Astron. Astrophys. Suppl. Ser. **117,** 281-289 (1996)

B[e] stars.
I. HD 51585 (=OY Gem)*

C. Jaschek[1], Y. Andrillat[2] and M. Jaschek[1]

[1] Observatoire de Strasbourg, URA 1280, CNRS, 11 rue de l'Université, 67000 Strasbourg, France
[2] Laboratoire d'Astronomie, Université de Montpellier 2, URA 1280 and 1981, CNRS, Place Eugène Bataillon., 34095 Montpellier Cedex 5, France

Received September 22; accepted November 6, 1995

Abstract. — We analyse CCD spectroscopic material obtained at the Haute Provence Observatory between 1990 and 1993, covering the wavelength region 3800 – 11000 Å. 320 emission lines were measured and identified. Of these about 40% correspond to permitted or forbidden lines of ionized iron. Many forbidden lines (20% of the total) are present, including many classic nebular lines. We also provide a comparison of our results with those of other authors. The equivalent width measurements permit to follow in detail the variations of the lines of several elements over the three years and to compare them to variations reported by other authors. On our material the largest variations correspond to helium, which varied by a factor of two and are not in phase with the variations of hydrogen. Many helium lines exhibit P Cyg type profiles, indicating strong outflow of matter from the star. The lines of other elements follow either the variations of the helium or of the hydrogen lines. The radial velocity varies over the years, with an amplitude of more than 60 km/s.

Key words: stars: emission line, B[e] — stars variables: others — stars: HD 51585

1. Introduction

The object HD 51585 (= OY Gem) is a well known B[e] star, discovered by Merrill & Burwell in 1933 (Merrill & Burwell 1934). Allen & Swings (1976) classified it as belonging to what they call group 3, in which they put all those objects with infrared excess which resemble planetary nebulae and present lines having ionization potentials larger than 25 ev. Line identification in this star were made by Arkhipova (1962), Ciatti et al. (1974), Andrillat & Swings (1976), Klutz & Swings (1977) and Houziaux et al. (1982). The one of Klutz & Swings is the most complete one. Many of the quoted papers provide no quantitative measures of the line strengths and several of them were based either on low dispersion and/or short wavelength stretches.

The aim of the present paper and of those which shall follow in the same series is to provide measurements of wavelengths and equivalent widths over an extended wavelength region. Since our material was taken at different epochs, we can also discuss quantitatively the variations of the equivalent width of the lines of several elements.

2. Material

All the material was obtained on CCD receivers at the Haute Provence Observatory (OPH) 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 < 6500 Å a grating with 1200 lines/mm was used, with blaze at 4000 Å, providing a dispersion of 33 Å/mm in the first order. For > 6500 Å a grating was used with 1200 lines/mm, with a blaze at 7500 Å which provides in the first order a dispersion of 33 Å/mm. A OG 590 filter was inserted to cut out the second order.

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

For the wavelength calibration we used Ne, A and He lamps. Flat field corrections were made with a tungsten

Send offprint requests to: C. Jaschek, Teso de la Feria 39, 37008 Salamanca, Spain

*Based upon observations carried out at the Observatoire de Haute Provence of the CNRS.

Tables 2-5 are available electronically from the CDS via anonymous ftp 130.79.128.5

Table 1. Observational data

Date	Wavelength	Code	Number
4-4-93	3736-4190	a	1
25-10-91	4285-4725	b	2
25-10-91	4698-5139	c	2
8-4-93	6012-6460	d	3
20 -4-92	6856-7246	e	1
24-10-91	6973-7383	f	2
6-4-93	7000-7445	g	2
28-12-90	7570-7994	h	2
7-4-93	7613-8054	i	2
31-3-93	8358-8792	j	3
21-2-92	8365-8785	k	2
27-12-90	8360-8776	l	1
27-12-90	9010-9425	m	1
14-4-92	9830-10234	n	1
30-12-90	9830-10220	o	2
20-4-92	10535-10927	p	2
30-12-90	10630-11026	q	1

The last column provides the number of times the spectrum was measured. The "Code" is used for tables 2 and 7

lamp mounted in the spectrograph. The slit width used was of 300 microns, corresponding to 2″ on the sky. The data were reduced with the software package IHAP, developed at ESO and installed at the OHP.

As remarked above, the 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. Errors were assessed from an intercomparison of plates taken at the same date and from the intercomparison of measurements of the same lines on a given plate; they are of the order of 10%.

3. Line identifications

These were made in the traditional way, using both the wavelength coincidences and the line intensities within the multiplets. The complete list of the line measured is given in Table 2. We have measured about 320 emission lines and could identify 85% of these. Most of the unidentified features are weak, except a few which are given in Table 3. It is probable that most of them are due to Fe II or [Fe II]. The identifications were made with the help of the Moore (1959) table, but for Fe II we used the more recent work of Johansson (1978). A few lines, quoted in the notes, were taken from other identification lists. We have also used the "Catalog of emission lines in astrophysical objects" by Meinel et al. (1989).

We have not observed any absorption feature, except the absorption components of those four lines of He or Ca which present P Cyg type profiles. The absence of absorption features implies that one cannot classify the spectral type of the underlying object. One can only conclude that it must be a hot object because it excites in its outer layers lines having a very high excitation potential.

It should be added that we observe a moderately strong diffuse interstellar absorption feature at 6278-83. No other interstellar feature is seen on our material.

Table 3. Strong unidentified lines. ($W > 0,50$ Å)

Wavelength	W	Note
3808,5	0,70	*1
4570,9	0,68	*1
7953,3	0,51	
8423,2	0,50	*2
8427,7	0,60	
8672,2	1,20	*2
8758,7	0,80	
8765,0	0,62	

If a line had been measured more than once, the table gives an average. An asterisk(*) stands for a mention in Meinel (1989) 1=found in symbiotic objects 2=found in nova-like objects

We have not observed any of the molecular bands suggested by Ciatti et al. (1974). Parts of the spectrum are reproduced in Fig. 1.

4. Elements present

Using the identifications given in Table 2, we shall discuss the elements present in the star, ordered by atomic number.

Hydrogen. Our material shows Balmer lines from 4 to 11 and Paschen lines from 6 to 22, all in emission. The equivalent widths in both series show a regular progression. The emissions are narrow and strong with the exception of H4 which is very broad (2500 km/s at the base). This width is similar to that given by Swings & Andrillat (1981) who found from observations made in 1981 that the base of H3 was of 2900 km/s.

We do not observe PCyg profiles for any hydrogen line, nor double peaked emissions. Due to our resolving power we should be able to see double peaks if the peak separation were larger than 80 km/s. This is at variance with the description of Klutz & Swings (1977) of their material taken between 1971 and 1976. These authors found double peaked emissions up to H5 (peak separation 150 km/s) and P Cyg profiles beyond H5. Our H4 line also appears twice as wide as the line they show in their paper. Our material fits better the description by Houziaux et al. (1981) who found that H4 to H8 are in strong single emission.

Furthermore on our material the hydrogen lines appear to have the same average radial velocity than the other emission lines. This applies to both series.

Our material permits to analyse also quantitatively the variability of the lines of the Paschen series. The variations are strong and are listed in Table 4 and plotted in Figs. 2 and 3. For instance P 12 varies from 11.0 to 7.6 Å over two years. The data are too scarce to know the character of the variations, but in the interval 1990-93 there exists a maximum in 1992. The variability also exist for the Balmer lines (Hβ, γ and δ) which have varied also by large factors. Leaving aside some equivalent widths obtained on low dispersion material, we can use the description by

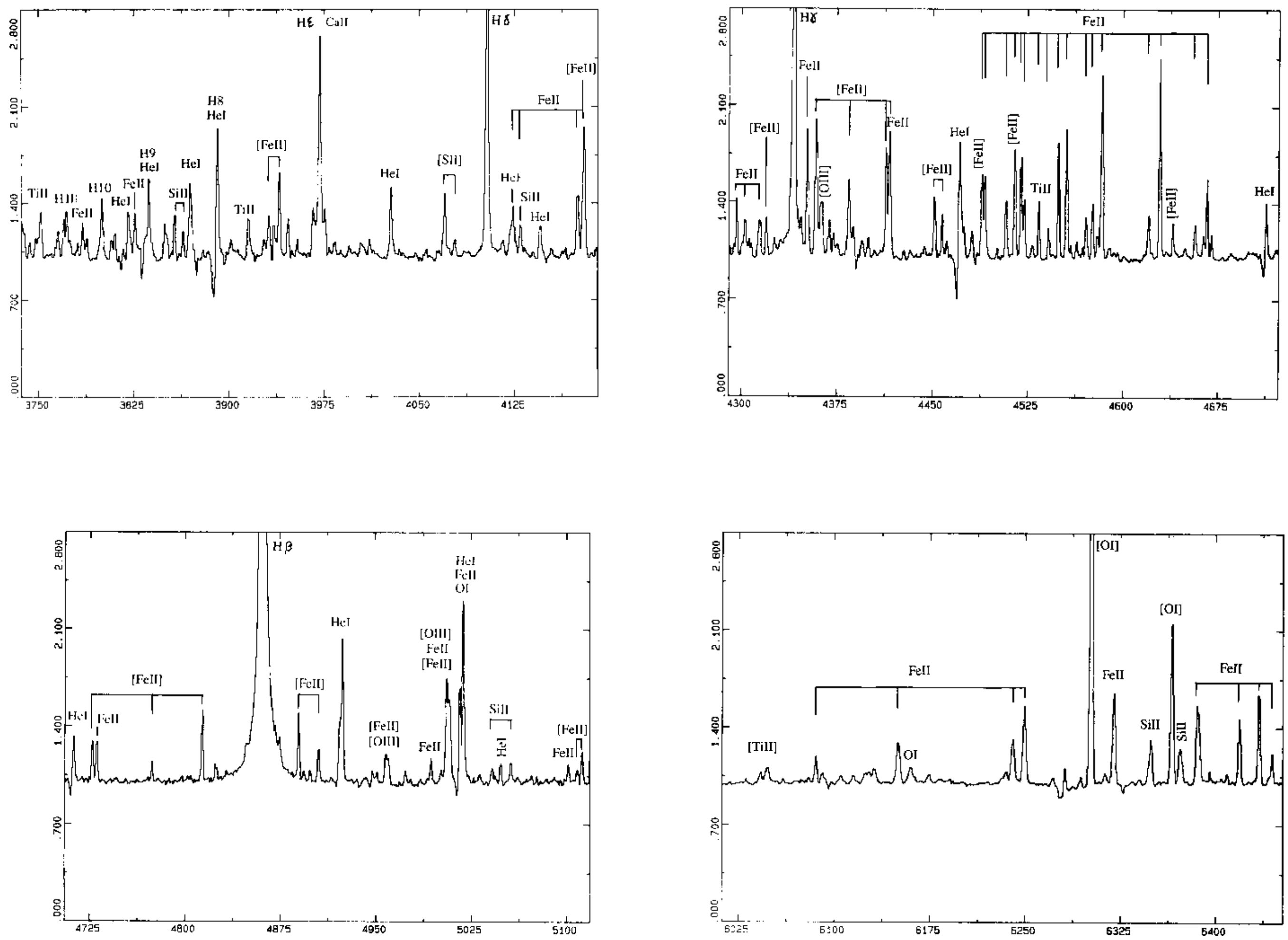

Fig. 1. Reproductions of CCD spectra of HD 51585. Abscissae: wavelengths in A Ordinates: Intensities. The continuum level is set to unity. Dates are marked on the upper border, in the order day, month, year. Important lines are identified. Elements between parentheses stand for forbidden lines

Andrillat & Houziaux (1973) of material taken between 1965 and 1971. When comparing their equivalent widths with ours one finds a good correlation, but at that times H 4 had 96 Å, whereas on our material it has only 76 Å. This confirms the variability of the hydrogen lines.

Helium. Neutral helium is represented by many lines given in Table 5, where they are listed by series. The first line(s) of each series shows a P Cyg profile. The only exception is 10830, but here the evidence is inconclusive since the spectrum is very noisy. Somewhat surprisingly the 3888 line also has a (strong) P Cyg profile. The average difference between the absorption and the emission components is of the order of 200 km/s. This description underlines the variability of the star. Klutz & Swings (1977) in their description of their 1971-76 material say that "the velocity of the P Cyg profiles that we observed in the case of the triplet lines is of the order of 100 km/s″.

Furthermore on our material the equivalent width of the lines of the different series deviates in several aspects from the laboratory intensity for instance 7065 being very strong. This is expected if non LTE effects are present.

All lines present are transitions from level two. From level three we observe only the ^{3}D series and a line which could be identified with $3^3\mathrm{D}-\ 9^3\mathrm{F}^0$ 9210. The line 10027 of the same series is observed if the continuum is conveniently smoothed. With respect to variations, we have three plates showing the lines 7065 and 7281 at different dates, in which the lines vary by a factor of almost two- i.e. more than the Paschen lines. (Let us caution however that the 7281 line lies in a region which is perturbed by atmospheric absorption). He I presents no maximum in 1992 as do the Paschen lines. The P Cyg profiles, well visible in 1991 and 1992 are not visible in 1993, when the lines are

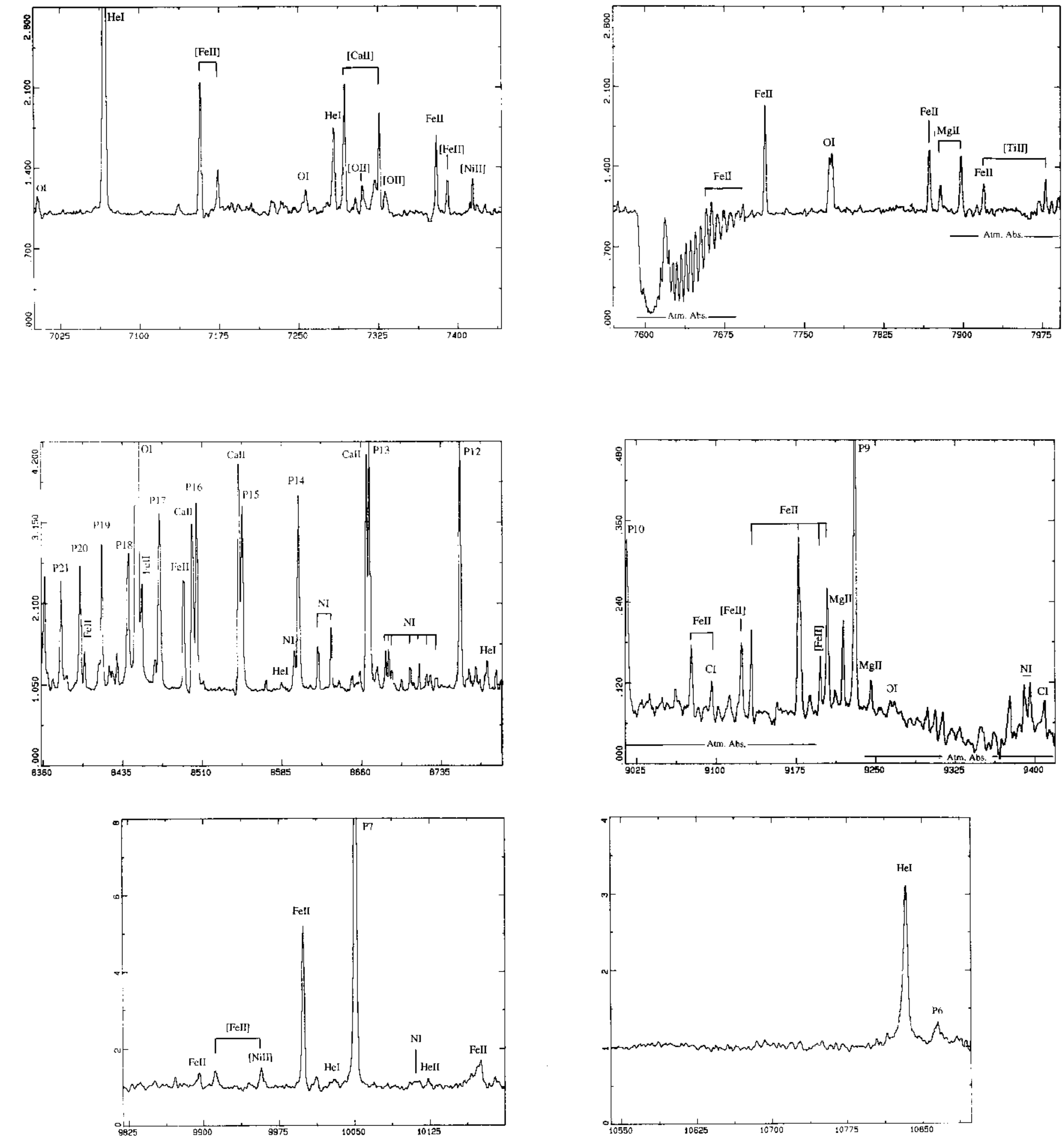

Fig. 1. continued

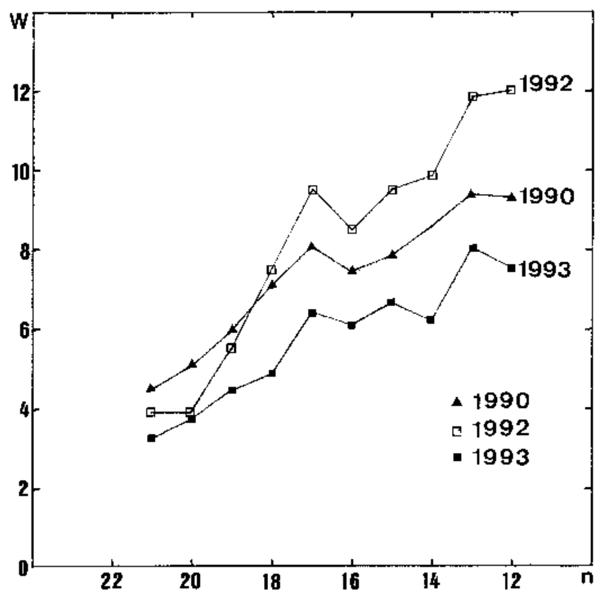

Fig. 2. Equivalent widths of Paschen lines in different years. Paschen lines corresponding to the same date were joined by a continuous line. Paschen lines blended with Ca II lines are also plotted. Ordinate: equivalent width in Angstroem Abscissa: Number of the Paschen line

Table 4. Variations in line strength

Date	P 12	P14	P16	Ca II 8662	Ca II 8498
27-12-90	9,30	8,68	7,49	9,70	4,18
31-2-92	12,02	9,82	8,50	10.08	9,19
31-3-93	7,63	6,24	6,06	6,40	5,96

Date	H alpha	H beta	H gamma	H delta	[O III] 5007	[O III] 4363
1948*	2,17					
1954**	88	18,5	4,7	1,6	5,4	0,7
1991		62,5				1,26
1993			13,52	7,80	1,89	

Date	He I 7065	[Fe II] 7155	[Ca II] 7294
24-10-91	8,13	2,36	1,68
20-4-92	10,25	2,55	1,43
6-4-93	12,98	3,11	2,81

Date	Mg II 7877	Mg II 7896	[TI II] 7917	Ti II 7977
28-12-90	0,51	1,22	0,49	0,72
7-4-93	0,62	1,43	0,67	0,61

Date	Fe II 8490	O I 8446	N I 8617	N I 8629
27-12-90	4,22	70,17	1,37	1,81
21- 2- 92	4,93	86,68	1,72	2,43
31- 3- 93	3,49	56,50	1,19	1,42

* from Beals C.S. and Hatcher R.D.(1948)
** from Arkhipova (1962)

The errors of the different measurements are 10%.

Table 5. Neutral helium lines

Series	Wavel.		Profile	W	Lab. int.
^{3}Po	10830	&	(16,6)	4500	
	3888	P	bl	20	
^{1}Po	5015	P	1,42 bl	6	
	3964		0,89	4	
^{3}D	5875	W			
	4471	P	2,04	7	
	4026		1,21	6	
	3820		1,08	5	
^{1}D	6678	W		6	
	4921	P	2,59 bl	4	
	4143		0,65	1	
	4009		0,38	1	
	3926		0,28	1	
	3871	Absent		1	
	3833	P	-	1	
^{3}S	7065	P	8,13*	6	
	4713	P	0,63	4	
	4121		1,38 bl	4	
	3867		1,49	3	
^{1}S	7281	(P)	1,45**	3	
	5047		0,26	2	
3^3Po-d^3D	9063	&	-	6	
	8776		1,03		
	8585		0,31-		

P P Cyg profile W not covered with our material bl blend & continuum too noisy to decide if P Cyg profile present.
* also 12,98 and 10,25
** also 2,29 and 2,10

stronger than in the preceding years. This is probably due to the fact that the emissions have completely covered the absorption components.

We may compare our results with those derived from material obtained by Andrillat & Houziaux (1973) between 1965-71. He I at that time had similar strength to ours, with 7065 having at that time 12 Å against 7.6 in 1990 and 12.0 in 1993.

All this confirms the larger variability of helium, when compared to hydrogen.

Ionized helium is represented by several weak lines, observed at different dates, so that its presence is well established.

Carbon. Neutral carbon is represented by the most intense lines of M.3 and 9405 of M. 9.

Nitrogen. Neutral nitrogen is represented by many lines from M.1, 3, 6, 7, 8, 9 10, 15 and 18. The line variations of this and other elements will be discussed together afterwards, except those of hydrogen and helium which have been already discussed. Ionized nitrogen is not present on our material.

Oxygen. Neutral oxygen is represented by lines from M.1, 4, 8, 10, 13, 19, 20 and 21. M.4 (8446) is abnormally strong. This a well known fluorescence effect induced by Lyman β. Ionized oxygen is represented by the most intense line from M.1. Forbidden lines: lines of [O I] M.1; of [O II] M.1 and 2 and of [O III] M.1 and 2 are present.

Neon. Probably the [Ne III] line 3868.74 is present. Our resolving power does not permit to separate this line from He 3867.55, but the equivalent width of the line is too large to correspond to He I alone.

Magnesium. Ionized magnesium is represented by lines from M.1, 4 and 8. M.4 (4481) is very weak, as it is usual in shell stars.

Silicon. Ionized silicon is represented by lines from M.1, 2, 3 and 5.

Sulphur. Lines of ionized sulphur are not seen on our material, but [S II] is represented by lines from M.1.

Calcium. Ionized calcium is represented by lines from M.1 and 2. [Ca II] is seen by lines from M.1. The infrared Ca II triplet lines show P Cyg profiles on a plate from 1993, the absorption components being rather weak. The intensities of all three triplet lines are about equal at this date, a fact which contrasts strongly with the plate from 1990, where the equivalent widths are proportional to the laboratory intensities.

Titanium. Ionized titanium is represented by the strongest lines from M.13, 19, 31, 34, 41, 50, 51 and 105. [Ti II] is also present through several lines from various multiplets; 6, 9, 11, 16 20, 22, 25, 26 and 28.

Vanadium. This element is probably present, since two lines of M.8 of [V II] are seen.

Chromium. Ionized chromium is probably present, since two intense lines from M.30 are seen. However the strong line 4558 is not observed.

Iron. Ionized iron is represented by many lines from eighteen multiplets (M.14, 21, 27, 28, 29, 32, 33, 35, 36, 37, 38, 40, 42, 43, 46, 73, 74 and 197.) Also [Fe II] is represented by many lines from multiplets 1, 3, 4 6, 7, 8, 14, 18, 19, 20, 21, 22, 23, 24, 29, 36, 44, 47 and 51. A plot of the equivalent widths against laboratory intensities (Smith & Wiese 1973) shows a very good agreement.

Nickel. Only four lines of M.3, 4 and 10 of [Ni II] are seen.

5. Comparison with other work

We have collected in Table 6 the elements found in HD 51585 by different authors. It should be taken into account that the different lists are based on a wide variety of material, with different dispersions, resolutions and wavelength regions. So far the only identification in the ultraviolet ($1200 - 2800$ Å) is the one by Houziaux et al. (1982). On the other hand the identifications by Andrillat & Swings (1976) refer only to the wavelength region 10 000 and 11 000 Å.

We have checked our identifications with those given by other authors, specially Klutz & Swings (1977). We have also checked carefully on our material all elements detected by other authors, but we were unable to confirm these.

As can be seen from an inspection of the table, there exists reasonable agreement for most of the elements. Occasional discrepancies can almost always be traced owing to the fact that the identification is based upon a few lines present in a wavelength region which another observer has not covered.

6. Line intensity variations

The next point to examine is the line intensity variations, represented by the equivalent widths of the lines. We have assembled in Table 4 the variations of some of the lines present in our material, plus some values taken from authors indicated in the references to the table. We have already discussed the variations of hydrogen and helium. Both elements vary, but not in phase. We have illustrated the variations of the other elements in Fig. 4. As can be seen the maximum variations are of the order of $1.5 - 2$. Recently Arkhipova (1992) has found even larger variations in Hα and in Hβ.

From our material one finds that an emission maximum exists in 1992, which can be seen in H I, N I, Ca II, O I and also in Fe II. In these elements, the equivalent width is larger in 1990 than in 1993. On the other hand, He I (7065) grows from 1990 to 1993. [Fe II] and [Ca II] apparently go with He I and $W(1993) > W(1990)$. For [Ti II] and Mg II the variations are too small to be meaningful. This implies that in this star - as in other objects with shells- the elements do not follow a uniform pattern of variation. It seems fundamental to follow in detail these variations over a number of years.

Allen & Swings (1976), as quoted at the beginning of the paper, allocated this star to their group 3, where lines with ionization potentials higher than 25 eV are found.

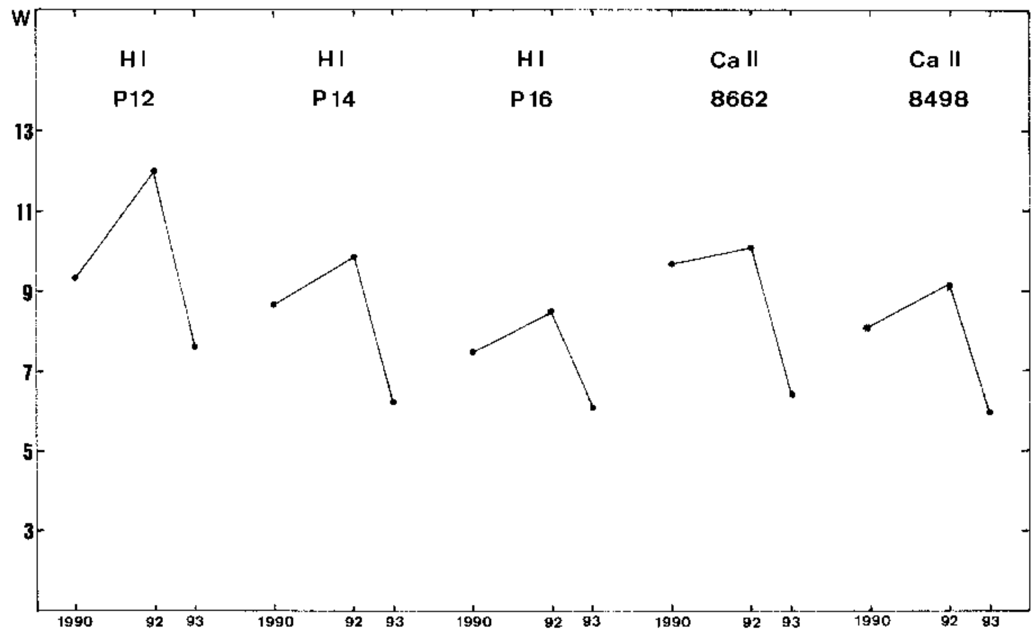

Fig. 3. Equivalent widths of hydrogen lines as a function of time: P 12, P 14, P 16. Are also plotted two ionized calcium lines (8662 and 8498)

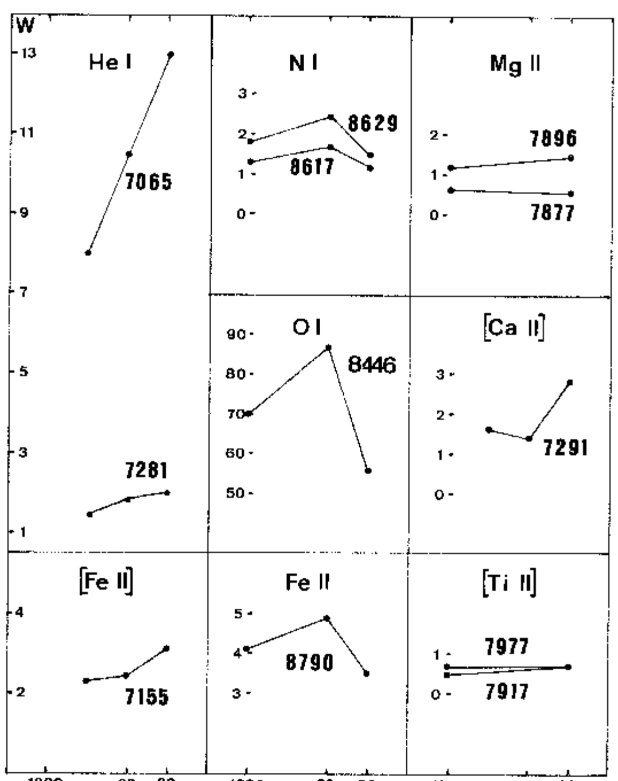

Fig. 4. The equivalent widths of lines of several elements as a function of time. In a given plot several lines of the same element may appear

From Table 6 one can see that several elements fall into this category: C IV, [O III], [Ne III] and [N IV]. It should be added that several of the lines observed are classical nebular lines, seen stronger in planetary nebulae- for instance He II, [S II], [O III] and [Ne III].

7. Radial velocities

We said at the beginning that our material is not well suited for radial velocity determinations, because the positions of the individual lines are affected by uncertainties of ±0.3 Å which translate into ±20 km/s . We have nevertheless derived the radial velocities from the unblended lines, excluding also those lines which exhibit anomalous profiles. Table 7 provides a summary of the results. The measurements are based on different wavelength regions of the spectrum and in each region the number of lines is different. It can be seen that the radial velocity varies over the years. The average of all velocities is 47 km/s and the amplitude is about 60 km/s. It should be mentioned that the variability of the radial velocity has already been suspected by Houziaux & Andrillat (1973).

It is possible that the velocity maximum could be related to the fact that the hydrogen line strength had also a maximum at this time. This points toward a complex relation between the velocity and the emission strength of the other layers of the star.

Another fact which emerges from our observations is that the velocity of the lines of the different elements do not deviate significantly from the average. We found

Table 6. Elements detected by different authors

Element	PP	KS	AI	AS	AH	HAHN
H	I	I	I	I	I	I
He	I,II	I	I,II	I	I	I,II?
C	I	IV				IV
[C]						III
N	I		II			II
[N]						III.IV
O	I,II	I		I		I
[O]	I,II,III	I,II,III	I,III		I,II,III	III
Ne		III				
[Ne]	III:				III	
Mg	II	II	I			II
Si	II	II	II			
S						
[S]	II	II		II?	II	II
Ca	II	II		II		
[Ca]	II	II				
Ti	II	II	II			
[Ti]	II					
V						
[V]	II?	II?				
Cr	II?	II	II			
Fe	II	II	II	II	II	II
[Fe]	II	II,III?	II	III	II	II
Ni		II				
[Ni]	II	II	II			

Codes
PP=present work
KS=Klutz and Swings (1977) 4020-5280,6300-7500 and 8200-11200 A
AI=Arkhipova and Ikonnikova (1992) 4300-7300 A
AS=Andrillat and Swings (1976) 7500-12000 A
AH=Andrillat and Houziaux (1973) 3300-8800 A.
HAHN=Houziaux,Andrillat,Heck and Nandy (1982) 1200-2800 and 4700-5000 A

Table 7. Radial velocities

25-10-91	b	15	3
25-10-91	c	12	4
08-04-93	d	54	6
20-04-92	e	67	5
24-10-91	f	36	4
06-04-93	g	42	6
28-12-90	h	62	7
07-04-93	i	41	5
31-03-93	j	56	3
21-02-92	k	74	3
27-12-90	l	62	4
27-12-90	m	48	6
30-12-92	o	43	7

First column: date in days ,month and (year-1900)
Second column: plate code
Third column: radial velocity in Km/s
Fourth column: error of the mean, rounded off to the next Km/s

an upper limit of +30 km/s for the dispersion of the individual velocities around the average plate velocity. In this figure are not included lines with P Cyg type profiles for which we remarked earlier that the average difference between absorption and emission components is of the order of 200 km/s.

8. Models

The model of HD 51585 has been discussed in several papers, the last one being the one by Arkhipova & Ikonnikova (1992). These authors write that the photometry permits to detect three sources- a body with a temperature of 28 000 K; hot dust with $T = 1100$ K and cool dust with $T = 180$ K. According to the scheme proposed by van der Veen et al. (1989) such a case is typical of a proto-planetary object on its way to become a typical old-disk planetary nebula.

The present observations confirm the temperature of the hot object, since the presence of He II lines is incompatible with $T < 25\,000$ K. On the other hand, the object is clearly abnormal, since we see no absorption line in the spectrum. We find an agreement of the emission line intensities with the laboratory intensities for elements like C, N, O and Fe. However one finds also many forbidden lines- specially from Fe- which are not seen in normal spectra. What one sees are the outer layers surrounding an invisible star and one can only surmise that its temperature must be much higher that the 28 000 K adjudicated to the outer parts.

Another fact which is somewhat difficult to understand is the variability of the spectral lines as evidenced in this paper, not accompanied by high ejection velocities. Except for the He I and the Ca II lines. But even here the differences between absorption and emission peaks are of the order of (only) 200 km/s.

It is probably appropriate to finish the paper with a call for much more observations of this interesting object, which might be one of the brightest candidates for becoming a planetary nebula in a relatively near future.

Acknowledgements. We wish to tank Mr. J. Marcout from the Strasbourg Observatory for drawing Figs. 2-4 and to Mrs. Hamm for providing literature of this object. We also thank Mr. Ph. Moreau of the Observatoire de Haute Provence for the reproduction of the spectra in Fig. 1.

References

Allen D.A., Swings J.P., 1976, A&A 47, 293
Andrillat Y., Houziaux L., 1973, Mém. Soc. Roy Sc. de Liège, sixième série V, 377
Andrillat Y., Swings J.P., 1976, ApJ 204, L 123
Andrillat Y., Houziaux L., 1996 (in press)

Arkhipova V.P., 1962, Sov. Astr. 6 , 286
Arkhipova V.P., Ikonnikova N.P., 1992, Sov. Astr. Lett. 18, 418
Beals C.S., Hatcher R.D., 1948, Contr. Dom. Obs. Ottawa 2, No. 1
Ciatti F., d'Odorico S., Mammano A., 1974, A&A 34, 131
Hamann F., Persson S.E., 1989, ApJS 71, 931
Houziaux L., Andrillat Y., Heck A., Nandy K., 1982, IAU Symp. 98. In: Jaschek M. and Groth H.J. (eds.) p. 427
Jaschek M., Andrillat Y., Houziaux L., Jaschek C., 1994, A&A 282, 911
Johansson S., 1977, MN 197, 17
Johansson S., 1978, Phys. Scripta 18, 217
Klutz M., Swings J.P., 1977, A&A 56, 143
Lemaître G., Kohler D., Lacroix D., Meunier J.P., Vin A., 1990, A&A 225, 545
Meinel A.B., Aveni A.F., Stockton H.W., 1981, "Catalog of emission lines in astrophysical objects", The University of Arizona, Tucson, Arizona
Merrill P.W., Burwell C.G., 1933, ApJ 78, 87
Moore Ch., 1959, "A multiplet table of astrophysical interest", NBS Tech. Note 36
Smith M.W., Wiese W.L., 1973, J. Phys. Chem. Ref. Data 2, 85
Swings J.P., Andrillat Y., 1981, A&A 103, L3