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B[e] stars.
II. MWC 349 A*

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Abstract. — We analyse spectroscopic CCD material obtained at the Haute Provence Observatory. We provide line identifications and equivalent width measurements in the wavelength region 3700−8790 Å. Over 300 emission features are identified and a comparison of our results with those of other authors is provided, as well as a table of all elements which have been identified in the spectrum of the object. The pattern of elements present is analogous to that of B-type stars, but some exceptions are noted, such as the absence of C, Al and Mn. We review the present knowledge of the spectrum variability of MWC 349 A. The observations indicate that the equivalent widths of the lines of many elements vary by factors of up to two. We also provide a list of diffuse interstellar features observed. The latter lead to an average $(B-V)$ excess of about two magnitudes, which is less than what is expected for an object having an interstellar extinction of 10−11 magnitudes.**

Key words: stars: emission line, B[e] — stars variables: others — stars: individual: MWC 349 A

MWC 349 A is an emission line object discovered by Merrill et al. (1932). Its spectrum is described as a continuum with many superimposed emission lines. It consists of two stars, separated $2''4$ (Brugel & Wallerstein 1979). The brigther component, MWC 349A, provides most of the radio and emission line flux and has properties similar to luminous young stellar objects (Hamann & Simon 1986, 1988). The secondary is of spectral type B. The primary is surrounded by a disc lying in the orbital plane of the two stars. Its existence is inferred from infrared speckle interferometry (Leinert 1986) and from double peaked line profiles (Hamann & Simon 1988). A slow bipolar wind (velocity about 50 km s^{-1}) emanates from MWC 349 A (White & Becker 1985). The wind may be fed by the disk. This bipolar wind accounts for the observed radio emission. The object is highly obscured, with a visual extinction of about 10−11 magnitudes (Kelly et al. 1994). Attention is called to the fact that the object has also been described as a protoplanetary nebula.

The aim of the present paper, as well as of the others in this series, is to provide an identification list over an extended wavelength interval, together with a list of equivalent widths of the emission lines. This should lead to an improved understanding of B[e] stars.

1. Material

All the material was obtained on CCD receivers at the Haute Provence Observatory (OHP) of the CNRS at the 193 cm telescope.The spectrograph used was CARELEC (Lemaitre et al. 1990) The observational data are collected in Table 1.

For λ <6500 Å a grating with 1200 lines/mm, blazed at 4000 Å was used, providing a dispersion of 33 Å/mm in the first order. For λ >6500 Å a grating was used with 1200 lines/mm, with a blaze at 7500 which provides in the first order a dispersion of 33 Å/mm; filter OG 590 was used to cut out the second order.

From 1990 to 1993 the receiver was a CCD Thomson with 576×384 pixel, (23 square microns), providing a resolving power of about 1 Å. After 1993 the receiver used was a CCD TK 512, with 512×512 pixels (27 square micron). The resolving power was about 1.2 Å.

For the calibration of wavelengths we used Ne, Ar and He lamps. Flat field corrections were made with a tungsten lamp mounted in the spectrograph. The slit width used was of 300 microns, corresponding to $2''$ on the sky.

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*Based on observations obtained at the Haute Provence Observatory (CNRS)

**Table 2 is available in electronic form at the CDS via anonymous ftp.130.79.128.5

Table 1. Observational data

Code	Range	Date	Spectrum
a	3740-4195	22-6-94	underexposed
b	4130-4594	24-7-93	noisy
c	4554-5007	25-7-93	noisy
d	4883-5335	22-6-94	
e	5533-5984	21-6-94	
f	6017-6467	22-6-94	
g	6332-6780	20-6--95	
h	7008-7450	18-6-94	
i	7590-8014	18-8-91	
j	7983-8420	23-7-93	
k	8370-8780	17-8-91	

Code: current designation of the spectrum (seeTables 2 and 6)

Range: given in Angström

Date: given in days, months and years (-1900)

The data were reduced with the software package IHAP,developed at ESO and installed at the OHP.

As remarked above, our resolving power is of about one Angström, which is not very well suited for radial velocity studies. The smallest equivalent width which can be measured is of the order of 0.15 Å. Since we are working with material obtained under the same conditions as those for HD 51585 (Jaschek et al. 1996, Paper I) we adopt the errors given in that paper which are of the order of ±10% for the equivalent widths.

2. Line identifications

These were made in the traditional way, paying attention to both wavelengths and line intensities within the multiplets.The identifications were made with the help of the Moore (1959) table; for Fe II we also used Johansson's (1978) compilation. In addition we have used the Meinel et al (1969) catalogue, for lines which we could not identify (see notes to Table 2).

On our spectra are present 315 emission lines. We were unable to identify 33 lines, i.e. 10%, which is about normal in identification work. Most of the unidentified lines are weak.

Besides the emission lines we found also 26 absorptions, identifiable with diffuse interstellar features. These are listed separately in Table 5 and discussed in Sect. 6 (Absorption features). Part of the spectrum is reproduced in Fig. 1.

3. Elements present

On the basis of the identifications given in Table 2 we shall discuss the elements present in the spectrum of the star, ordered by atomic number.

Hydrogen. The Balmer series is seen in emission on our material up to n=9. The Paschen series is also seen in emission up to n=37. The lines of the Paschen series show a regular progression in intensities, despite the fact that the series was observed on two different dates. The overlapping lines (P 20 and P 21) showed variations of the order of 10−15%. It should be added that Hamann & Simon (1988) only detected the Paschen series in emission up to n=35 in 1986.

Helium. Neutral helium is represented by a number of lines from the different series. No P Cyg profile is observed. He I 4921 (^{1}D) appears on plates taken in 1993 and 1994 and its equivalent width has changed from 5.7 to 4.6 Å. This variation cannot be attributed to the nearby Fe II line. It should be noticed that λ7065 (^{3}S) is very intense. No ionized helium was observed.

Carbon. No carbon line was observed.

Nitrogen. Neutral nitrogen is represented by many lines from M.1, 2, 8 and 10. No [N I] is observed. Ionized nitrogen is represented by the strongest lines from M. 3, 8 and 28. [N II] is represented by lines from M.1 and M.3.

Oxygen. This element is observed in three ionization stages. Neutral oxygen is represented by lines from M. 1, 4, 10, 20 and 34. It must be remarked that λ8446 (M.4) is very strong (W=48 Å), whereas λ7772 (M.1) has only 1.5 Å. This can be explained by fluorescence from Lyman β. [O I] is represented by M.1 and 3.

Singly and doubly ionized oxygen are represented by M.2 of [O II] and by one line (λ4958) from M.1 of [O III]. The lines of [O II] are much stronger than either [O I] or [O III].

Sodium. Neutral sodium is represented by weak lines of M.1 and M.4.

Magnesium. This element is present in its singly ionized form. Only lines from M.8 are observed, as in other early type peculiar stars (Jaschek et al. 1993).

Silicon. Singly ionized silicon is represented by lines from M. 2, 4, 5 and 8.

Sulphur. Only the intense line λ6310 (M.3) of [S III] is seen.

Argon. The presence of this element is evidenced by the lines $\lambda\lambda$7135 and 7751 (M.1) of [Ar III].

Calcium. Ionized calcium is represented only by the strong lines from the infrared M.2. [Ca II] is present weakly with the lines from M.1.

Titanium. This element is represented by several lines of [Ti II] from eight different multiplets (6, 9, 15, 16, 22, 28, 29 and 39).

Vanadium. This element is represented by lines of [V II] from multiplets 4, 8, 14 and 18.

Chromium. This element is represented by six lines of [Cr II] from three multiplets (1, 11 and 19)

Iron. No neutral iron is observed.

Singly ionized iron, both permitted and forbidden, provides half of all the emission lines observed in the spectrum. Fe II is represented by the most intense lines of M. 8, 21, 27, 35, 36, 37, 38, 40, 42, 43, 46, 49, 55, 57, 73, 74, 182, 186 and 197. [Fe II] is represented by numerous lines

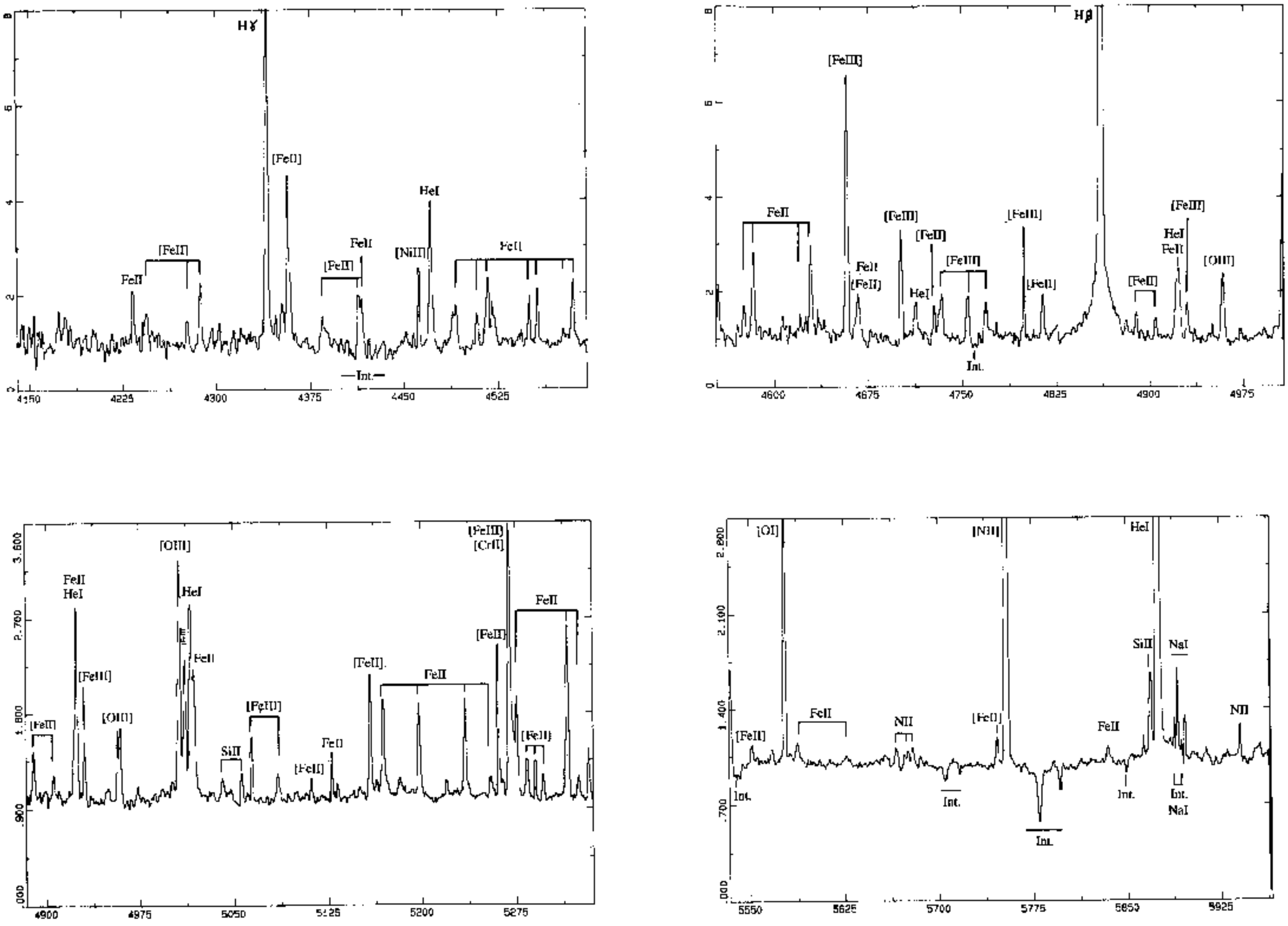


Fig. 1. Reproductions of CCD spectra of MWC 349 A. In abscissae are given the wavelengths (in Angström) and in ordinates the intensities. The continuum level is set to unity. Important lines are identified. Int = interstellar feature

from multiplets M.1, 3, 4, 6, 7, 13, 14, 17, 18, 19, 20, 21, 22, 29, 30, 34, 35, 36 and 39.

[Fe III] is represented by lines from M.1, 2, 3 and 10.

Nickel. This is the heaviest element detected. It is represented by three lines from multiplets 8, 10 and 12 of [Ni II].

4. Comparison with other work

We have collected in Table 3 the elements found by other authors in the spectrum of this star. In the notes to the table are given the wavelength ranges covered by each author. As can be seen a wide variety of wavelength ranges was used, which explains some of the discrepancies one finds. We have also searched on our material for all the elements detected by other authors, namely C I, [N I], Ne I, [S II], [Cl II], Ar I, K I,Cr II and Fe I. We have searched for the most intense lines of these elements which should be present in our wavelength region, but we have found no convincing evidence for their presence.

For completeness it should be added that a few papers providing identifications were not included in Table 3. These are the following: Ciatti & Mammano (1975) provide reproductions of spectra having dispersions of 127 and 365 Å/mm. They find the same elements as Allen & Swings (1976), adding Ca II, O I and probably [O III]. Paschen lines were observed in emission up to n=21.

Thompson & Reed (1976) working in the 4000−8000 cm^{-1} region detected H and He I in emission. They observed Brackett lines 7, 8, 10−15 in emission. McGregor et al. (1984) working in the 4500−10500 cm^{-1} observed H, O I, He I, and [S III] in emission. They observed the Brackett series in emission from B7 to B 20.

Two comments are perhaps in order. The first one is that a given element might be variable. The fact that we have not found it does not prove that it was not present at other times.

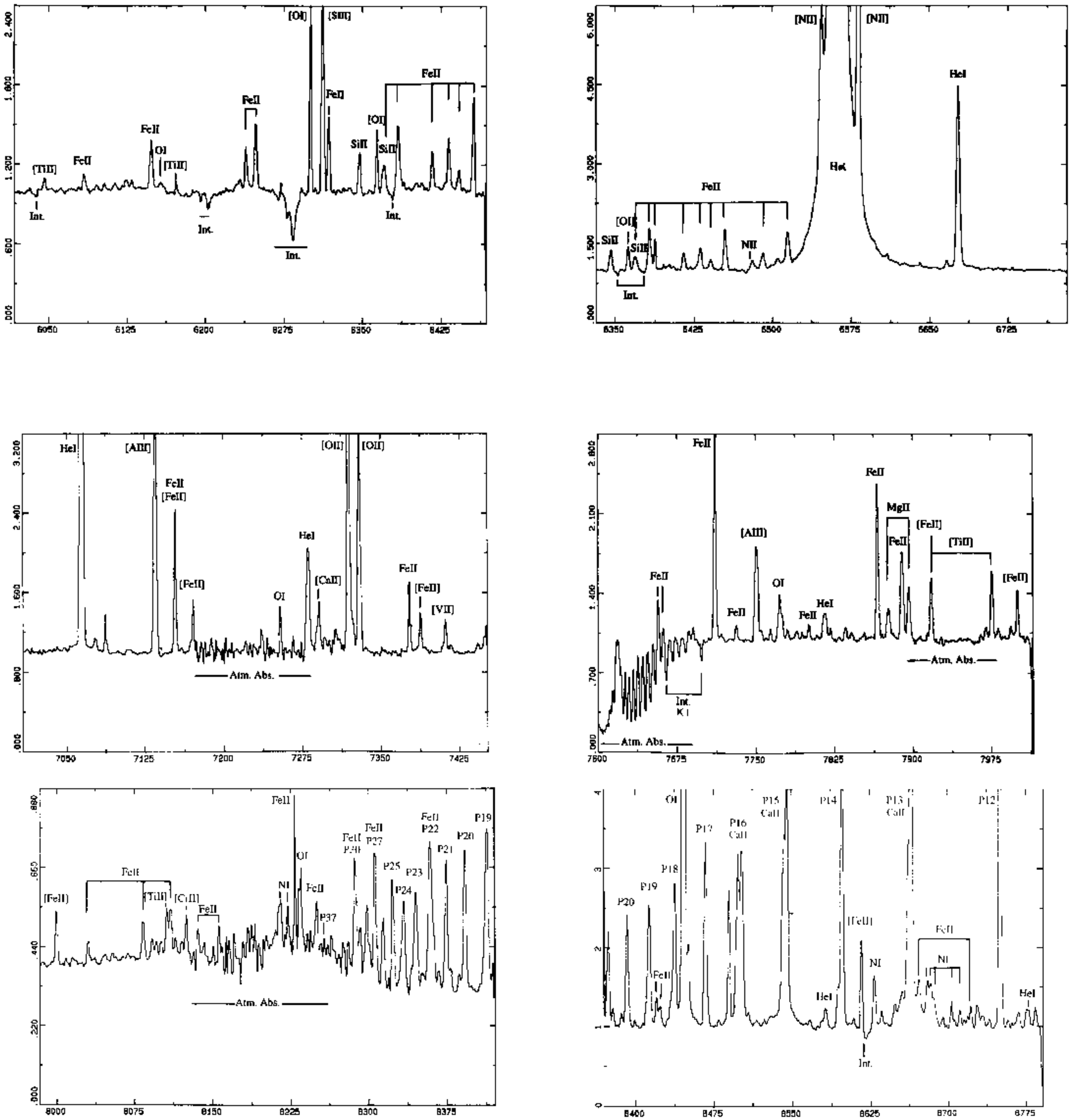


Fig. 1. continued

Table 3. Chemical elements present in MWC 349 A according to different authors

	A-J-J	Sw-Str	Al-Sw	Br-Wa	A-C-Sw	H-S	K-R-C
H	I	I	I	I	I	I	I
He	I	I	I	I,II	I	I	I
C						I	
N	I,II [II]	[II]	[II]	[II]		I	I [I]
O	I [I],[II],[III]	[I]	[I]	I [I],[II]	I [I]	I	I
Ne						I*	
Na	I			I			
Mg	II			II		II	
Si	II		II	II			
S	[III]		[III]	[III]	[III]	[III]	[II],[III]
Cl						[II]	
Ar	[III]		[III]	[III]		I* [III]	
K						I	
Ca	II [II]			II [II]	II	II	
Ti	[II]			[II]			
V	[II]						
Cr	[II]			II [II]		[II]	
Fe	II [II],[III]	II [II]	II [II],[III]	II [II]	II	I*,II [I]*,[II],[III]*	II [II]
Ni	[II]		[II]?	[II]			

Notes- * presence considered only as probable.
AJJ = :present work, Range 3700-8400
Sw-Str = Swings and Struve (1942) Range:4300-6600
Al-Sw = Allen and Swings (1976) Range 6100-7100
Br-Wa = Brugel and Wallerstein (1979) Range 5300-8600
A-C-Sw = Andrillat,Ciatti and Swings (1982) Range 8400-11000
H-S = Hamann and Simon (1988) Range 7500-9300
K-R-C = Kelly,Rieke and Campbell (1994) Range 9000-13500

The second comment refers to the elements present. If we compare these with the elements usually found in stellar spectra- see for instance Jaschek and Jaschek (1995)- we find a pattern that is very similar to that of B-type stars. Nevertheless there exist some differences which are interesting. We find an absence of C, Ne and Al . Of the metals, we do not find neither Sc nor Mn.

Since it does not seem significant to discuss the behavior of the elements on the basis of just one B[e] star, the discussion will be postponed until the last paper of this series.

5. Variability

We have tried to gather all relevant information concerning the line variability in this object which is rather meager.

Greenstein (1973) found large nigth to night changes (H3 by a factor of four, H4 and H5 by a factor of two). Since he worked with broad spectro-photometric channels,

Table 4. Lines present on spectra obtained at different dates

Lambda	Identification	W	W
		24-7- 93	25-7-93
4583.83	Fe II 38	5.09	4.65
		25-7- 93	22-6,94
4889.67	[Fe II] 4+]Fe III] 3	1.30	1.06
4921.93	He I 48	5.92+f	4.76
30.5	[Fe III] 1	1.95	1.34
		22- 6- 94	23- 7- 95
6347.09	Si II 2	0.93	1.22
63.88	[O I] 1	1.16	1.25
83.72	Fe II 10	1.93	2.60
6416.90	Fe II 74	0.78	0.93
32.65	Fe II 40	1.23	1.68
42.95	Fe II J	0.45	0.72
56.37	Fe II 74	1.90	2.47
		18-8-91	23-7-93
7999.79	[Fe II] 1+[Cr II] 1	0.94	1.05
		17-8-91	23-7-93
8392.40	P 20	3.76	4.28
8413.32	P 19	4.87	6.06

The heading of each subset gives the dates of the spectra.
Columns provide successively the wavelength (in Å), the identification and the equivalent widths measured at the dates given on top of the column.

Table 5. Diffuse interstellar absorption features observed

Wavelength	W	W(H)	Notes
4410-4435	-	4428	Emission at 4413
4759-4762		4754.9	Emission at 4754
4765.9		4763	
5537-5541	0.57	5535	Emission at 5535
5705	0.29	5705	
5717	0.11		
5774			
5780	2.31	5778	
5785		5780	
5797	0.54	5797	
5849	0.11	5849	
5889			Na I
5890			Na I
6038	0.24	6042	
6098			
6178	0.30	6177	
6195	0.26	6196	
6203	0.82	6203	
6206			blended with prec.line
6270	0.27	6270	
6278	0.80		
6283	2.14	6284	
6353	0.10	6353	
6376	0.19+f	6376	
6378		6379	
7665		7665	K I
7699		7699	K I
8620	0.89	8021	

First column: measured position
Second column; equivalent width in A.
Third column: position taken from Herbig (1975) or Herbig and Leka (1991)
Fourth column: notes.

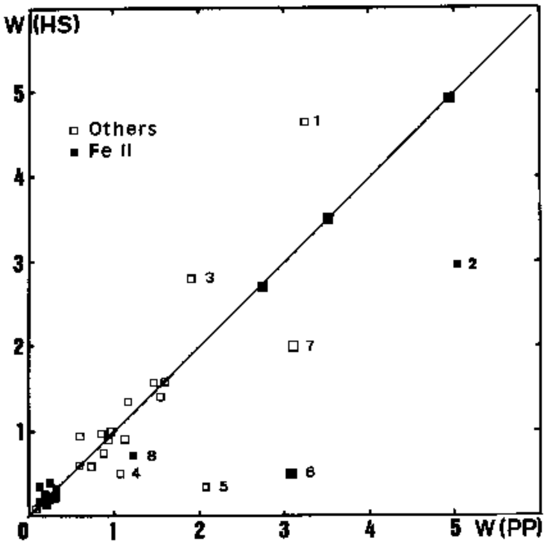


Fig. 2. Comparison of equivalenth widths. Hamann & Simon (1986) (HS) versus present paper (PP), based on 1991 data. Filled squares = Fe II; squares = other elements The numbers refer to the following lines: 1) 7135 [Ar III], 2) 8490 Fe II + [Ti II], 3) 8616 [Fe II], 4) 8648 [Ti II], 5) 8655 N I+ [Cr II], 6) 8672 Fe II, 7) 8680-3 N I, 8) 8722 Fe II +[Ti II]

he felt that the changes in H3 may come in part from changes in the nearby [N II] emissions.

Ciatti & Mammano (1975) comment that [O III]λ4959 was visible in 1969, but had disappeared in 1974.

Brugel & Wall çerstein(1979) made a line identification in the region λ 5200−8600 Å and provided visual estimates of the emission line intensities from Coudé plates. The difficulties of such estimates are well known; as a rule intense lines are underestimated because of saturation effects. From a detailed comparison, the only remarkable point which comes out is that [N II] has intensified considerably on our spectra from 1995.

Hartmann et al. (1980) provided data for a few lines. They quote equivalent widths for H3 (735 Å - June 1979), He I 5876 (26.7 Å - June 1979) and H4 (71.7 Å - November 1978) They observed broad wings in H 3 and central absorption reversal in both H3 and 5876, with $V < R$.

Swings & Andrillat (1981) showed in their Fig. 1, based on photon counts in 1980-81 rather weak [N II] emissions around H3. From a comparison with our material, the intensity of the nitrogen emissions has increased by a factor of about three between 1981 and 1995.

Andrillat et al. (1982) analysed the variations between 1979 and 1980 on the basis of Reticon material. They find no noticeable changes in the line intensities of H, Ca II, Fe II and [S III], a strengthening of He I 10830 (4.8 to 6.8) and a large enhancement of O I 8446 (1.8 to 3.1).

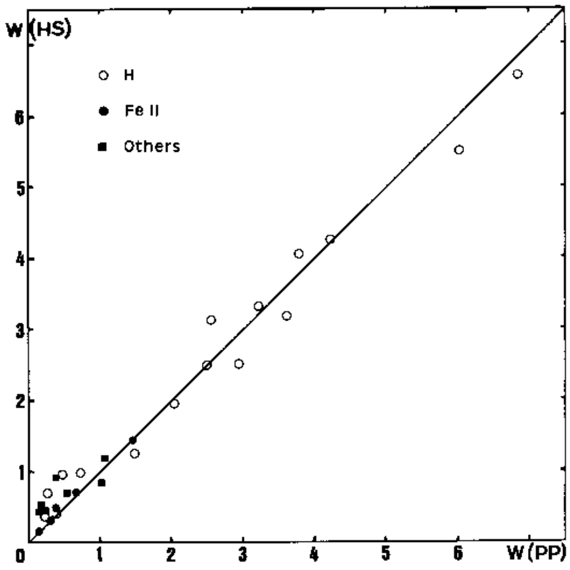


Fig. 3. a) Comparison of equivalent widths. Hamann & Simon (1986) (HS) versus present paper, based on 1993 data. Cercles = hydrogen, Filled cercles = Fe II, Filled squares = other elements

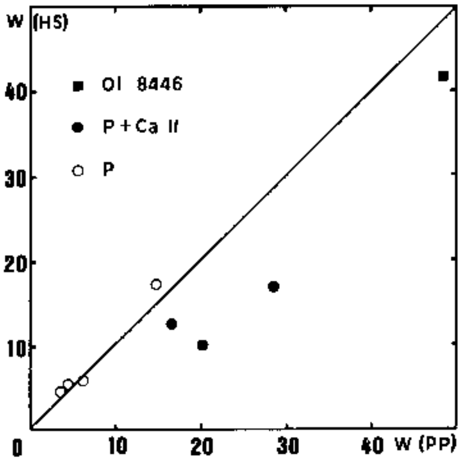


Fig. 3. b) Comparison of equivalent widths. Hamann & Simon (1986) (HS) versus present paper, based on 1993 data. This figure is for the stronger lines. Please observe the change in scale with Fig. 2a. Cercles = Hydrogen Filled cercles = H+Ca II. Square = O I (8446)

Hamann & Simon (1988) provide a large set of measured equivalent widths which can be compared directly with ours, in the overlap between their range (7500−9300) and ours (3800−8500). Taking into account the errors involved (of the order of ±10%) a discussion leads to the following conclusions:

a) between 1986 (HS) and 1991 we find no noticeable changes in the majority of the elements, as can be seen in Fig. 2. There are however eigth points in the figure which merit some comments, because they behave differently. Points 1 and 3 refer to [Ar III] and [Fe II] lines, respectively which have both weakened in 1991. Points 2, 4, 5 and 8 have strenghtened in 1991 and this cannot be

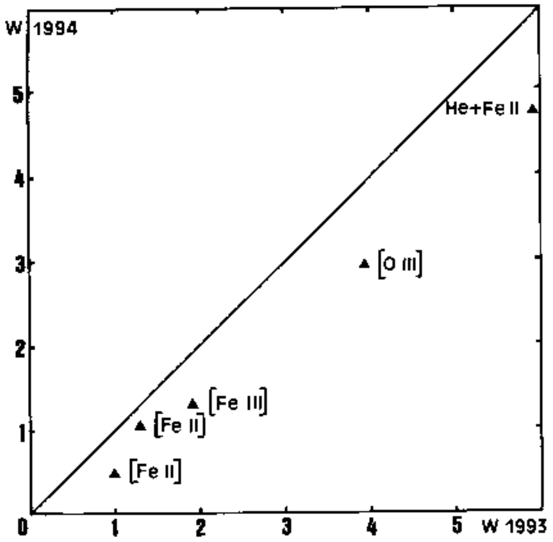


Fig. 4. Comparison of equivalent widths from the present paper based on 1993 and 1994 data. The main contributor of each line is given

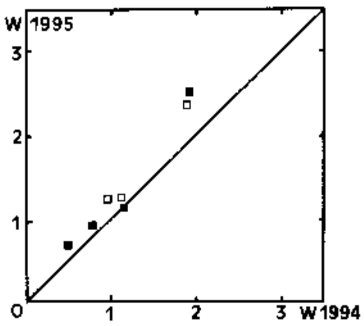


Fig. 5. Comparison of equivalent widths from the present paper, based on 1994 and 1995 data. Filled squares = Fe II Squares = other elements

due to the elements identified by HS as main contributor, but to other contributors, in our case [TiII] (points 2, 4 and 8) and [Cr II] (point 5) which have strenghtened in 1991. Two points- 6 and 7- have no clear explanation since they are identified both in this paper and by HS with the same elements (Fe II and N I). These two elements possess several other lines which have the same equivalent width in both years.Thus probably an unidentified contributor has enhanced these lines in 1991. Another explanation for the case of point 6 is that the measure is perturbed by the nearby strong blend of H+Ca II.

b) between 1986 (HS) and 1993 we find a general agreement of the equivalent widths of all lines (see Fig. 3a) with a somewhat larger scatter, due to difficulties in estimations of the level of the continuum. The intense lines are plotted in Fig. 3b and it can be seen that Ca II is enhanced in 1993, as also O I (8446).

We include also plots of the equivalent widths of the few lines which overlap on our material at different dates (see Figs. 4 and 5). In Fig. 4 (1993 vs. 1994) we see that the lines corresponding to [Fe II], [Fe III] and [O III] have strengthened in 1993, similar as the blend of Fe II and He I. In the latter feature, according to the spectrum it is the He I which has strenghtened. The strenghtening of the forbidden lines agrees with the fact that several more forbidden lines visible in 1993 are absent in the 1994 spectrum.

A comparison between 1994 and 1995 (see Fig. 5) shows a sligth strenghtening in 1995 of the Fe II lines.

We can thus conclude that the emission line strengths have not changed by more than a factor two, except [N II]. Another conclusion is that one observes changes in a large number of elements which according to the Hamann-Simon model are formed in different layers of the atmosphere. It seems thus that all layers - not only the outmost ones - show line variability. It would be highly desirable to obtain more material to examine the variability in detail.

Recently Bergner et al. (1995) observed this star photometrically in the *B*, *V*, *R*, *I*, *J*, *H* and *K* bands of the Johnson system. They find irregular variations in all bands with amplitudes of about $0^{m}5$.

6. Absorption features

As said in Sect. 2, the observed absorption features are listed in Table 5, with the measure of their equivalent widths. All lines can be identified with known diffuse interstellar features (Herbig 1975; Herbig & Leka 1991). We have not observed any of the absorption bands attributed to CN by Ciatti & Mammano (1975).

The presence of the diffuse interstellar features is in line with the presence of the large interstellar extinction suffered by the object, which amounts to 10−11 magnitudes (Cohen et al. 1985).

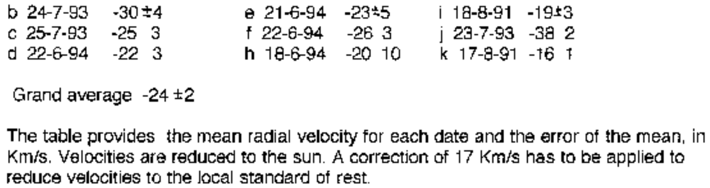
Using the correlations between the color excess $E(B-V)$ and the strength of the interstellar bands given by Herbig (1975) one obtains color excesses between $1^{m}2$ and $2^{m}9$, with an average of $2^{m}25$ magnitudes. Such a dispersion in the color excesses derived from interstellar features is not uncommon; nevertheless the amount of interstellar extinction is less than what one could expect for an object with about $10-11^{m}$ interstellar extinction. The probable explanation lies in an insufficient separation of the interstellar and the circumstellar absorption components.

Due to our resolving power, we see only faintly the interstellar components of the Na lines, and we do not see the interstellar components of the Ca II K lines studied by Hamann & Simon (1988).

7. Radial velocities

Despite the fact that our material is not well suited for radial velocy studies because of the low resolving power (as

Table 6. Radial velocities



b	24-7-93	-30	±4	e	21-6-94	-23	±5	i	18-8-91	-19	±3
c	25-7-93	-25	3	f	22-6-94	-26	3	j	23-7-93	-38	2
d	22-6-94	-22	3	h	18-6-94	-20	10	k	17-8-91	-16	1

Grand average -24 ±2

The table provides the mean radial velocity for each date and the error of the mean, in Km/s. Velocities are reduced to the sun. A correction of 17 Km/s has to be applied to reduce velocities to the local standard of rest.

remarked in Sect. 1), we have derived the radial velocity for each of the different wavelength regions observed at the different dates. The average of the velocities is -24 ± 2 km s^{-1} If the errors of the velocity are taken into account, we see no significant changes of the radial velocity with time, so that we take -24 km s^{-1} to be the average velocity of the shell of the star. We have also examined if different elements have different radial velocities. Significantly different velocities were found for [Fe III] , [N II] and [Ar III] which have a velocity of -58 km s^{-1}, [SIII] gives $+90$ km s^{-1} and the three Ca II lines $+9$ km s^{-1}, but the latter measures may be influenced by the Paschen lines. The different velocities are very probably due to stratification effects, as discussed by Hamannn & Simon (1986) and confirmed by Gordon (1992).

The radial velocities quoted in the literature for the object refer to different parts of it. We have an average velocity of the H 31 alpha transition of $+8{,}16$ km s^{-1}, -7 km s^{-1} for the non masing H 41 alpha line and -15 km s^{-1} for the normal H76 alpha line. All these velocities are referred to the local standard of rest, so that a correction of 17 km/s must be applied to make them heliocentric.

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