 1. фотосферические линии C IV возможно наблюдать у звезд спектрального типа B2 и более ранних, Si IV у звезд B8 и более ранних и N V для практически всех O звезд. 2. Перекрытие многочисленных линий Fe III создает фиктивные линии, которые по близости симулируют C IV в его локационном положении для средние и быстро вращающихся B3—B8 звезд. Подобно, больше всего линии Fe II, которые доминируют в спектрах сверхгигантов типа A2 (или звезд с оболочкой), создаются в случаях звезд B7 и более позднего типа две фиктивных линии очень похожих на дублет C IV смещений на приблизительно — 1050 км/сек. 3. Линии Si IV остаются почти те же, что и в исследуемом интервале температуры, но перекрытие линий вызывает кажущуюся асимметрию обеих дублетов при каждом звезд типа B3—B8, которую возможно легко ошибочно интерпретировать как эффект потери массы. Двое подобных черты возникают в случае спектров расширенных средних и большим вращением для звезд A0 и более позднего типа. Эти черты напоминают линии Si IV со скоростью около — 200 км/сек. 4. Многочисленные перекрытия линий в интервале 1225—1235 Å могут ошибочно интерпретироваться как (неразрешенные) линии N V, смещенные на — (1000—2000) км/сек для спектров звезд позднего типа В или В типа. Области суперрионизации являются соединенными с В компонентами, которые являются между двумя системами типа W Ser. Суперрионизация возможно также ожидать в случаях ранних звезд типа В, у которых известны резонансные линии O VI, хотя исследование подобное настоящему желательно. Но кажется, что все доказательства основанные на наблюдениях линий C IV, Si IV и N V не так достоверны как считают до сих пор. „Узкие линии“ ультрафиолетовых резонансных линий и профили типа P Cyg указывают на большое поле скоростей для некоторых Be звезд. Но это линии не суперрионизированы относительно атмосферы звезды.

The problem of the spectroscopic diagnostics of superionization and large mass outflows in B stars via the UV resonance lines of the C IV, Si IV, and N V has been investigated. The effects of line blending in the neighbourhood of these lines were estimated by means of a grid of theoretical spectra, computed for the main-sequence and supergiant model atmospheres in the range of effective temperatures from 8000 to 40 000 K. It is argued that the supergiant spectra may simulate the spectra of Be envelopes reasonably well for this purpose. The principal results are the following: 1. The photospheric C IV lines should be observable for stars of the spectral type B2 and earlier, those of Si IV for B8 stars and earlier, and those of N V for practically all O stars. 2. Blends of numerous Fe III lines produce two fictitious lines, closely simulating the C IV doublet at its rest wavelengths, for moderately and rapidly rotating B3—B8 stars. Two similar fictitious lines, very reminiscent of the C IV doublet with a velocity of about —1050 km/s, are produced by mainly Fe II lines in the B7 and later-type atmospheres, being prominent for the A2 supergiant (or shell) atmospheres. 3. The Si IV lines remain almost undisplaced in the temperature range of B stars but the blending causes an apparent asymmetry of both lines in B3—B8 stars, which may easily be misinterpreted as an effect of mass loss. Two spurious features develop for moderately to rapidly rotationally broadened spectra of A0 and later-type stars which may mimic the Si IV lines with velocities of some — 200 km/s. 4. Numerous blends in the wavelength region 1225—1235 Å may be misinterpreted as the (unresolved) N V lines, blue-shifted for 1000—2000 km/s, in rotationally broadened spectra of late O and B stars. Superionized regions appear to be associated with the B-type mass-gaining components of W Ser binaries. Superionization may also be present in early-B stars showing the O VI resonance lines (though a study similar to the present one would be desirable) but all the evidence of superionization based on observations of the C IV, Si IV, and N V lines appears to be much less safe than believed so far. Large velocity fields are still indicated by the so-called "narrow components" of the UV resonance lines, and by the P Cyg line profiles, for some B/Be stars but these lines are not usually superionized with respect to the stellar atmosphere.
1. Introduction

One of the most surprising findings in the UV spectra of B stars has been the discovery of strong resonance lines of C IV, Si IV, and N V, corresponding apparently to a higher degree of ionization than expected for the respective photospheres (c.f. Bohlin, 1970; Morton et al., 1972a, b; and many subsequent reports, some of which will be mentioned later).

Further studies indicated that one should, in fact, distinguish three different phenomena:

i. occurrence of strong, broad and sometimes asymmetric resonance lines, which are observed either near the expected laboratory wavelengths or with large negative displacements typically of about 1000 km/s;

ii. occurrence of so called “narrow components” of these (and other) resonance lines (with the total width usually less than some 200 km/s), which are always blue-shifted by at least several hundreds of km/s; and

iii. occurrence of the emission resonance lines of these and other ions, associated with the mass-gaining B-type components of certain strongly interacting binaries.

The narrow, blue-shifted absorption components in the spectra of B stars seem to represent a continuation of the same phenomenon observed for luminous O stars. The available observational evidence indicates that these lines vary strongly in intensity but never in radial velocity in O stars. In the case of ζ Oph (09.5 Ve) such a conclusion is based on more than 10 years of UV observations (see, e.g., Willis, 1983). The same type of behaviour is also known for some B stars (for instance, for a Be star KX And (Śtefl, 1985), which, incidentally, is a strongly interacting binary). For other B stars, however, even the radial-velocity changes of the narrow components are observed, although a “memory” for particular radial-velocity values still exists (see the excellent review by Henrichs, 1984, and references therein). Reviewing briefly this problem, Harmanec (1983) tentatively suggested that the narrow components of the C IV, Si IV, and N V lines occur only in B stars of spectral types earlier than B 3. His conclusion seems to be well supported by the results of Henrichs (1984) based on a much larger sample of stars. [Narrow components of the resonance lines are sometimes seen in the UV spectra of the B 6e star 9 CrB — see Doazan et al. (1984a) and Underhill (1985) — but always with radial velocities less than some 100 km/s. They thus probably represent a different phenomenon.]
B 6e star β CrB. These lines, observed with the radial velocities of only about −100 km/s, disappeared completely several times during last few years of UV observations.

The emission lines of C IV, N V, Si IV, Al II and other ions were discovered by Plavec and Koch (1978) in the UV spectra of several strongly interacting binaries. Plavec (1980) proposed that such objects be called W Serpentis stars, according to the prominent member of the group. It has been objected that the observed emission lines may originate in the transition region between the chromosphere and corona associated with the cool secondaries of these systems. However, such emissions are observed also in β Lyr, a system composed of two B stars. Moreover, the fact that most of the W Ser stars are eclipsing binaries allowed Plavec et al. (1982b) and Plavec (1983a, b) to obtain observations during eclipses and to demonstrate convincingly that the emission lines are associated with the (mass-gaining) B-type components also in several other W Ser binaries. Moreover, studying U Cep, a well-known binary with a B 7 V primary and a G 8 III secondary, Plavec (1983a) arrived at a very important finding that the same circumstellar material, responsible for the C IV etc. emissions, produces the C IV, etc., absorption lines when projected against the disk of the B 7 component in a different orbital phase! Recently, Peters and Polidan (1984) reported observations of variable broad absorption lines of C IV, Si IV, N V, etc., for the mass-gaining B-type primaries of several other interacting Algol binaries.

The above-mentioned observational facts represent a number of puzzles from the point of view of our current ideas about the atmospheric structure of B/Be stars.

Here, we shall leave aside the question of the narrow components as well as the question of superionization in the W Ser binaries. Very briefly, a number of hypotheses has been suggested dealing with various aspects of the problem. Excellent reviews of the hypotheses dealing with the narrow absorption components (and rejection of most of them by confrontation with the detailed observations) have been presented by Henrichs (1984) and by Howarth (1984). The superionization, evidenced by the emission and absorption lines in the W Ser and other interacting binaries, has been interpreted by Kondo et al. (1981) and by Plavec and his collaborators as being caused by the accretion of matter due to mass exchange between the binary components but there are still some problems with this interpretation (see, e.g., Plavec et al., 1982b; Plavec, 1983b).

We shall concentrate primarily on the problem of broad, often asymmetric, and often blue-shifted features ascribed to the C IV, Si IV, and N V resonance lines. The essence of the enigma consists in the following: If one interprets the observed features as true C IV, etc., lines, two physical phenomena are inevitably invoked:

i. superionization — due to the mere presence of the lines; and

ii. (variable) mass flux — due to their shifts and/or asymmetries — in the atmospheres of these stars.

This finding prompted Thomas, Doazan and collaborators (see Chapter 13 in Underhill and Doazan, 1982, and references therein; Doazan and Thomas, 1983; Thomas, 1983) to extend the previous ideas about the general scheme of stellar atmospheric regions (Pecker et al., 1973; Thomas, 1973) and to advertise on many occasions an “empirical-theoretical” model of the atmospheric structure of B/Be stars.

Recently, Thomas (1983) has formulated quite general ideas about the stellar atmospheric structural patterns of all types of stars. In essence, he argues that stellar atmospheres, in a wide sense, can no longer be modelled as closed thermal systems. He stresses that not only the radiative energy flux, but also the mass flux and non-radiative energy flux should be considered as independent model parameters. He postulates the existence of a radial sequence of several distinct atmospheric regions differing in the type of balance of the dominant energy fluxes. Some observational evidence is employed to argue that such a basic picture must apply to all types of stars; other observational evidence (particularly the variability of a given star and the differences in the detailed behaviour of spectra between otherwise similar stars) is understood in terms of an “individuality” of the “real-world” stars, and/or in terms of intrinsic variations of the non-radiative energy input.

As stressed by Thomas (1983), the methodological importance of B/Be stars lies in their "cross-road" character — i.e., some of their observed properties may be viewed as a continuation of the behaviour found in other spectral types (e.g., in WR stars, O B supergiants, planetaries, T Tauri stars, symbiotic stars, etc.). Therefore, the B/Be stars represent one of the most important clues to understanding general stellar atmospheric physics.

The mere existence of “superionized” and “high-velocity” regions plays the crucial role not only in Thomas’ argumentation mentioned above, but also in some alternative theoretical approaches to the problem (see, e.g., Lamers and Snow, 1978; Cassinelli
and Gregor, 1982, and references therein). Our title question "How strong is the evidence of superionization and large mass outflows in B/Be stars?" thus appears to be very important and hence worth the effort to answer it more specifically.

2. The Motivation of the Present Study

As explained above, the observations of the C IV (Si IV, NV) lines in the spectra of B/Be type stars have led to far-reaching conclusions concerning not only the atmospheric structure of the B/Be stars, but also quite general stellar atmospheric structural patterns.

However, not all these conclusions are easily acceptable when confronted with other existing observational evidence. This is well documented in papers and discussions of the Munich and Hvar conferences (Jaschek and Groth, 1982; Harmanec and Pavlovski, 1983).

To put the basic methodological problem — what can really be inferred from the observed data? — into sharp focus, let us quote Thomas (1983, p. 185): "The Be stars, especially in a few well-studied examples, like 59 Cyg and γ Cas, exhibit a melange of both episodic and continuous mass-ejection, in both visual and far UV spectra — when we understand how to diagnose the data, in terms of thermodynamic consistency of spatial evolution of atmospheric regions." This phrase represents, in some sense, the basic philosophy of the proponents of the variable mass flux hypothesis of the Be phenomenon.

However, we would like to stress explicitly, and also demonstrate numerically, that the "philosophy" so posed is not quite internally consistent. Indeed, in order to be able to speak of "exhibiting a melange of both episodic and continuous mass-ejection", one has to be sure that the observed data really indicate a mass-ejection, i.e. to really understand "how to diagnose the data". Yet the great majority of recent investigations of the far UV resonance lines does not pay any attention to the apparently trivial but in fact a very serious problem of line blending in the UV spectra of early-type stars. Modest attempts to bring this question into focus (see, e.g., Kurucz, 1974; Harmanec, 1982) were usually ignored. However, to "understand how to diagnose the data" would necessarily imply a crucial question, which should be viewed as superior to any further interpretation: Do the observed features (e.g. in the region of the C IV resonance lines) really and unambiguously represent the expected lines (i.e. the true C IV lines)?

And, furthermore, do their observed asymmetries and/or shifts necessarily imply velocity fields?

The rest of the quotation, "in terms of thermodynamic consistency of spatial evolution of atmospheric layers" has thus rather the meaning, in the context of the B/Be stars, of an ad hoc postulate (and notice that, otherwise, ad hoc postulates are strongly criticized by Thomas), unless the above basic diagnostic problem — the identification of lines — is sufficiently well understood.

Therefore, it seems quite reasonable to focus attention on the problem of the UV line blending. As we shall show in this paper, an application of current spectrum synthesis techniques lead to very surprising and unexpected results which clearly demonstrate that a straightforward interpretation of the observed far UV spectral features may be quite misleading in particular cases.

3. The Method of Physical Description Used

a) Computational Approach

The importance of a careful treatment of line-blending effects has already been demonstrated by Kurucz (1974), who has carried out a sample calculation of the spectral region in the vicinity of the C IV resonance doublet for the classical model atmosphere with \( T_{\text{eff}} = 25,000 \text{ K}, \log g = 4 \). He has shown that neither a continuum level, nor reliable line equivalent widths may be directly determined from observed spectra without detailed spectrum synthesis calculations. In particular, the observed absorption features in the ultraviolet are virtually always blends of many lines; hence, both their central wavelengths and profiles, are rather complicated functions of blending and rotation. Consequently, if misinterpreted as Doppler shifts, the apparent displacements and profile asymmetries may easily yield quite erroneous conclusions about the presence as well as the magnitude of atmospheric velocity fields, chemical composition, superionization, etc.

However, it is not clear, whether and how one can apply the current spectrum synthesis techniques to modelling the Be spectra. Indeed, had we aimed at fitting theoretical predictions to observations of real stars, we would have been faced with serious conceptual problems which are far from being understood at present. We could have either attempted a self-consistent description of the system star + circumstellar envelope, which is clearly beyond the present state of the art (both on the physical as well as numer-
ical level), or to deal with parametrized schematic models. Yet, the number of such empirical parameters would be enormous and, hence, the practical usefulness of such an approach would be at least questionable.

Nevertheless, we do not aim at detailed modelling of the atmospheres of Be stars, neither do we intend to propose an actual model. The primary objective of this study is to stress the crucial importance of a careful interpretation of the observed UV features by means of the spectrum synthesis. To this end, we may avoid an unnecessarily complicated description and simply assume that the circumstellar envelope may simulate a cooler, classical stellar atmosphere. The observational evidence supporting this picture will be summarized in Subsection 3b, and further discussion will be presented in 6b.

Leaving aside, for a while, the questions concerning the geometrical configuration of the envelope (e.g. its extent, orientation, etc.), or its actual physical state (temperature, density, rotation, expansion, etc.) we may ask: Provided that the envelope is represented, as regards its emergent radiation, by a classical stellar atmosphere, what is the behaviour of the predicted spectrum in the vicinity of the C IV (Si IV, N V) resonance lines? In particular, it should be clarified whether the line blending effects can give rise to a spurious asymmetry, shift, or even apparent presence of the C IV (Si IV, N V) lines.

Therefore, it seems quite reasonable to calculate detailed synthetic spectra for a variety of classical stellar atmospheres. As explained above, we shall not limit ourselves to the atmospheric parameters $T_{\text{eff}}$ and $\log g$ appropriate for B stars, but we shall rather consider a wide range of effective temperatures ($8000 \leq T_{\text{eff}} \leq 40000$ K) and surface gravities ($2 \leq \log g \leq 4$). These calculations are expected not only to provide the relevant diagnostic information about the origin of the UV spectral features observed in normal O, B, A stars, but also, according to the above considerations, to yield some conclusions about the formation of the C IV (Si IV, N V) features in the observed Be spectra.

b) Observational Evidence of "Pseudophotospheres"

As already mentioned, we aim neither at constructing a real model of the Be envelope nor at specifying the geometry of Be envelopes. It should be kept in mind that there is still no general agreement as to the geometrical structure of the Be envelopes. According to currently existing -- and competing -- theories, they may be either disk-like rotating and/or expanding structures, or accretion disk and/or envelopes around mass-gaining components of binary stars, hazy structures with a high degree of clumpiness controlled by local magnetic fields, or essentially spherical structures.

Our present problem is: can the continuous radiation of the Be envelope (or its part) simulate the continuous radiation of an apparently normal stellar photosphere over a wide wavelength range? Available observations and indirect arguments seem to indicate that this is indeed the case in a number of real Be stars and related objects.

Let us first discuss the particular case of 88 Her (HD 162 732), one of the best studied Be stars during the last 20 years (c.f. Harmanec et al., 1978; Doazan et al., 1982a, b and references therein). This star exhibited characteristic long-term changes during the indicated period, which have been well documented in optical spectroscopy and photometry, and partly also by UV observations. A gradual weakening of the shell was observed by the end of sixties. In 1972, the metallic shell lines virtually disappeared and the H I shell weakened substantially. Also the H$\alpha$ emission weakened almost to the limit of detectability. This nearly-normal B phase lasted until 1977 when a new shell began to develop. Very interesting light variations, well documented by systematic $UBV$ observations, as well as by corresponding UV flux variations (see Barylak, Doazan and Thomas, 1985 – preprint), accompanied these spectral changes. The object was the brightest when the signatures of the Be envelope almost disappeared. In the $U - B/\beta - V$ diagram, a shift along the main sequence from B 8 to B 6 was observed, along with the weakening of the shell. A reverse shift to B 7 has subsequently occurred, when the shell has been developing again. Now, the modern independent spectroscopic estimates of the spectral type of 88 Her are the following: B 6 – Bidelman and Svolopulos (1960); B 6 V – Herman and Duval (1962); B 6 IV – V – Slettebak (1966); B 7 V n – Jaschek et al. (1980). More importantly, also the BCD spectrophotometry by Divan and Zorec (1982), obtained in July 1977 and in July 1980 (i.e. at the beginning and after the development of the new shell), invariably indicates the spectral type B 6 IV for the underlying star.

Doazan et al. (1982a, b) also observed the apparent long-term variations of the central intensity of the photospheric He I 4026 line. This line appeared stronger (thus indicating an earlier spectral subclass) when the shell lines and the H I emission were stronger – in striking contrast with photometry. However, Doazan et al. showed that these apparent variations
of the line depth can be accounted for perfectly well by the continuum variations observed.

Plavec et al. (1982a) obtained a detailed spectral energy distribution of 88 Her (over the range of 119 to 685 nm) in 1979 and found that it can be fitted very well with a Kurucz (1979) model atmosphere corresponding to a B 7 V star. At the same time, the object appeared as B 7 also in the $U-B/B-V$ diagram. Barylak et al. (1985) presented the data about the spectral energy distribution of 88 Her also for other epochs, covering the years 1973 and 1983. The energy distribution observed in 1973, when the shell was nearly absent, corresponds to a B 6 V star, while those observed in 1979 and 1983 (i.e. during the new shell phase) corresponds to a B 7 V star.

All these facts clearly indicate that the Be envelope of 88 Her has been able to simulate a stellar photosphere in the continuum radiation over a large range of wavelengths. Plavec et al. (1982a) studied the energy distribution of more shell stars. They concluded that for eleven of them this distribution can be fitted by the Kurucz model atmospheres over the whole spectral region and that no additional source of radiation is required. A closer inspection of their results indicates, however, that similar effects as described above for 88 Her can also be suspected for other shell stars they studied.

That a Be envelope can simulate a later spectral type (and lower $v \cdot \sin i$ value) is well-known and documented by the mere existence of the shell spectra. In some cases the effects are so strong that the shell spectrum may be misinterpreted as a stellar photosphere of a later spectral subtype (c.f., e.g., the case of SX Cas, Plavec et al., 1982b). Symbiotic stars and novae provide us with another examples of such a situation.

An important point, relevant to this discussion, is a recent finding by Štefl (1985). He studied the well-known Be shell star KX And (HD 218 393), which is now known to be an interacting binary with a period of 38-9 days. Recurrent shell phases occur with the same periodicity. The shell lines are clearly visible in optical spectra in only less than half of each cycle. However, Štefl found that the shell lines of the cool envelope remain visible in the UV spectra of the star even in the phases of their complete absence in the optical spectra.

Note: To avoid misunderstandings, we stress that throughout this paper we use the term “shell lines” for absorption lines presumably originating in the circumstellar envelope, no matter how narrow or broad they are.

4. Spectrum Synthesis

We have employed a set of computer programs developed by one of us (I. H.). Their detailed description will be presented elsewhere; here, we shall only emphasize several important points.

Two basic sets of input data are the physical parameters describing a given model atmosphere and a set of line data. The model atmosphere may be either an LTE or NLTE one. In the former case, the temperature, electron number density, and total mass density as functions of depth should be specified. If one considers a NLTE input model atmosphere, the populations of the prechosen NLTE atomic energy levels are also required. Here, the output from the computer code TLUSTY (see Hubeny, 1983) provides a complete model atmosphere input to the spectrum synthesis programs.

An extended and coherent grid of model atmospheres is required for our purposes. Therefore, we employ the Kurucz (1979) grid of LTE line-blanketed models; its relevance to the present study being discussed in Sect. 6.

The basic source of line data is the Kurucz and Peytremann (1975) line list. To enable more flexible manipulations with the input data sets, we have extracted several partial sets of line data for the prechosen wavelength intervals (for instance for $\lambda$ 110–140 nm, 140–170 nm, etc.), excluding a priori: i) lines of elements with atomic number greater than 30 (i.e. we consider lines of hydrogen through zinc); ii) lines of elements ionized more than four times; and iii) lines with $\log gf < -4$. These partial line-data sets were updated to include additions and corrections to the Kurucz-Peytremann data whenever better data were available. We thus employed the data of Wiese et al. (1966) for hydrogen through neon; Wiese et al. (1969) for sodium through calcium; and Kurucz (1981) for Fe II.

The absorption coefficient in a line transition $i \rightarrow j$ of a given ion (labelled ION) is given by

$$k_{ij}(v) = \frac{\pi e^2}{mc} N_{\text{ION}} \frac{g_i f_{ij}}{U_{\text{ION}}} \left(1 - \frac{b_j}{b_i} \exp\left(-\frac{h v}{kT}\right)\right) \cdot \exp\left(-\frac{E_i}{kT}\right) \cdot H(a, v),$$

where $N_{\text{ION}}$ and $U_{\text{ION}}$ are the total number density and the partition function of the ion ION, respectively; $g_i$ and $E_i$ are the statistical weight and the excitation potential of the lower level $i$, respectively; $f_{ij}$ is the oscillator strength; $H(a, v)$ is the Voigt function, $v = (v - v_{ij})/\Delta v_{p}$ being the frequency displacement from the line centre frequency, $v_{ij}$, measured in units
of Doppler widths, $\Delta v_p$. The damping parameter $a$ is given by

$$a = (\Gamma_R + \Gamma_S + \Gamma_w)/(4\pi \Delta v_p),$$

where $\Gamma_R$, $\Gamma_S$, $\Gamma_w$ represent radiative, Stark, and Van der Waals broadening parameters, respectively. They are evaluated here by the classical expressions summarized, e.g., in Kurucz and Furenlid (1979).

The quantities $v_{ij}$, $g_i$, $g_j$, and $E_i$, are provided by the input line data; the partition functions are calculated after Traving et al. (1966), and the Voigt function is evaluated using the procedure of Humlíček (1979).

The NLTE departure coefficients, $b_i$ and $b_j$, are viewed here as the prespecified functions of depth. As discussed in Sect. 6, we are satisfied with the complete LTE approach, where $b_i = b_j = 1$ for all lines. Further, $N_{\text{ion}}$ is calculated by solving the LTE state equations (i.e. a set of the Saha equations — for details refer, e.g., to Mihalas, 1978). In the same degree of approximation, the line source function is assumed to be given by the Planck function.

The computer code enables a rather involved treatment of continuum opacity sources. Nevertheless, it is satisfactory to consider only the hydrogen bound-free and free-free transitions, Rayleigh scattering, electron scattering, and sometimes (in the low-temperature models), the opacity of the Lyman-alpha wing. These mechanisms represent the dominant continuum opacity sources in the wavelength regions studied. Again, we assume LTE in the continua; the electron and Rayleigh scattering are assumed coherent. In the low-temperature models, the ground-configuration continua of C I and Si I should be, in principle, considered, but the NLTE model atmosphere calculations (Hubeny, 1981a) indicate that neglecting the C I, Si I continua is, in fact, a better approximation than their LTE treatment.

While satisfactory for the region of the C IV and Si IV lines (see also Sect. 6), this approach is questionable for the case of the region of the N V resonance doublet at 1238-81 and 1242-80 Å for the low-temperature models ($T_{\text{eff}} \lesssim 10,000$ K). This is basically due to the presence of the important discontinuity at 1240-4 Å arising from the $2p^2 1D$ level of neutral carbon. As shown by Hubeny (1981a), this jump appears in emission due to NLTE effects. Therefore, in order to estimate the importance of this phenomenon, we have computed (see Sect. 5c) the synthetic spectrum in the vicinity of the N V resonance doublet for one representative example of the NLTE model atmosphere with $T_{\text{eff}} = 10,000$ K, $\log g = 2$, with departures from LTE allowed for H, C I, Si I, S I (for more details refer to Hubený, 1981a — the type A model in the terminology of that paper).

Having specified the total opacity and source function at each depth, the calculation of the synthetic spectra consists in a straightforward solution of the radiative transfer equation. Due to the assumption of LTE and the coherence in the continuum scattering processes, the total source function does not contain a coupling of different frequencies. The transfer equation is thus solved frequency-by-frequency for a large number of frequency points. Particular care is devoted to the proper choice of the frequency points. Instead of some preselecetd frequency mesh, the frequency points are set up during the execution of the program. The program goes through the line list and first sets up a preliminary mesh that consists of the frequency points situated exactly in the line centres and in the midpoints between two immediately neighbouring lines. If the distance between any two frequency points is larger than some prechosen value (in practice taken about $\Delta \nu = 6$ fiducial Doppler widths), the program adds further frequency points to ensure a sufficiently dense spacing. This procedure thus ensures that each line from the adopted line list is really accounted for in calculating synthetic spectra and, moreover, prevents some spurious numerical effects in performing the rotational convolution that might otherwise arise due to an insufficient frequency spacing.

In solving the radiative transfer equation, a correct depth dependence of all the parameters entering the opacities is allowed for. Nevertheless, in order to appreciate the relative importance of the individual components of resulting blended features, as well as for purposes of an easy identification of lines, the program calculates an indicatory equivalent width for every single line. The latter quantity is determined by the standard procedure of the classical radiative transfer theory (see, e.g., Mihalas, 1978, § 10.3). For this purpose only, one replaces the actual model atmosphere by a constant-property atmosphere with $\Delta v_p$, $a = k_{ij}(v_{ij})/k_{\text{total}}(v_{ij})$ given by their actual values in some prechosen characteristic layer (taken usually as the depth where the monochromatic continuum optical depth at the wavelength under study is about $0.1-0.5$).

The final step consists in calculating the rotationally broadened spectra. We adopted a simple procedure (see Gray, 1976), with the limb-darkening parameter $e = 0.6$. The rotationally broadened spectrum may further be convolved with an instrumental profile, which enables direct comparison with observations. All the subsequent calculations were performed.
assuming the Gaussian instrumental response function with the FWHM equal to 0.14 Å, which corresponds to the mean FWHM value of the high resolution IUE short wavelength spectrograph.

5. The Theoretical Spectra Near the C IV, Si IV, and NV Lines

As explained above, we have modelled the theoretical spectra in the neighbourhood of the UV resonance lines using the LTE plane-parallel model atmospheres. The temperature sequences of the models have been computed for the log $g$ values corresponding to normal main-sequence stars as well as to supergiant stars. The idea is to model the effects of the cooler Be envelopes via the effects of supergiant atmospheres. It is well known that the shell spectra are reminiscent of the spectra of late B or early A supergiants. Moreover, the effective radii of the Be envelopes are often estimated to be about 3 to 30 times larger than those of the underlying stars. The radii of the B supergiants are typically 3 to 15 times larger than those of the corresponding main-sequence B stars (c.f. Underhill and Doazan, 1982) — quite a comparable number. These rough considerations indicate that our spectrum simulation may not be so irrelevant even as regards the relative intensity of the spectral lines.

A typical observed rotational velocity ($v \cdot \sin i$) of a Be star is about 200–300 km/s. It is known, however, that lower rotational velocities were observed for the lines in the UV spectral region. A part of the effect can be explained by the gravity darkening (c.f. Hutchings, 1976), but values as low as about 100–150 km/s, observed for ζ Tau, for example, cannot be accounted for in this way for stars with $v \cdot \sin i$ in excess of 300 km/s — see Hutchings et al. (1979).

These authors and Harmance (1984) proposed that the observed difference may represent a real stratification, i.e. that the UV lines are in fact the shell lines. We, therefore, present the results of our computations for three values of $v \cdot \sin i$, namely 20, 100, and 300 km/s. All the spectra are plotted as relative spectra with respect to the theoretical continuum and can thus be directly compared. More precisely, the calculated synthetic spectra (i.e. the emergent flux from 1 cm$^2$ of the stellar surface) is normalized to the average value of the theoretical continuum flux over the respective frequency regions.

a. The C IV Lines at 1548-199 and 1550-770 Å

The theoretical spectra in the neighbourhood of the C IV resonance doublet are shown in Fig. 1a, b, c.
Fig. 1. A grid of theoretical spectra in the neighbourhood of the C IV resonance lines. The \((T_{\text{eff}}, \log g)\) values are specified on the right-hand side of the diagrams for each model spectrum shown. The spectra corresponding to the main-sequence atmospheres are shown by full, and those for supergiant atmospheres by dashed lines. a) \(v \sin i = 20 \text{ km/s}\); b) \(v \sin i = 100 \text{ km/s}\); c) \(v \sin i = 300 \text{ km/s}\).
1. Our computations show that the C IV lines are observable for effective temperatures higher than about 20 000 K. This means that their presence in B0–B2.5 stars does not represent any evidence of superionization.

2. In the temperature range of about 15 000 to 20 000 K the numerous blends of the Fe II lines produce two features in the rotationally broadened spectra which closely simulate the C IV doublet in its laboratory position! The radial velocities of these features (measured for $v \cdot \sin i = 100 \text{ km/s}$ in Fig. 1b as being the C IV lines) range from +10 to −70 km/s.

3. Below about 15 000 K, two new features develop at about 1542-5 and 1545 Å, which again simulate the C IV doublet remarkably well — now with the radial velocity of both components of about −1020 to −1090 km/s! These features are produced mainly by the blends of Fe II and some other lines and are dominant around effective temperatures of about 8 000–10 000 K, i.e. typical temperatures of the Be envelopes! At temperatures around 12 000–13 000 K both shifted and unshifted features coexist, though they are not very conspicuous there. The principal (strongest) blending contributors producing these artificial broad lines are listed in Tab. 1 for two characteristic temperatures: 16 000 K, and 9000 K.

b. The Si IV Lines at 1393-754 and 1402-770 Å

The computed theoretical spectra in the neighborhood of these lines are shown in Fig. 2 and the strongest blending lines are listed in Tab. 2. The results are the following:

1. The real Si IV lines disappear only at temperatures below 12 000 K. This indicates again that the presence of the Si IV lines in B stars earlier than B9 does not represent any evidence of superionization.

2. The inspection of Fig. 2 reveals that for $v \cdot \sin i = 100 \text{ km/s}$ the blends produce extended violet wings of both of the Si IV lines in the temperature range of 12 000 to 20 000 K, reminiscent of the "wind" profiles. These would almost certainly be misinterpreted as signatures of a mass outflow from the star by most investigators! Notably, an opposite asymmetry of both lines develops for $v \cdot \sin i = 300 \text{ km/s}$.

3. Two features which may be misinterpreted as the Si IV doublet develop at about 10 000 K, and are quite strong at 8000 K. Their "radial velocities" range from −140 to −250 km/s.

---

**Table 2**

A list of stronger spectral lines contributing to the blends in the neighborhood of the Si IV resonance lines.

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>Ion</th>
<th>$\log gf$</th>
<th>$W$(mÅ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1392.813</td>
<td>Fe II</td>
<td>−0.24</td>
<td>43</td>
</tr>
<tr>
<td>1393.323</td>
<td>Ni II</td>
<td>−0.96</td>
<td>54</td>
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<tr>
<td>1394.710</td>
<td>Fe II</td>
<td>−2.55</td>
<td>20</td>
</tr>
<tr>
<td>1401.540</td>
<td>S I</td>
<td>−1.10</td>
<td>33</td>
</tr>
<tr>
<td>1401.769</td>
<td>Fe II</td>
<td>−0.98</td>
<td>29</td>
</tr>
<tr>
<td>1401.937</td>
<td>Fe II</td>
<td>−3.60</td>
<td>19</td>
</tr>
<tr>
<td>1403.098</td>
<td>Fe II</td>
<td>−2.05</td>
<td>32</td>
</tr>
</tbody>
</table>

---

c. The N V Lines at 1238-81 and 1242-80 Å

The theoretical spectra of these lines are shown in Fig. 3 and the principal blending lines listed in Tab. 3. Our results are not as straightforward as for the C IV and Si IV lines. It seems that the true N V lines should be unobservable in B stars, but the presence of the N V lines in the O spectra again does not indicate any superionization. Features reminiscent of the red-shifted N V lines develop below about 15 000 K. Moreover, numerous blends occur in the wavelength range of 1225 to 1235 Å over the whole temperature range studied. Considering the low efficiency and limited resolution of the IUE in the neighbourhood of the N V lines, and the fact that the individual components of the doublet are often not resolved, it is possible that the above-mentioned blends could be misinterpreted as strongly blue-shifted N V lines in particular cases.

The above results for the N V region have been obtained using the same procedure as for the C IV and Si IV regions, i.e. adopting Kurucz’s LTE model atmospheres. To illustrate the effects of NLTE model atmospheres mentioned in the preceding section, we have compared the spectra calculated with the
Fig. 2. Same as Fig. 1 but for the Si IV lines.
Fig. 3. Same as Fig. 1 but for the N V lines.
Table 3
A list of stronger spectral lines contributing to the blends in the neighbourhood of the $\text{N V}$ resonance lines

A. The $T_{\text{eff}} = 16000$ K, log $g = 2.0$ model

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>Ion</th>
<th>log $gf$</th>
<th>$W$ (mÅ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1232-438</td>
<td>S II</td>
<td>-0.69</td>
<td>40</td>
</tr>
<tr>
<td>1234-149</td>
<td>S II</td>
<td>-2.36</td>
<td>28</td>
</tr>
<tr>
<td>1235-517</td>
<td>Cr III</td>
<td>-0.60</td>
<td>29</td>
</tr>
<tr>
<td>1239-240</td>
<td>Mn III</td>
<td>-1.42</td>
<td>20</td>
</tr>
<tr>
<td>1239-254</td>
<td>Mn III</td>
<td>-1.54</td>
<td>19</td>
</tr>
<tr>
<td>1243-170</td>
<td>N I</td>
<td>-1.47</td>
<td>19</td>
</tr>
<tr>
<td>1243-178</td>
<td>N I</td>
<td>-0.31</td>
<td>36</td>
</tr>
<tr>
<td>1243-305</td>
<td>N I</td>
<td>-0.50</td>
<td>34</td>
</tr>
<tr>
<td>1243-313</td>
<td>N I</td>
<td>-1.46</td>
<td>19</td>
</tr>
</tbody>
</table>

B. The $T_{\text{eff}} = 9000$ K, log $g = 2.0$ model

<table>
<thead>
<tr>
<th>$\lambda$</th>
<th>Ion</th>
<th>log $gf$</th>
<th>$W$ (mÅ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1233-323</td>
<td>S I</td>
<td>-1.75</td>
<td>13</td>
</tr>
<tr>
<td>1233-358</td>
<td>S I</td>
<td>-1.00</td>
<td>20</td>
</tr>
<tr>
<td>1233-438</td>
<td>S II</td>
<td>-0.69</td>
<td>27</td>
</tr>
<tr>
<td>1233-660</td>
<td>Fe II</td>
<td>-0.92</td>
<td>19</td>
</tr>
<tr>
<td>1238-257</td>
<td>Fe II</td>
<td>-1.20</td>
<td>18</td>
</tr>
<tr>
<td>1239-339</td>
<td>S I</td>
<td>-1.75</td>
<td>15</td>
</tr>
<tr>
<td>1239-370</td>
<td>S I</td>
<td>-1.28</td>
<td>20</td>
</tr>
<tr>
<td>1239-871</td>
<td>Fe II</td>
<td>-0.73</td>
<td>19</td>
</tr>
<tr>
<td>1239-925</td>
<td>Mg II</td>
<td>-3.53</td>
<td>28</td>
</tr>
<tr>
<td>1240-395</td>
<td>Mg II</td>
<td>-3.83</td>
<td>26</td>
</tr>
<tr>
<td>1242-044</td>
<td>Fe II</td>
<td>-1.80</td>
<td>20</td>
</tr>
<tr>
<td>1242-073</td>
<td>S I</td>
<td>-1.63</td>
<td>17</td>
</tr>
<tr>
<td>1243-170</td>
<td>N I</td>
<td>-1.47</td>
<td>37</td>
</tr>
<tr>
<td>1243-178</td>
<td>N I</td>
<td>-0.31</td>
<td>55</td>
</tr>
<tr>
<td>1243-305</td>
<td>N I</td>
<td>-0.50</td>
<td>44</td>
</tr>
<tr>
<td>1243-313</td>
<td>N I</td>
<td>-1.46</td>
<td>37</td>
</tr>
</tbody>
</table>

6. Uncertainties of the Adopted Procedure

Above all, we should answer the following question: May we expect the results presented above to represent real stellar spectra? In view of the two-fold significance of our results, we should discuss two separate questions concerning

i. the intrinsic limitations of the spectrum synthesis procedure; and

ii. the relevance of the adopted model to mimic the actual atmospheric pattern of Be stars. We shall discuss both of them in turn.

a. Intrinsic Limitations of the Spectrum Synthesis

From the interpretational point of view, this problem is linked with the relevance of the theoretical spectra to matching observations of presumably "normal" stellar photospheres. The reliability of our spectrum synthesis procedure depends primarily on the following factors:

1. The accuracy of the atomic data: Among them, the uncertainties in the $gf$-values, wavelengths and in the intrinsic line profile parameters (damping constants) most likely represent the major source of possible errors; uncertainties in other parameters (e.g. partition functions) do not probably affect the resulting theoretical spectra in a substantial way. Another important factor is the completeness of the adopted line list.

The line list we used (see Sect. 3) is neither complete nor free of significant errors in $gf$-values. However, as demonstrated by Burger (1981), the accuracy of the $gf$-values need not be as critical as might seem at first sight. Indeed, when calculating synthetic spectra with as accurate $gf$-values as possible, and then with a constant value of log $gf = -0.5$ for all considered lines, she has found that all the gross features in the theoretical spectra retained a very similar appearance. Although she has considered only one representative model atmosphere ($T_{\text{eff}} = 10000$ K, log $g = 2.0$) and one spectral region (4895 to 2595 Å), her results still indicate, quite generally, that small errors in the $gf$-values are acceptable when calculating theoretical UV spectra where virtually all spectral features are blends of several lines. The accuracy of damping factors has been analysed, for instance, by Peytreman (1972); again, it appears that the classical damping parameters are a good substitute for the lines for which no accurate damping parameters are known.

It should be stressed again that our primary objective is to examine some general trends of the behaviour

![Fig. 4. A comparison of the LTE and NLTE model spectrum ($T_{\text{eff}} = 10000$ K, log $g = 2.0$) in the neighbourhood of the $\text{N V}$ resonance lines.](image-url)
of theoretical spectra for a wide range of model atmospheres. Thus, even if a single theoretical spectrum may be affected by the above-mentioned uncertainties, the substantial features of the trends in synthetic spectra when passing from early spectral types to the later ones are most probably represented quite realistically.

2. The assumption of LTE: One should recognize the two-fold significance of this assumption. First, we use a grid of LTE model atmospheres, and, second, the lines are supposed to be formed in LTE.

Generally, the LTE approach can be proved satisfactory using exactly the same arguments as those presented above. Moreover, for the purpose of studying the systematic trends in the theoretical spectra for a wide range of spectral types, Kurucz's (1979) grid represents the most complete and coherent grid available at present. For certain spectral types, where NLTE models are available, the spectrum synthesis would yield some differences caused by both different atmospheric structure (the run of temperature, density, etc., with depth), and by different continuum source function. However, the existing NLTE models (for a review see Mihalas, 1978) do not treat the influence of metal line blanketing properly (with the exception of the very recent work of Anderson, 1985). Anyway, significant differences in the atmospheric structure between the LTE and NLTE models arise mainly in the most superficial layers which have little influence on the formation of all but the strongest lines.

Concerning the assumption of the LTE for the formation of lines, a similar justification may be given. Roughly speaking, the departures from LTE are pronounced primarily in the cores and to a lesser extent in the wings of resonance lines, while weak and/or subordinate lines are usually influenced little by departures from LTE. Since we are studying particularly the effects of blending of lines, most of them being subordinate and weak lines, the LTE approach seems quite satisfactory for the exploratory calculations presented here.

The crucial resonance lines of C IV (Si IV, N V) may certainly be affected by NLTE effects. Yet, we are basically interested in the global behaviour of theoretical spectra in the neighbourhood of these lines, rather than in calculating their detailed profiles. Therefore, possible NLTE effects can probably somewhat change the relative magnitudes and profiles of resulting blends, but can hardly change the overall behaviour and trends of the theoretical spectra. Moreover, the most interesting result — the formation of the fictitious C IV lines — is virtually insensitive to the possible NLTE effects in C IV.

A specific problem concerns the spectral region in the vicinity of the N V resonance doublet in the low-temperature models. Regardless of the type of model atmosphere employed (LTE or NLTE), there is a large uncertainty in the theoretical spectra due to the presence of a number of high-order members of the spectral series $2p^2 \, ^1D \rightarrow nd \, ^1D^0$, $2p^2 \, ^1D \rightarrow nd \, ^1P^0$, $2p^2 \, ^1D \rightarrow nd \, ^1F^0$ of neutral carbon, in the region between 1240 and 1250 Å, which are mostly missing in the adopted line list. Moreover, for the NLTE model atmospheres, these lines are predicted to be in emission (Hubeny, 1981b). Consequently, the N V region for the low-temperature models would have, in reality, a much more complex behaviour than that displayed in Figs 3 and 4.

A detailed comparison of our theoretical spectra with the observed spectra is beyond the scope of this paper and will be presented elsewhere. Here, we only remark that we have verified, on several published UV spectrograms of B and A stars, that our model spectra reflect most of the features observed in the vicinity of the studied resonance lines quite satisfactorily. This is true for both main sequence and supergiant stars.

b. The Relevance of the Adopted Model for Be Stars

Since we represent a complex circumstellar envelope by a classical stellar atmosphere, it is clear that our theoretical spectra cannot be used directly to interpret the actual observations of Be stars. This problem has already been partly discussed at the beginning of Section 5. Only some more general considerations are thus presented here.

From the physical point of view, the problem of determining a theoretical spectrum of a circumstellar envelope would require, in principle, a careful examination of a number of important problems, e.g., the departures from a plane-parallel stratification, a finite and non-uniform optical thickness of the envelope, non-uniform effective temperature (more generally, a non-uniform total radiative energy flux), non-radiative energy flux, velocity fields, etc. Also, the simple rotational convolution we have used is generally inapplicable to (even if physically quite simplified) circumstellar envelopes. However, given the lack of detailed studies of theoretical UV spectra of Be stars, it seems quite reasonable to elaborate the simplest physical model in some detail.

From the methodological point of view, the basis of our philosophy lies in the following point: spectroscopic diagnostics inevitably rely on the proper and unambiguous identification of observed spectral
features, particularly in the UV region where this represents a mostly overlooked, yet non-trivial problem. No physical modelling based on observations of certain spectral features can be viewed as reliable without a careful consideration of the effects of line blending. Just one illustrative example: a first-order estimate of the effects of outflow velocities in the envelope may simply be obtained (without solving the transfer equation) by shifting the corresponding spectral features calculated for a non-moving medium by an appropriate wavelength; but there is no way of getting a qualitative picture of the global appearance of the theoretical spectrum (blends, spurious shifts, etc.) without performing the detailed (and, unfortunately, very cumbersome) spectrum synthesis calculations.

In spite of gross simplifications, our synthetic spectra agree surprisingly well with the observed spectra of certain Be stars (see Stefl, 1985). Moreover, our procedure offers a straightforward explanation of some observed features, which otherwise invoke "superionization" or a large "mass outflow". Thus, from the interpretational point of view, this gives even more credence to the adequacy of our spectrum synthesis procedure than would follow from a purely theoretical viewpoint.

7. Conclusions

We summarize our main results below:

1. The model spectra indicate an exciting possibility that the phenomena observed in the UV spectra of B-type stars, and so far interpreted as evidence of superionized regions around these stars, can in fact be in some cases manifestations of the variable subionized Be envelopes, well known from optical spectra! A distinct possibility exists that the appearance of the UV spectra of B stars is more sensitive to the slight variations of the Be envelopes. In other words, it is possible that some shell lines of the Be envelope are observable in the UV spectra even when these lines are virtually unobservable in the optical spectra. In yet other words: it is possible that some reports of "superionization" in absorption-line B stars in fact represent discoveries of these stars as weak Be stars. This possibility should be investigated further.

2. Our results explain quite naturally why the observed "C IV" lines are the subject of much larger variations than the (usually well-behaved) Si IV lines: the blending effects near the Si IV lines are much less severe than in the neighbourhood of the C IV lines. A closer inspection of the spectra, presented in Sect. 5, indicates that the principal conclusions of the statistical studies, quoted in Sect. 1, are quite understandable in the light of our alternative explanation. Moreover, it seems that our theoretical spectra reflect many features seen in the observed spectra of 59 Cyg, for example (Underhill and Doazan, 1982). Also, the episodic red-wing structure of Si IV lines in γ Cas (see Doazan et al., 1984b), or the Si IV and C IV profiles of the "pole-on" star HR 5223 (Dachs and Hanuschik, 1984), seem to bear a close resemblance to our results.

Of course, the detailed comparison of the theoretical and observed spectra requires a more sophisticated approach to the problem, and has, therefore, been postponed to a future study. Nevertheless, it appears probable that it will be possible to explain the observed UV spectra of at least some Be stars as a superposition of the contributions from the stellar atmosphere, the variable subionized Be envelope, and in some cases also from the (still unknown) medium producing the narrow blue-shifted components of resonance lines and/or from a transition zone in the accretion disk in interacting binaries.

3. The true Si IV lines can be observed (as normal stellar lines) over almost the whole range of the spectral class B, those of N V for practically all O stars, and also the stellar C IV lines are quite normal for B0—B2.5 stars. Harmann's (1983) tentative conclusion that the narrow components of the resonance lines are found preferably in stars earlier than B3 is then quite understandable as most of the work on narrow components concerns the C IV lines. This also indicates that the narrow components -- whatever they represent -- remain the indicators of large velocity fields in early B stars. In most cases, however, they do not indicate any superionization.

The remaining evidence of superionization in the UV spectra of B stars seems to rest upon the observations of the emission (and partly absorption) lines in W Ser binaries, and on the observations of the O VI (and, possibly N V) lines in some early B stars -- see the noteworthy work carried out by Lamers, Snow, Morton and others (see, e.g., Lamers and Snow, 1978; Morton, 1979; Gathier et al., 1981, and references cited therein).

For mainly technical reasons, we did not tackle the question of possible line blending in the vicinity of the O VI lines in this study.

To emphasize our basic conclusion, we shall once more borrow two statements from Thomas' (1983) book (pp. 7 and 17): "One often assumes the diagnostic method to be independent of configuration, which leads to erroneous 'empirical' results, which can lead
to erroneous confirmation or rejection of theoretical models' and "We had first be sure what we must explain".

We tried to demonstrate that just the a priori identification of the observed features in the vicinity of the C IV, Si IV, and N V resonance lines with the actual C IV, etc., lines (and we stress again that the identification is a very important part of spectroscopic diagnostics), like in the work of Thomas, Doazan and some other investigators, may well serve as a particular example of the above-quoted assumption of independence of the diagnostic method of configuration. Thus, the truth contained in the above-quoted Thomas' statements may, in fact, turn against the variable mass-flux empirical model of B/Be stars put forward by Thomas and Doazan, and also against some other Be-envelope "scenarios" (see, e.g., the review by Poeckert, 1982). No matter how large the real uncertainties in our simplified modelling approach, our results represent a very serious warning that no reliable conclusions about the velocity fields or the degree of ionization can be drawn from the UV spectra of hot stars without a simultaneous and very careful study of the problem of line blending.

Acknowledgments

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REFERENCES


AN ANALYSIS OF SPECTRAL LINES IN SUNSPOT UMBRAE

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1. Introduction

One of several reasons for studying spectral line profiles in sunspot umbrae is the effort to obtain information on the physical conditions at various depths of the umbral atmosphere, i.e. to construct a semiempirical model. A large amount of work has been devoted to the synthesis of umbral models and, of the large number of papers, only a few can be mentioned here – e.g. Zwaan (1965, 1974, 1975), Hénoux (1969), Stellmacher and Wiehr (1970, 1972, 1975), Teplitskaya et al. (1978) and recent models proposed by Albretsgen and Maltby (1981), Lites and Skumanich (1982), Avrett (1981), Staude (1981) and Staude et al. (1983). Besides the one-component models mentioned above, interest is now focused on the two-component models (Makita, 1963, Obridko, 1974, Obridko and Teplitskaya, 1978, Adjabshirzadeh and Koutchmy, 1983), which seem to describe the inhomogeneous structure of the umbra better.

However, the whole effort of model construction has until recently been mainly concentrated on umbrae, which warranted optimal conditions for obtaining good-quality spectra – i.e. to large, well-developed and stable sunspots. Essentially little attention has been paid to other evolutionary phases of sunspots, particularly to small ones and pores, the spectroscopic observation of which is much more difficult due to the strong disturbing effect of stray light.

Rozhavskij (1975) dealt with temperature models of sunspots of different areas and found a higher