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Spectral Variations and Evidence for Edge and/or Line Locking Mechanism(s) in the Low-excitation Planetary Nebula HD 138403*

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Summary. Within the last decades, striking variations occurred in the visual spectrum of the low-excitation planetary nebula HD 138403 ≡ 315 − 13°1: the [O III], He II λ4686 and other high excitation lines of e.g. He I which were reported absent (or very faint) in 1950 are now present in emission (with moderate intensity). In addition, a [O III] nebula extending to 5″ in diameter has been discovered around the central star.

Furthermore, faint red and blue emission satellites have been found around the central Balmer (H_β–H_9) and [O II] λλ 3726, 3729 lines, with a mean velocity separation of +122 and −126 km s^{-1}, respectively. These spectral features are best interpreted as evidence for mass-outflow from the central object via the selective radiative process of edge and/or line locking mechanism(s). It is also argued that the presence of these satellites directly reflects the formation of a bipolar structure around the central nucleus.

Key words: spectroscopy – planetary nebula – HD 138403 – 315 −13°1 – line and/or edge locking

1. Introduction

On a coudé spectrogram of the planetary nebula HD 138403[1] obtained on July 8, 1976 at the European Southern Observatory (La Silla, Chile) one could readily detect faint red and blue emission satellites on both sides of the brightest Balmer and [O II] λλ 3726, 3729 lines. As these satellites were not reported in the literature and that, furthermore, variations of other lines were apparent when comparing our data with previous ones, we initiated additional spectroscopic and direct photographic observations (see Sect. 2) of this interesting object. The description of the nebula as photographed through different interference filters at the prime-focus of the ESO 3.6 m telescope is given in Sect. 3, and the spectral variations as well as the discovery of the faint emission satellites are presented in Sect. 4. Discussion of the results and general conclusions form the last two sections. A preliminary abstract and discussion of the present work was given by Surdej et al. (1980).

In the remainder of this introduction, we present a brief summary of the observations and of the theoretical investigations carried out on HD 138403 until now.

On account of its inclusion in Cannon's (1916) list of P Cygni objects, the "star" HD 138403 was examined for the first time by Thackeray in 1950. By means of visual and direct photographic observations with the 74-inch Radcliffe reflector, Thackeray (1950) found this object to be surrounded by a reddish circular disk, about 6″ in diameter. In that same paper, Thackeray reports the first spectroscopic observations of HD 138403: the Balmer ($H_\beta \rightarrow H_9$), [O II] λλ 3726, 3729 and [S II] λλ 4069, 4076 lines appear as strong emissions superimposed on a bright continuous spectrum. Furthermore, due to the apparent total absence of the nebulium pair, Thackeray attributed a low-excitation class to the nebulosity surrounding HD 138403.

A few years later, Thackeray (1956) gives a more detailed qualitative description of the spectrum. Among other things, the author notes the P Cygni-like profiles for various line transitions of He, C, N, and Si ions. He also reports the presence of faint [O III] λλ 4959, 5007 lines and notices the strange absence of He II λ4686.

Koelbloed (1962) published a spectrophotometric study of this low-excitation object. Using a method of calibration due to Petrie, he assigns a spectral type O 7.5 (f) to the central nucleus with an excitation temperature $T_s = 32{,}500$ K. He also finds that the nebula has a high surface brightness, comparable with those of NGC 6572 and IC 418. He succeeds in deriving the physical parameters $n_e = 2\ 10^4\,\mathrm{cm}^{-3}$ and $T_e = 9000 \pm 1000$ K.

HD 138403 has been observed photometrically in the ultraviolet (Pottasch et al., 1977, 1978), in the visible (Webster, 1969b), in the infrared (Persson and Frogel, 1972, 1973; Allen and Glass, 1974), and at radio wavelengths (Terzian, 1968; Milne and Aller, 1975; Milne and Webster, 1979). Photoelectric spectrophotometry of emission lines and continua in the 3400–7400 Å range has been published by Webster (1969a, b), Perek (1971), and Torres-Peimbert and Peimbert (1977). Combination of all these observational data allows a direct determination of the extinction towards the nebula (see Pottasch et al., 1977) as well as an estimate of the chemical abundances and physical parameters of the star plus nebula (Webster, 1969b; Kaler, 1970, 1978a, b, 1979; Torres-Peimbert and Peimbert, 1977; Seaton, 1980). In principle it is also possible to infer the distance to HD 138403, and this critical point is discussed in Sect. 5.

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1 (≡ 315 − 13°1 ≡ He 2 − 131 ≡ DM − 711889 ≡ MWC 236 ≡ MYL 90 ≡ WRA 1329 ≡ SAO 257300, etc.; R.A. (1950) = $15^h31^m54^s$, Decl. (1950) = −71°44′59″)

Table 1. List of the direct plates obtained for HD 138403

Plate no.	Date	Plate + filter combination	Exp. (s)	Seeing (arc s)
1333	1978 February 2/3	IIaO(B) + [O III]	1, 10, 30	1.5
1549	1978 April 2/3	IIIaJ(B) + [O III]	20, 30, 60, 120	2.5
1550	1978 April 2/3	098-04(B) + H_β	5, 10, 20, 30, 60	2.5
1648	1978 April 13/14	IIIaF(B) + H_α	2, 3, 4, 5, 10	2.0
1649	1978 April 13/14	IIIaF(B) + [O III]	20, 30, 60	2.0

Table 2. List of the spectrograms observed for HD 138403

Plate no.	Date (U.T.)	Exp. (min)	Dispersion (Å/mm)	Widening (μ)	Spectral range (Å)
F4752	1976 July 9, 4^h16^m	77	20.0	300	3700 – 4950
F4756	1976 July 11, 7^h16^m	108	20.0	300	3700–4950
G7737	1976 July 12, 3^h36^m	190	12.3	None	3600–5020
F6193	1978 March 28, 7^h51^m	40	20.0	None	3700–4950
F6385	1978 June 19, 5^h55^m	10	20.0	None	3700–4950
G9451	1978 June 20, 2^h56^m	75	12.3	470	3600–5020

It is worth mentioning that Gilra et al. (1978) detected spectral variations, in the strength and profile of the C IV resonance doublet at λ1550, on time scales of six months. Observations by Rich and Williams (1974) suggest that the nucleus of HD 138403 shows circularly polarized radiation which, if confirmed, could be interpreted in terms of the existence of large stellar magnetic fields.

Heap (1977a, b) has also investigated the atmospheric properties of HD 138403. She confirmed the fact that the object is a young, very bright and compact evolving low-excitation planetary nebula whose central nucleus can be classified O 7 (f) eq with a visual absolute magnitude $M_v = -2.1$.

With the aim of finding a velocity splitting of some emission lines, Thackeray (1977) has studied the visual, red and near infrared regions of the spectrum at high dispersion: no splitting was actually found.

Finally, Méndez and Niemela (1979) have illustrated in their paper spectroscopic observations of HD 138403 showing noticeable variations in the P Cygni profile of some line transitions of C, N, and Si within a few days.

2. Observations

Direct plates with multi-exposures of the planetary nebula HD 138403 were taken through interference filters at the prime focus (F/3, scale 18″.9/mm) of the ESO 3.6 m telescope. The parameters of these plates are summarized in Table 1. We have underlined in that table the exposure times for which the spectral images of the nebula appear optimal. The interference filters we used have the following characteristics (central wavelength/FWHM):

[O III]: 5014/22 Å

Hβ: 4858/40

and

Hα: 6573/120

Let us remark that because of the comparable strength of [N II] λ6584 and H_α in the spectrum of HD 138403 (Thackeray, 1956), the red colour of the nebula on plate No. 1648 is about equally distributed among the H_α and [N II] $\lambda\lambda$6548, 6584 emission lines.

The spectrograms studied hereafter have been obtained with the coudé spectrograph of the ESO 1.52 m telescope. Baked Kodak IIaO emulsion was used and all plates were calibrated photometrically by means of the ETA calibration spectrograph. Table 2 indicates the epoch of mean exposure, exposure time, dispersion, widening, and useful spectral range for each spectrogram.

3. The Nebula

During a visual examination with the 74-inch Radcliffe reflector Thackeray (1950) discovered, on 1950 April 28, a circular disk, about 5″ in diameter, around the central star HD 138403. He subsequently obtained red exposures (10 and 30 s) on Kodak O–E plates through a Wratten filter from which he could measure diameters of 4″.9 and 6″.3 respectively. A reproduction of these plates may be found in Thackeray (1956). Thackeray also reports that deeper exposures showed no faint extensions.

HD 138403 appears as the highest surface brightness object (log $S(H_\beta) = +0.29$, see Perek and Kohoutek, 1967) among the southern planetary nebulae compiled by Westerlund and Henize (1967). The latter report a corrected value of 6″ ± 1″ for the diameter of the nebula, as measured from a 103aE plate exposed during 6 s behind a chance OR 1 filter at the Newtonian focus of the Mount Stromlo 74-inch telescope. However, a footnote to their Table 1 indicates: "Intensity distribution slightly irregular. May be bipolar".

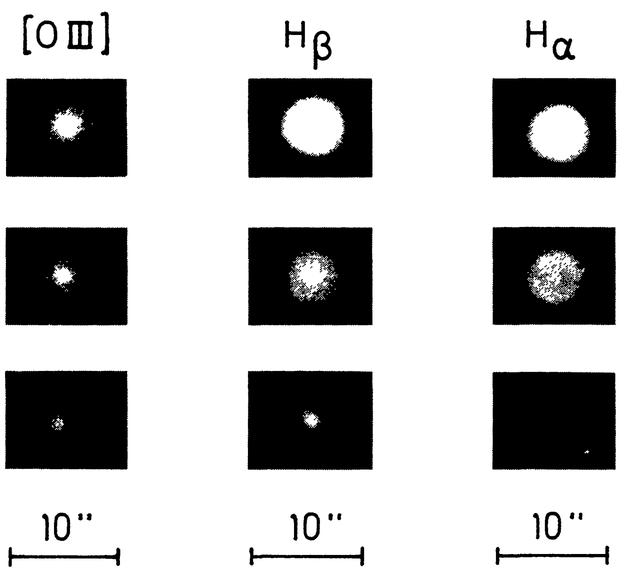

Fig. 1. The planetary nebula HD 138403 in [O III] (Plate No. 1333, Exposures: 30, 10, 1 s), in H_β (Plate No. 1550, Exposures: 30, 20, 10 s) and in H_α + [N II] (Plate No. 1648, Exposures: 5, 4, 3 s) as photographed at the prime-focus of the ESO 3.6 m telescope. North is up and East to the left

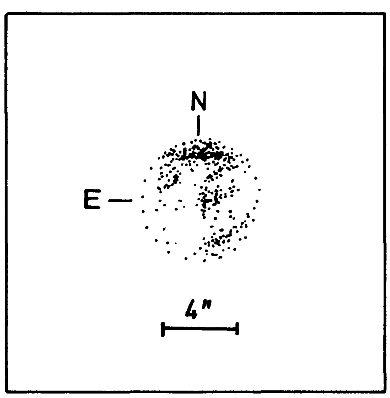

Fig. 2. Structure of the nebula around HD 138403 as seen from isodensity tracings of the multi-exposure (2–5 s) Plate No. 1648 (H_α + [N II])

Our main interest in getting new direct plates of HD 138403 was led by the fact that Koelbloed's (1962) description of the shape of the [O III] $\lambda\lambda$ 4959, 5007 lines from his unwidened 1954 spectra contrasted with the aspect of these lines as seen on our unwidened 1976 spectrum. Indeed, Koelbloed reports that the "... [O III] $\lambda\lambda$ 4959 and λ 5007 are very faint and are only visible very close to the stellar spectrum ...", whereas these lines appear with moderate intensity on spectrogram No. G 7737 and are spatially resolved ($>4''$ in diameter) by comparison to the narrow underlying stellar continuum. This result has subsequently been confirmed on three different direct plates taken through an [O III] interference filter. We reproduce in Fig. 1 selected regions of the direct plates No. 1333, 1550, and 1648 (see Table 1) which illustrate the aspects of the nebula in the monochromatic light of [O III], H_β, and H_α + [N II], respectively.

Each of the plates listed in Table 1 has been scanned with a PDS 1010A micro-densitometer at the European Southern Observatory (Geneva), and the image data were reduced with the IHAP program written by F. Middelburg (ESO). On the basis of the different image scans, we have derived the mean diameter d of the nebula as follows: from a few distinct one-dimensional density tracings radially crossing the central star, we measure the diameter d_n given by the inner distance between the two intersections of the nebular tracing and the fog level. We then correct these for atmospheric and instrumental dispersion by means of the relation

$$d=(d_n^2-d_s^2)^{1/2},$$

where d_s is the diameter of a nearby stellar image having about the same density as the nebular image. The corrected diameter d is finally transformed to arc s units by using the plate scale of 18''9/mm. The resulting diameters derived from the optimal exposure on the different plates are:

$d([\mathrm{O\,III}])=5''0$

$d(H_\beta)=6''8$

and

$d(H_\alpha)=7''0.$

We estimate that the maximum error in the determination of the diameter values, arising from the setting of the fog level and the correction of dispersion effects, is $\pm 0''4$.

At this stage, we tend to conclude that the 7''0 diameter value measured for the H_α + [N II] disk is about 1'' larger than the previously published values. However, it is nearly impossible to compare, within such an accuracy, data observed and reduced with different instruments and techniques. Nevertheless, it would obviously be worthwhile to remeasure the first direct plates taken by Thackeray (1950) together with those studied in the present work.

Figure 2 is a schematic representation of the structure of the nebula derived from two-dimensional isodensity tracings of the multi-exposure (2–5 s) H_α + [N II] plate (No. 1648). The non-uniform brightness distribution of the nebulosity and the resulting bipolar-like structure appearing in that figure are probably what Westerlund and Henize (1967) refer to in their description of the planetary nebula He 2–131.

4. The Visual Spectrum

Since the visual spectrum of HD 138403 has been largely studied in the past (Thackeray, 1950, 1956, 1977; Koelbloed, 1962; Heap, 1977a; Méndez and Niemela, 1979), it is not our aim to fully describe it here, but rather to point out the main spectral changes that it underwent.

A first look at our spectrograms (see Table 2) shows that the Balmer lines ($H_\beta \rightarrow H_{33}$) as well as [O II] $\lambda\lambda$ 3726, 3729 and [S II] $\lambda\lambda$ 4069, 4076 are made of strong nebular emissions superimposed on a bright stellar continuum. At the red end of the spectra, the [O III] $\lambda\lambda$ 4959, 5007 lines are present with moderate intensity. The broad stellar emission lines due to N III $\lambda\lambda$ 4634, 4641–42 which confer the O (f) type characteristic to the central star (Thackeray, 1956) are conspicuous as well. The unidentified (high-excitation?) emission lines at $\lambda\lambda$ 4486, 4504, which are often seen in Of-type spectra, are unusually strong in HD 138403 (cf. Heap, 1977a). A great number of He I lines are distributed throughout the visual spectrum with profiles ranging from pure emission to P Cygni-like

Table 3. List of newly observed He I line transitions in the visual spectrum of HD 138403

λ_{lab}	Multiplet no.	Remarks
3613.6	6	P Cygni profile
3705.0, 3705.1 *	25	Emission
3819.6, 3819.8 *	22	P Cygni profile
3964.7	5	P Cygni profile
4120.8, 4121.0 *	16	Emission
4143.8	53	Emission
4921.9	48	Emission
5015.7	4	Emission

Note: A blend between two lines is marked with an asterisk

ones. P Cygni profiles are also found for various line transitions of the C, N, and Si ions.

All the spectra listed in Table 2 were scanned on a Grant measuring machine, and the reduction, which included radial velocity and equivalent width measurements of various lines, was also performed with the IHAP system of ESO Geneva.

Out of 33 nebular emissions, most of which are Balmer lines, we find for HD 138403 a heliocentric radial velocity $v = 7 \pm 3\,\mathrm{km\,s^{-1}}$. This value compares well with that ($v = 6 \pm 5\,\mathrm{km\,s^{-1}}$) measured by Méndez and Niemela (1979). From nine well defined P Cygni profiles due to line transitions of He, C, N, and Si, we measured the velocity separation v_{ea} between the emission peak and the most blueshifted part of the P Cygni absorption. We find a mean value $\overline{v_{ea}} = 137 \pm 25\,\mathrm{km\,s^{-1}}$, in good agreement with the mean value $\overline{v_{ea}} = 127 \pm 38\,\mathrm{km\,s^{-1}}$ deduced by Thackeray (1956) from seven individual measurements.

In the remainder of this section we describe more specifically the variability of the visual spectrum as well as the discovery of faint emission satellites.

A. Variability

In their description of the Balmer line profiles, both Thackeray (1950, 1956) and Koelbloed (1962) note that the emission lines are superimposed on a rather wide and very shallow absorption, the equivalent width of which has been reported by Koelbloed to be $EW_{\mathrm{abs}} = 1.2$ Å for H_γ and $EW_{\mathrm{abs}} = 1.9$ Å for H_δ. Such profiles are no longer seen on our spectra. Instead, as in Heap's description (Heap, 1977a), a faint absorption is present on the violet wing of the central Balmer lines, with a blueshift of about $120\,\mathrm{km\,s^{-1}}$. Furthermore, since He II λ4542 appears on our spectra as a faint absorption, it is very likely that the other line transitions due to the He II Pickering series partially contribute to the formation of the blueshifted Balmer absorptions. One should note that the true situation is even more complicated by the fact that a faint emission satellite is superimposed on the latter component (see below).

Whereas Koelbloed's remark (Koelbloed, 1962) "the non appearance of He II λ4686 in the spectrum must be due to the filling in of the absorption line with the emission of the extended atmosphere ..." has been confirmed by all previous and subsequent spectroscopic investigations, we do report the presence of this line in emission ($EW_{em} \simeq 0.7$ Å from plates *F*4752 and *F*4756) on all our spectrograms, with the exception of the underexposed plate No. *F*6385. Let us point out that a footnote in the work by Méndez and Niemela (1979) directly confirms our results: "R. N. Walborn (private communication) has also found a well-marked emission of He II λ4686 on a low resolution spectrogram recorded on 1977 March 9–10".

In contrast, the He II $\lambda\lambda$4200, 4542 absorption lines, whose equivalent widths have been measured by Koelbloed (1962) and Heap (1977a) to be $EW_{\mathrm{abs}}(4200) \simeq 0.5$ Å and $EW_{\mathrm{abs}}(4542) \simeq 0.7$ Å, have noticeably weaker intensities on our spectrograms: He II λ4542 is faint and He II λ4200 is barely visible. Also, when comparing our two well exposed unwidened spectrograms (No. *G*7737 and *F*6193) it is obvious that the strength of the He II λ4542 absorption line (resp. He II λ4686 emission line) has weakened (resp. increased) between July 1976 and March 1978.

Of great importance also is the evolution of the [O III] emission lines. Indeed, the apparent absence of the [O III] $\lambda\lambda$4959, 5007 lines (see Thackeray, 1950; Henize, 1967; etc.), indicating an exceptionally low-excitation in the nebular component of the spectrum, led Koelbloed (1962), Sanduleak and Stephenson (1972), and Sanduleak (1976) to assign to the nebula an excitation class between 1 and 2, in the classification system adopted by Aller (1956). In view of the direct photographic and spectroscopic observations reported in Sect. 3, it is clear that the [O III] nebular emission in HD 138403 has strengthened during the last three decades. In order to get an idea about the relative strength of these lines with respect to H_β, we measured their equivalent widths on spectrogram No. *G*7737. We find $EW_{em}(H_\beta) \simeq 23.4$ Å, $EW_{em}(4959) \simeq 1.4$ Å, and $EW_{em}(5007) \simeq 2.9$ Å. Unfortunately, one cannot find in the literature any quantitative information concerning the strength of the [O III] lines until Webster's (1969a) photoelectric spectrophotometry of emission lines in southern planetary nebulae ($\log F(N_1) - \log F(H_\beta) = -0.88$). Consequently, it is not possible to derive a meaningful estimate for the scale of variation of the [O III] line strength in the spectrum of HD 138403 within the last three decades.

Among the spectral variations reported by Méndez and Niemela (1979) for the various line transitions belonging to the C, N, and Si ions, we confirm those for C II $\lambda\lambda$4267.0, 4267.3. Indeed, Thackeray (1956) observed these lines with a P Cygni profile and Méndez and Niemela found these lines to vary between a P Cygni and absorption line profiles. On the contrary, on our spectrograms, they are seen as a single emission. Similarly the C II $\lambda\lambda$ 3919.0, 3920.7 lines, which were not found by Thackeray (1977), are conspicuously present in emission on our spectra.

Finally, we list in Table 3 all He I line transitions visible on our spectrograms that have never been reported before. All these He I lines correspond to higher excitation transitions than those previously observed.

B. Presence of Emission Satellites

It was very unexpected to see on our first spectrogram of HD 138403 (No. *F*4752) that each of the Balmer ($H_\beta \rightarrow H_9$) and [O II] $\lambda\lambda$3727, 3729 lines was flanked on either side by a faint emission (just like grating ghosts appearing symmetrically around a strong line). The untrailed spectrum No. *G*7737 directly showed us that, unlike the central emission lines, these satellites are spatially unresolved.

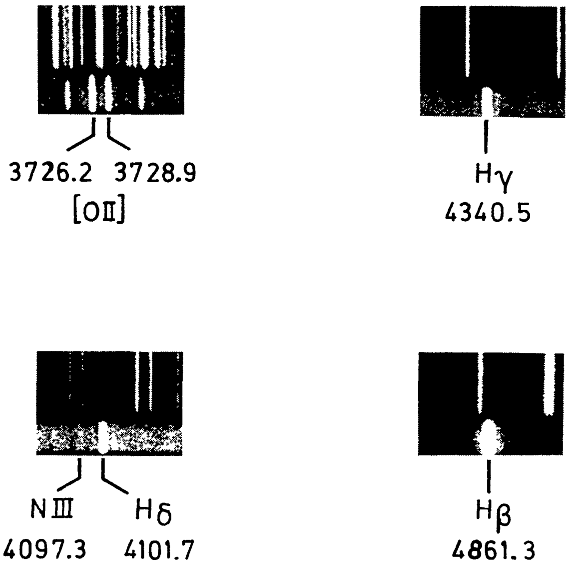

Fig. 3. Selected regions of the spectogram No. *F*4756 (see Table 2) showing the blue and red emission satellites around H_β, H_γ, H_δ, and [O II]

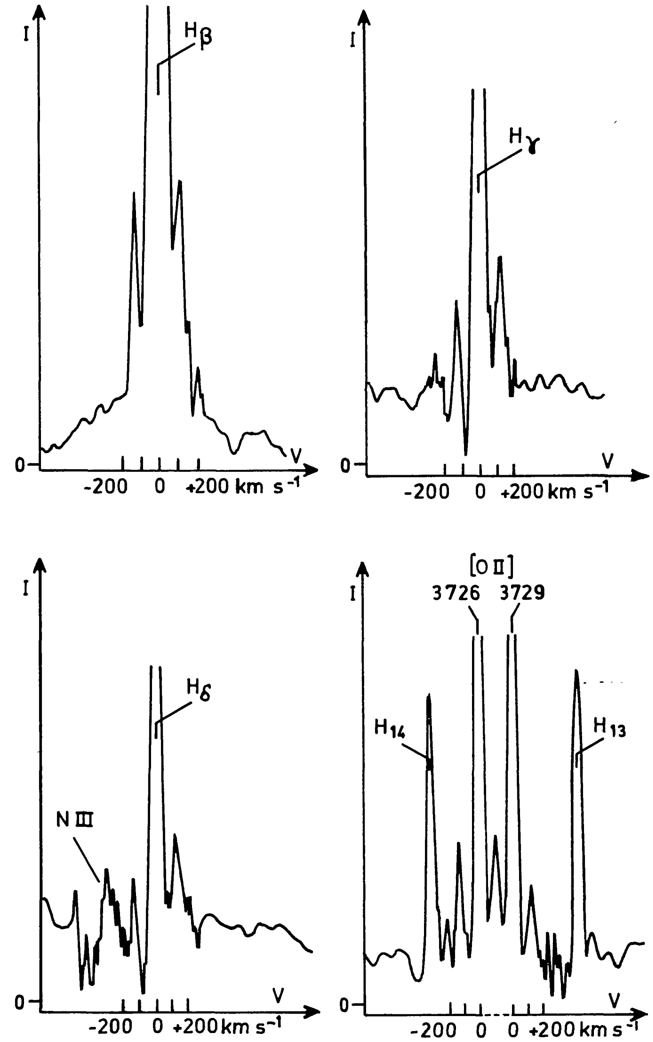

Fig. 4. Intensity tracings across the narrow stellar continuum around H_β, H_γ, H_δ, and [O II] (spectrogram No. *G*7737). H_β is overexposed and its bright wings are not real

We illustrate in Fig. 3 the spectral neighbourhood around each of the H_β, H_γ, H_δ, and [O II] $\lambda\lambda$ 3726, 3729 emission lines as they appear on spectrogram No. *F*4756. Similarly, Fig. 4 represents intensity tracings across the narrow stellar continuum recorded on spectrogram No. *G*7737.

For all lines of interest, we measured the velocity separation between the central component and its corresponding satellites. These velocities and their mean errors resulting from internal deviations between measurements carried out on different spectra are tabulated in Table 4. From these values, we directly conclude that the mean velocity separations between the blue and red satellites and their central component are equal to -126 ± 7 and 122 ± 7 km s^{-1}, respectively, and that furthermore there appears to be no correlation between the individual velocity separations and the wavelength or sequence of the line transitions. Let us also note that the width (velocity dispersion) of the emission satellites is found to be smaller than 25 km s^{-1}.

In order to estimate the relative strength of the emission satellites with respect to their central component, we measured their equivalent widths. Because of the presence of a blueshifted absorption at each Balmer line, we systematically lowered the continuum level when measuring the equivalent width of a blue satellite. Therefore, our measurements refer more to a flux determination than to a true equivalent width. Our results are summarized in Table 5 from which we deduce that, on the average, the blue (resp. red) satellite is about 30 (resp. 20) times fainter than the main central component.

A critical discussion of the origin of these emission satellites in the spectrum of HD 138403 is presented in the next section.

5. Discussion

In the following, we concentrate our discussion on three major points: the origin of the emission satellites (see Sect. 4A), the spectral variability (see Sect. 4B), and the different evaluations of the distance of HD 138403 (see Sect. 1).

A. Emission Satellites

Recalling the case of the discrete velocities observed for the Ca II (H and K) absorption components in the spectrum of the A0ep star HD 190073 (Surdej and Swings, 1977), we are directly tempted to invoke a selective radiative process in order to interpret the origin of the emission satellites present in the spectrum of HD 138403. Furthermore, because the velocity separation measured between the satellites and their central component is just about equal to the velocity splitting v_s (see below) between the Lyman (resp. Balmer, Paschen, etc.) series of hydrogen and the relevant transitions from the $n=2$ (resp. $n=4$, 6, etc.) levels of He^+, one immediately thinks in terms of edge and/or line locking mechanism(s) as the selective process of radiatively accelerating the gas from which the emission satellites arise. This mechanism was first suggested by Milne (1926) from theoretical considerations and has been later applied, under different forms, to the interpretation of the discrete velocity shifts of absorption components observed in the spectrum of stars (Scargle, 1973; Burbidge and Burbidge, 1975; Rees, 1975) and Seyfert nuclei (Scargle, 1973).

Table 4. Velocity separations between the emission satellites and their central component

Central line	Blue satellite (km s^{-1})	No. of spectra	Red satellite (km s^{-1})	No. of spectra
H_β	-125 ± 6	5	123 ± 9	5
H_γ	-126 ± 12	4	121 ± 5	4
H_δ	-132 ± 6	3	132 ± 2	3
H_ε	Perturbed by Ca II (*H*) absorption		111 ± 3	2
H_8	Perturbed by He I λλ 3888.6, 3889.1		119 ± 4	2
H_9	-118	1	118	1
[O II] λ 3726	-125 ± 6	4	116 ± 6[a]	4
[O II] λ 3729	-109 ± 9[a]	4	121 ± 5	4

[a] These two satellites form a blend and are thus not taken into account in the evaluation of the mean velocity separations

Table 5. Approximate equivalent widths for the emission satellites and their central component

Central line	Blue satellite (Å)	Red satellite (Å)	Central component (Å)
H_β	0.8 ± 0.1	1.2 ± 0.1	23.4 ± 5.5
H_γ	0.4	0.5	10.7 ± 2.5
H_δ	0.2	0.4	7.7 ± 2.9
H_ε	Perturbed by Ca II (*H*) absorption	0.2	5.8 ± 2.1
[O II] λ 3726	0.4	0.5[a]	11.8 ± 3.4
[O II] λ 3729	0.5[a]	0.4	7.7 ± 2.5

[a] These two satellites form a blend

Basically, the form under which we consider the action of edge and/or line locking mechanism(s) is the following. We suppose that around the central nucleus of HD 138403 a small sphere of He^+ ions is located, totally or partially absorbing the underlying stellar continuum in the lines and in the continua. If radiation pressure acting on the gas in the nebula overwhelms gravity it is very probable that due to the high abundance of hydrogen, the radiation scattered in lines and continua by the H atoms will contribute the most to the resulting positive acceleration. If this is the case, the gas under acceleration will recede from the central star with an increasing velocity until, because of the Doppler effect, the incident stellar radiation scattered by the H atoms will be shielded by the underlying absorbing He^+ sphere. At this stage, the gas has reached the velocity v_s and it is very easy to show that v_s constitutes in fact a stable saturation velocity (see Milne, 1926).

Because the velocity splitting v_s is due to the difference of reduced mass of the electron between the H atom and He^+ ion, it directly follows that

$$v_s = \left(\frac{R(\mathrm{H})}{R(\mathrm{He}^+)} - 1 \right) c,$$

where c is the velocity of light and

$$R(X) = R_\infty \Big/ \left(1 + \frac{m}{XM} \right)$$

the Rydberg constant for the hydrogen-like atom having an atomic weight X. m and M represent the masses of the electron and of the proton, respectively, and R_∞ is the value of $R(X)$ for infinite ratio of M/m. Inserting the values of the physical constants in the last equations, with $X(\mathrm{H}) = 1$ and $X(\mathrm{He}^+) = 4$, we obtain $v_s = 122$ km s^{-1}.

If the mass-loss were taking place isotropically with respect to the central star, we would expect to observe a rectangular or parabolic emission profile within the velocity range $\pm v_s$ around the central lines, depending on whether the nebula is optically thin or thick in the lines (cf. Sobolev, 1958). The fact that we actually observe discrete blue and red emission satellites in the spectrum of HD 138403 is best interpreted as being due to an ejection of matter (puffs?) with a velocity v_s, in two opposite directions approximately confined along the line of sight. This model may naturally lead to the formation of a bipolar structure, aligned along the line of sight, and probably located well inside the main nebula. The existence of such a bipolar structure, seen on direct photographs under the form of two bright knots aligned symmetrically around the central core, is well known from the case of other planetary nebulae (see 164+31°1, etc. in Perek and Kohoutek, 1967) although we do not claim here the existence of any specific mechanism responsible for those. Furthermore, the near coincidence between the wavelength $\lambda_{max} \simeq 900$ Å at which maximum light is emitted by the central core, and the limit of the H I Lyman series adds further support to the effectiveness of the edge and/or line locking mechanism(s) through the control of He^+ and H radiative transitions.

Let us finally note that two (and perhaps more!) bipolar structures can be present (Dennefeld and Schuster, 1980) along different directions within a main nebula. We suspect this to be also the case for HD 138403. Indeed, one bipolar structure is seen on direct photographic plates (see Westerlund and Henize, 1967 and Sect. 3) and the second one is inferred from the presence of the emission satellites.

B. Variability

The spectral variations detected in the strength and profile of the C IV resonance doublet at λ 1550 (Gilra et al., 1978), of the Si IV λλ 4088, 4116, N III λ 4097, C II λ 4267 (Méndez and Niemela, 1979), of the C II λλ 3919, 4267 line transitions and of the central Balmer lines (see Sect. 4A of the present work) over time scales ranging from a few days to a few tens of years, suggest a certain activity and/or instability in the deep layers surrounding HD 138403. Therefore, the mass-loss mechanism leading to the formation of the observed P Cygni profiles (with $\bar{v}_{ea} = 137$ km s^{-1}, see Sect. 4) is certainly different from that responsible for the presence of the emission satellites. It could also be that the edge and/or line locking mechanism(s) discussed above do not really act as an ejection mechanism but just as a driving one.

Furthermore, the appearance of higher-excitation lines of He I, of He II λ 4686 together with an increase in the intensity of the [O III] lines during the last three decades seem clearly to indicate a higher excitation class than previously assigned to this planetary nebula.

The changes recorded for the He II λλ 4200, 4542 absorptions and He II λ 4686 emission (see Sect. 4A) are reminiscent of those observed by Méndez and Niemela (1979) in the spectrum of NGC 246. If, on the basis of further spectroscopic observations, we can establish that these variations (increase in the intensity of He II λ 4686, etc.) are not erratic but follow a secular rise, it is very possible that they reflect evolutionary changes of the planetary nebula as suggested by Pilyugin and Khromov (1979).

C. Distances to HD *138403*

Although various methods have been proposed for estimating distances to planetary nebulae, the most difficult task remains in assigning an error bar to these estimates. In the following, we try to do so for HD 138403.

Harman and Seaton (1964, 1966) have well established that the nebula around HD 138403 is optically thick in the H I (Lyman) continuum. Consequently, the method due to Shklovsky (1956) for determining distances to planetary nebulae will only provide an upper limit in the case of HD 138403. We recall that Shklovsky's method consists in assuming that all planetaries are similar objects in different stages of expansion and, hence, that the ejected nebular mass M_n may be considered as a constant for all planetary nebulae which are optically thin in the H I continuum. Using formulae of the type (Acker, 1976; with $T_e = 10{,}000$ K)

$$\log D(\mathrm{pc}) = 1.88 - 0.6 \log r'' - 0.2 \log F(\mathrm{H}_\beta) - 0.2\,C$$

where D represents the distance of the nebula, r'' its radius (in arc s), $\log F(\mathrm{H}_\beta)$ its observed flux in H_β and C the interstellar extinction constant, Cahn and Kaler (1971), Milne and Aller (1975), and Cahn (1976) have deduced upper distance limits ranging between $D = 2.6$ and $D = 4.0$ kpc. The wide scatter observed between these values merely reflects the one existing among the observational data published for HD 138403. Adopting the most plausible values $\log F(\mathrm{H}_\beta) = -10.14 \pm 0.03$ (Webster, 1969a; Torres-Peimbert and Peimbert, 1977) and $C = 0.20$ (Milne and Aller, 1975; Pottasch et al., 1977; Torres-Peimbert, 1977) we find an upper limit $\underline{D = 3.8 \text{ kpc}}$ for the distance to HD 138403.

The assumption due to Minkowski (1965) that all optically thick planetaries have a constant absolute magnitude is only good for deriving statistical distances. Therefore, the distance $D = 1.7$ kpc to HD 138403 calculated by Torres-Peimbert and Peimbert (1977) has no real significance in itself. Seaton (1954) has suggested that distances to planetary nebulae could be obtained using the electron density n_e deduced from relative intensities of forbidden lines together with the measured H_β surface brightness. With relations similar to (cf. O'Dell, 1962)

$$\log D\ (\mathrm{pc}) = 22.85 + \log F(\mathrm{H}_\beta) - 3 \log r'' - 2 \log n_e + C$$

and adopting the values $\log F(\mathrm{H}_\beta) = -9.58$, $r'' = 3''$, $C = 0.20$ and the electron density $n_e = 2\ 10^4\ \mathrm{cm}^{-3}$, Koelbloed (1962) and Seaton (1966) have deduced a distance $D = 2.7$ and $D = 3.1$ kpc, respectively. Let us immediately note that these results are not of high accuracy due to their large dependence on observational errors and on the detailed structure of the nebula (cf. Sect. 3 and Fig. 4). With the improved values $\log F(\mathrm{H}_\beta) = -10.14$ and $n_e = 0.9\ 10^4\ \mathrm{cm}^{-3}$ (Webster, 1969a, Torres-Peimbert and Peimbert, 1977), we deduce the value $\underline{D = 3.7 \text{ kpc}}$.

Finally, we shall mention Heap's suggestion to use the spectroscopic parallax technique in order to calculate the distance to HD 138403 (Heap, 1977a). The latter follows from the relation

$$\log D\ (\mathrm{pc}) = 0.2\ [m_v - M_v - R \cdot E(B-V) + 5],$$

where m_v, M_v are the apparent and absolute visual magnitudes of the central star, $E(B-V)$ the color excess and R the value of total to selective extinction. With $m_v = 10.59 \pm 0.03$ (Webster, 1969b), $M_v = -2.1 \pm 0.8$ (Heap, 1977a), $E(B-V) = 0.13 \pm 0.05$ and $R = 3.2 \pm 0.7$ (Pottasch et al., 1977) we obtain $\underline{D = 2.8 \text{ kpc}}$. In view of all previous estimates and taking into account the observational uncertainties, we adopt a distance $\underline{D = 2.8 \pm 1.0 \text{ kpc}}$ to the planetary nebula HD 138403. At such a distance, the linear radius of the nebula would be $r = 0.04$ pc, a typical value for an optically thick planetary.

6. Conclusions

We have shown in the present work that the spectral variations detected within the last three decades for the lines of He II λ 4686, [O III] λλ 4959, 5007, He I, etc. in the spectrum of HD 138403 suggest an appreciable activity in the deep atmospheric layers of the nucleus, as well as an increase of the excitation of the nebula. Noticing that the star HD 138403 is just located at the beginning of the Harman-Seaton sequence of planetaries (see Harman and Seaton, 1964; Seaton, 1966; Webster, 1969b), it is quite possible that the observed spectral variations constitute signs of an evolutionary change (cf. Pilyugin and Khromov, 1979) of the low-excitation object towards the stage of a more classical planetary nebula in the Hertzsprung-Russell diagram.

We have also seen that the spectrum of HD 138403 is quite unusual due to the presence of red and blue emission satellites around the central Balmer ($\mathrm{H}_\beta - \mathrm{H}_9$) and [O II] λλ 3726, 3729 lines, with a velocity separation equal to +122 and −126 km s^{-1}, respectively. Invoking the near coincidence ($v_s = 122$ km s^{-1}) between the wavelengths of line transitions due to H ($n = 1, 2, \ldots \rightarrow n'$) and He II ($n = 2, 4, \ldots \rightarrow 2n'$), we have interpreted this discovery in terms of the formation of a bipolar structure, nearly aligned along the line of sight, and driven away from the central star by the selective radiative processes of edge and/or line locking (Milne, 1926). We actually plan to investigate, in the large sample of known planetaries, the possible relations between the presence of a bipolar structure and the activity, temperature, luminosity, etc. of the central nucleus.

It is very interesting to note, from the intrinsic width ($\Delta v \lesssim 25$ km s^{-1}) of the emission satellites, the very small dispersion in velocity of the moving gas from which they arise. This may be compared with the extreme case found in quasar spectra where absorption widths happen to be as small as 30 km s^{-1} while the wavelength displacements correspond to velocities of 100,000 km s^{-1} or even greater. This contrast has often been used in the past to argue against an intrinsic mechanism (ejection of matter) as the origin of the blue-shifted absorption components in favour of cosmological interpretations (intergalactic gas, etc.). Our present observations of the emission satellites in the spectrum of HD 138403 thus clearly demonstrate that also for the case of quasars, the line and/or edge locking mechanisms may operate and account for the presence of highly blueshifted absorption components with intrinsically small widths. On theoretical grounds, the problem looks very attractive: to specify the general physical conditions under which matter is radiatively accelerated up to a certain velocity at which it keeps locked within a very narrow window ($\Delta v \lesssim 30$ km s^{-1}). However, the most attractive for now will be to record additional observations of HD 138403 in order to witness signs of its present evolution.

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