

The “red shelf” of the $H\beta$ line in the Seyfert 1 galaxies RXS J01177+3637 and HS 0328+05

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Abstract. A few Seyfert 1s have a $H\beta$ profile with a red wing usually called the “red shelf”. The most popular interpretation of this feature is that it is due to broad redshifted lines of $H\beta$ and [O III] $\lambda\lambda$ 4959, 5007; we have observed two Seyfert 1s displaying a “red shelf” and showed that in these two objects the main contributor is most probably the He I $\lambda\lambda$ 4922, 5016 lines having the velocity and width of the broad $H\beta$ component. There is no evidence for the presence of a broad redshifted component of $H\beta$ or [O III] in any of these two objects.

Key words. galaxies: Seyfert – galaxies: individual: RXS J01177+3637, HS 0328+05

1. Introduction

A few Seyfert 1s have a very complex $H\beta$ profile with a strong red wing extending underneath the [O III] $\lambda\lambda$ 4959, 5007 lines. The excess emission in the red wing is referred to as the “shelf” feature or the “red shelf” (Meyers & Peterson 1985). In most Seyfert 1s showing such a feature, it appears to be made of two components: a broad red wing to $H\beta$, and a broad wing on the long wavelength side of the [O III] λ 5007 line (van Groningen & de Bruyn 1989).

Several interpretations have been proposed to explain the “red shelf”: it could be due to $H\beta$ or to the presence of other broad emission lines such as [O III], Si II λ 5056, He I λ 5016 (Meyers & Peterson 1985; van Groningen & de Bruyn 1989; Kollatschny et al. 2001) or Fe II (Korista 1992).

Meyers & Peterson (1985), Crenshaw & Peterson (1986) and Stirpe et al. (1989) have argued that broad [O III] lines are most probably the main contributor to the observed λ 5007 red wing. Van Groningen & de Bruyn (1989) have found the same red wing in [O III] λ 4363 in several objects, confirming that they are indeed due to [O III] emission.

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* Based on observations obtained with the ESO NTT telescope, La Silla, Chile and the 1.93-m telescope at the Observatoire de Haute Provence (CNRS), France.

To investigate the nature of the “red shelf”, we have made spectroscopic observations of two Seyfert 1s: RXS J01177+3637 and HS 0328+05.

2. Observations and data reduction

RXS J01177+3637 was observed on January 15, 1999, with the CARELEC spectrograph (Lemaître et al. 1989) attached to the Cassegrain focus of the OHP 1.93-m telescope. We obtained one 20 min exposure with a dispersion of 130 \AA mm^{-1} in the range 4600 to 7900 \AA . The detector was a 1024×2048 , $13.5 \times 13.5 \mu\text{m}$ pixel EEV CCD. Nine lines were extracted. The slit width was $2''.2$ corresponding to 4.0 pixels on the detector; the resolution, as measured on the night sky lines, was $\sim 6 \text{ \AA FWHM}$. The spectrum was flux calibrated with the standard stars EG 166 and EG 247 (Oke 1974) and Feige 66 (Massey et al. 1988).

In the case of HS 0328+05, the observations were carried out with the EMMI spectrograph attached to one of the Nasmyth foci of the ESO 3.58-m NTT telescope at La Silla. The detector was a 2048×2047 , $24 \times 24 \mu\text{m}$ pixel Tektronix CCD. Two spectra with a high signal-to-noise ratio (>50 in the continuum) were obtained, one in the red on November 24, 2000 (grism#6, 6000–8300 \AA), the other in the blue on November 23 (grism#5, 4000–6600 \AA). The exposure times were 30 and 45 min respectively. The slit width was $1''$, corresponding to 3.7 pixels on the detector; the resolution, as measured on the night sky lines, was $\sim 4.5 \text{ \AA FWHM}$. The nucleus was centered on the slit

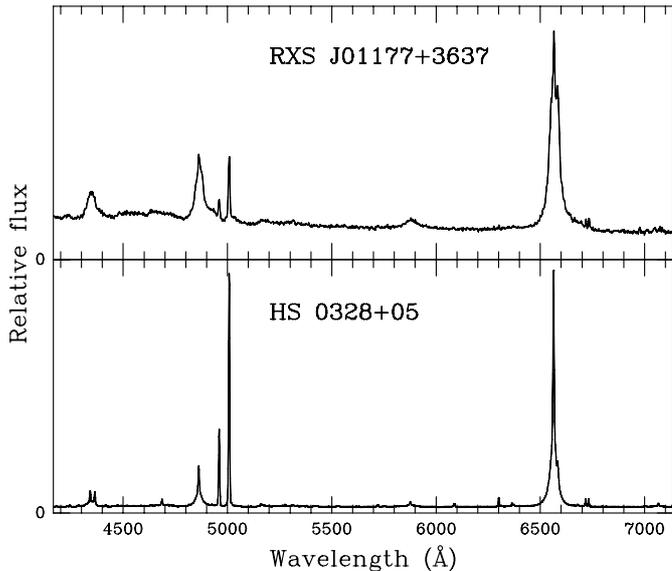


Fig. 1. Deredshifted spectra of RXS J01177+3637 and HS 0328+05.

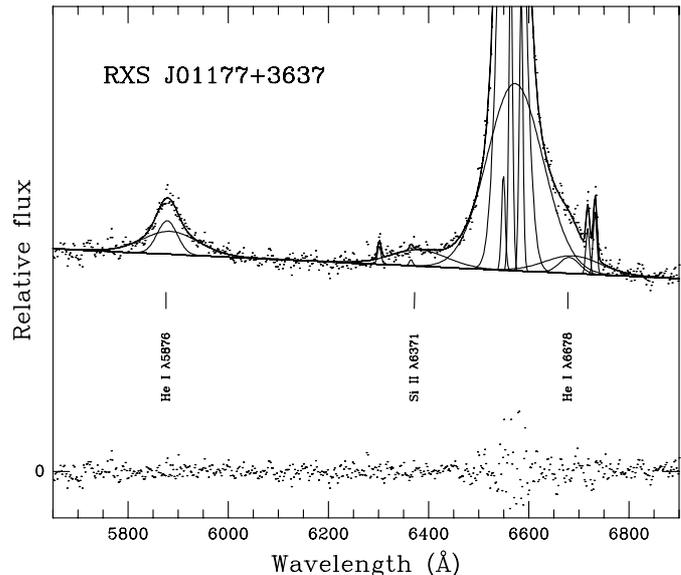


Fig. 2. Fit of the red part of the spectrum of RXS J01177+3637. The figure shows the data, the fit, the individual components and the residuals.

which was aligned with the parallactic angle. Seven lines were extracted. The spectra were flux calibrated with the standard stars LTT 2415, LTT 3218 and LTT 9491 taken from Hamuy et al. (1992, 1994).

The spectra of the two objects are shown in Fig. 1. All the following analysis was done using our own software (Véron et al. 1980).

3. Analysis

3.1. RXS J01177+3637

RXS J01177+3637 is a Seyfert 1 at $z = 0.106$ (Wei et al. 1999). Our spectrum clearly shows the presence of the “red shelf” (Fig. 1).

In a first step the broad $H\alpha$ line was fitted with two Gaussians; the first (G1) has a $FWHM$ of 2150 km s^{-1} and a velocity of 130 km s^{-1} (with respect to the narrow emission lines), while the second (G2) has a peak intensity of 24% of that of the first, a $FWHM$ of 6100 km s^{-1} and a velocity of 560 km s^{-1} .

The red part of the spectrum also shows broad He I lines: $\lambda 5876$, $\lambda 6678$, $\lambda 7065$ and a line near $\lambda 6370$. The three He I lines have the width of the narrower $H\alpha$ component G1 ($\lambda 5876/H\alpha = 4.1\%$, $\lambda 6678/H\alpha = 2.0\%$; $\lambda 7065/H\alpha = 2.6\%$; here the $H\alpha$ flux is that of the G1 component). The ionization potentials of Si I, Si II and Si III are nearly identical to the ionization potentials of Fe I, Fe II and Fe III and therefore the Fe^+ and Si^+ zones should be virtually the same; consequently Si II lines are expected in objects with strong Fe II emission (Phillips 1978); in several Seyfert 1s, an emission feature near 5050 \AA has been attributed to Si II $\lambda 5056$ (Crenshaw & Peterson 1986); we therefore feel confident that the line observed at $\lambda 6370$ is Si II $\lambda 6371$; this line has the width of the

broader $H\alpha$ component G2 ($\lambda 6371/H\alpha = 8.6\%$), while the He I $\lambda 5876$ and $\lambda 6678$ lines also have a broader component ($\lambda 5876/H\alpha = 12\%$ and $\lambda 6678/H\alpha = 9.5\%$). Figure 2 shows the result of the fit of the red part of the spectrum.

In a second step we removed the Fe II multiplets in the blue part of the spectrum following the method described by Boroson & Green (1992), using a Fe II template obtained by taking a high signal-to-noise spectrum of I Zw 1 (Véron-Cetty et al. 2001), an NLS1 showing strong narrow Fe II emission. The resulting spectrum still shows strong broad red wings to $H\beta$ and $\lambda 5007$ (Fig. 3).

We fitted the broad $H\beta$ line with two Gaussian profiles having the velocities and widths of the Gaussian components (G1 and G2) of the broad $H\alpha$ line. The broad red wings to $H\beta$ and $\lambda 5007$ are well fitted with broad ($FWHM = 6100 \text{ km s}^{-1}$) Gaussian profiles (G2) at the wavelengths of He I $\lambda 4922$ and $\lambda 5016$ ($\lambda 4922/H\beta = 30\%$; $\lambda 5016/H\beta = 22\%$); the $\lambda 5016$ line may also have a narrower (2150 km s^{-1} $FWHM$) component (G1) with $\lambda 5016/H\beta = 2.4\%$. The He II $\lambda 4686$ and He I $\lambda 4713$ lines are fitted each with a Gaussian profile with $FWHM = 6100 \text{ km s}^{-1}$ (G2); the He II line is very strong ($\lambda 4686/H\beta = 42\%$; $\lambda 4713/H\beta = 19\%$) (Fig. 3).

Although higher quality spectra would be necessary to conclude unambiguously, it seems that the red wings to $H\beta$ and $\lambda 5007$ may be fully accounted for by the presence of the broad He I $\lambda 4922$ and $\lambda 5016$ lines respectively.

3.2. HS 0328+05

HS 0328+05 is a Seyfert 1 at $z = 0.043$ (Perlman et al. 1996; Engels et al. 1998). The Balmer lines have been fitted with a broad Lorentzian profile with a $FWHM$ of

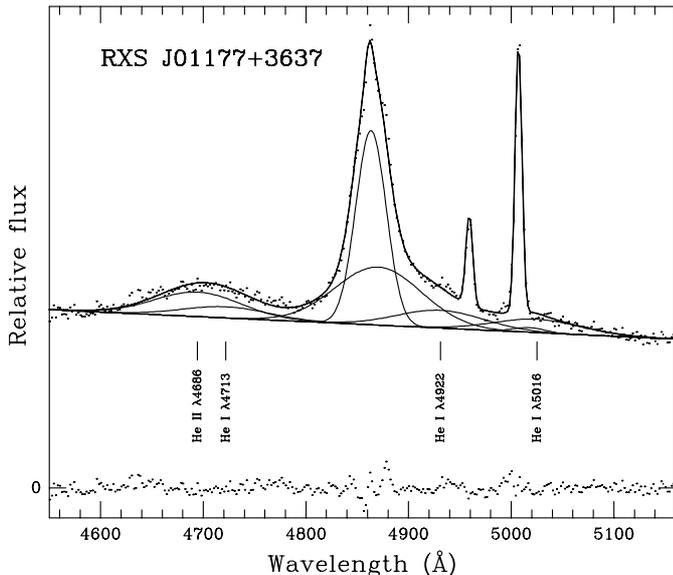


Fig. 3. Fit of the blue part of the spectrum of RXS J01177+3637. The figure shows the data (after subtraction of the Fe II emission), the fit, the individual broad components ($H\beta$, He I $\lambda 4713$, $\lambda 4922$ and $\lambda 5016$ and He II $\lambda 4686$) and the residuals.

$\sim 1500 \text{ km s}^{-1}$ leading to the classification of this object as a NLS1; the Fe II emission was not detected, with the ratio of the Fe II emission measured between 4450 and 4684 Å and the total $H\beta$ flux $R_{4570} < 0.6$ (Véron-Cetty et al. 2001); our new high quality spectrum shows that $H\beta$ has a weak, but definitively present, “red shelf”; in addition, the Fe II emission is detected with $R_{4570} = 0.43$.

3.2.1. Narrow emission lines in the range 5080–5430 Å

In a first step we removed the broad Fe II multiplets as described above. In so doing we made the implicit assumption that the Fe II spectra of HS 0328+05 and I Zw 1 are identical; however according to Joly (1988) the relative intensities of the various multiplets are not the same in all objects, being a function of the temperature. Is then our assumption justified?

Inspection of the I Zw 1 Fe II spectrum (Fig. 4) shows that, in this object, the intensities of multiplets 25 (4846–5000 Å), 35 (5100–5180 Å) and 36 ($\lambda\lambda 4893, 4993, 5037$) are quite small compared to that of m. 42 ($\lambda\lambda 4924, 5018, 5169$), thus suggesting a temperature $T_e > 8000 \text{ K}$; if the temperature in HS 0328+05 were smaller ($T_e < 7000 \text{ K}$) the relative intensity of the first three multiplets would be much larger with respect to m. 42 (Joly 1988). Inspection of the residuals in Fig. 5 shows that the Fe II m. 35 has been completely cancelled out from the spectrum of HS 0328+05 by subtracting the template. It seems therefore that our procedure has indeed removed all the Fe II emission and that our initial assumption is justified.

The resulting spectrum is rich in narrow emission lines. We analysed a region free of broad emission

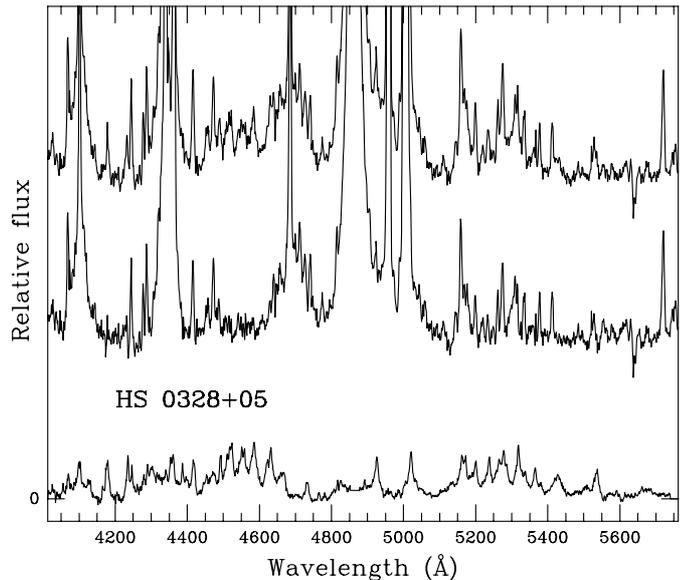


Fig. 4. The upper curve is the spectrum of HS 0328+05; the lower curve is the suitably scaled template Fe II spectrum; the middle curve is the difference (moved downward by an arbitrary amount for clarity). The quality of the iron removal is well seen in the spectral range 4450 to 4650 Å.

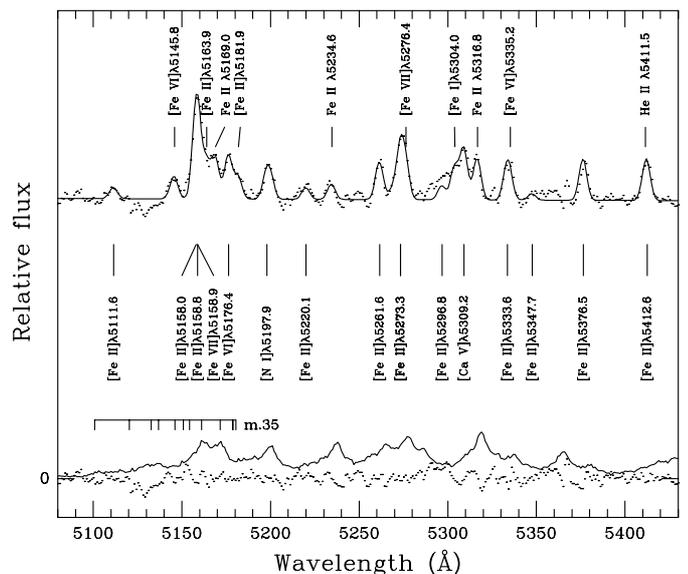


Fig. 5. Spectrum of HS 0328+05 (after subtraction of the broad permitted Fe II lines) in the range 5080 to 5430 Å. All identified emission features were included in the fit assuming that they all have the same velocity and width (namely 4.9 \AA FWHM). Thirteen forbidden and three permitted Fe II emission lines are clearly detected. The bottom dotted line shows the residuals, while the solid line is the Fe II template subtracted from the original spectrum. The positions of the twelve lines in Fe II multiplet 35 are indicated.

features: 5080–5430 Å. Figure 5 shows all the lines identified in this range including thirteen [Fe II] lines, three Fe II lines ($\lambda 5169$ (42), $\lambda 5234$ (49) and $\lambda 5317$ (48)), three [Fe VI] (2F) lines at $\lambda 5145.8$, $\lambda 5176.4$ and $\lambda 5335.2$, and two [Fe VII] (2F) lines at $\lambda 5158.9$ and $\lambda 5276.4$.

Table 1. [Fe II] lines observed in HS 0328+05. Column 2 gives the multiplet numbers, Col. 3 the radiative transition probabilities A (from Quinet et al. 1996), Col. 4 the line intensities measured in the Orion nebula relative to He I $\lambda 6678$, multiplied by 100 (Verner et al. 2000), Col. 5 the relative intensities measured in HS 0328+05, Col. 6 the log of the ratio of the intensities observed in HS 0328+05 and Orion.

λ_{lab} (Å)		A	$I(\text{Orion})$	$I(\text{HS})$	
4114.5	23F	0.103	0.25	0.30	0.08
4177.2	21F	0.194	0.26	0.23	-0.05
4244.0	21F	1.12	1.18	1.23	0.06
4276.8	21F	0.819	0.92	0.77	-0.08
4287.4	7F	1.65	2.32	1.58	-0.17
4319.6	21F	0.658		0.25	
4352.8	21F	0.380	0.51	0.45	-0.05
4358.4	21F	0.875		1.98	
4359.3	7F	1.22	1.60	1.36	-0.07
4372.4	21F	0.340		0.20	
4413.8	7F	0.858	1.16	0.82	-0.16
4416.3	6F	0.454	1.41	0.73	-0.28
4452.1	7F	0.548	0.90	0.53	-0.23
4457.9	6F	0.279	0.49	0.56	0.06
4474.9	7F	0.267	0.35	0.26	-0.13
4488.7	6F	0.150		0.55	
4639.7	4F	0.499		0.58	
4664.4	4F	0.156		0.18	
4728.1	4F	0.478	0.16	0.56	0.54
4774.7	20F	0.163	0.17	0.34	0.30
4814.5	20F	0.521	1.20	1.01	-0.07
4874.5	20F	0.223		1.16	
4889.6	4F	0.347	0.67	1.25	0.27
4905.3	20F	0.285	0.23	0.53	0.36
4947.4	20F	0.075	0.49	0.53	0.03
4950.7	20F	0.225	0.35	0.24	-0.16
4973.4	20F	0.183	0.36	0.17	-0.33
5020.2	20F	0.236		0.25	
5043.5	20F	0.094		0.49	
5111.6	19F	0.131	0.38	0.23	-0.22
5158.0	18F	0.440		0.62	
5158.8	19F	0.605	1.82	1.25	-0.16
5163.9	35F	0.309		0.67	
5181.9	18F	0.500		0.51	
5220.1	19F	0.144	0.15	0.27	0.26
5261.6	19F	0.429	1.36	0.68	-0.30
5268.9	18F	0.288	0.09	0.21	0.37
5273.3	18F	0.550	0.67	1.16	0.24
5296.8	19F	0.118	0.08	0.54	0.83
5333.6	19F	0.351	0.35	0.62	0.25
5347.7	18F	0.087		0.12	
5376.4	19F	0.348	0.46	0.78	0.23
5412.6	17F	0.283		0.63	
5527.3	17F	0.273		0.46	
5747.0	34F	0.373	0.08	0.49	0.79
7155.2	14F	0.153	1.50	0.99	-0.18
7172.0	14F	0.588	0.35	0.62	0.25
7388.2	14F	0.045	0.24	0.24	0.00
7452.5	14F	0.049	0.45	0.44	-0.01

The observed [Fe VI] lines have large predicted intensities (Garstang et al. 1978).

The two [Fe VII] lines $\lambda\lambda 5721, 6087$ (1F) are relatively strong with a ratio $\lambda 6087/\lambda 5721 = 1.53$, near the theoretical value of 1.60 (Nussbaumer & Storey 1982). According to Keenan & Norrington (1987), for densities lower than $\sim 10^6 \text{ cm}^{-3}$, the intensity ratio $\lambda 5159/\lambda 6087$ is in the range 0.20–0.35. In the Seyfert 1 III Zw 77, Osterbrock (1981) has observed $\lambda 5159/\lambda 6087 = 0.20$. The two [Fe VII] lines $\lambda 5159$ and $\lambda 5276$ are blended with [Fe II] $\lambda 5159$ (19F) and $\lambda 5273$ (18F) respectively; we could however determine the intensity of [Fe VII] $\lambda 5276$; assuming that the intensities of $\lambda 5276$ and $\lambda 5159$ are equal (their radiative transition probabilities are about equal, Keenan & Norrington 1987), we got $\lambda 5159/\lambda 6087 = 0.2$, confirming the identification of these two blended lines.

Having shown that the spectrum is dominated by [Fe II] lines, we looked for lines from this ion in the whole spectrum; the lines found are listed in Table 1 with their radiative transition probabilities and their relative intensities both in Orion when available (Verner et al. 2000) and HS 0328+05. These intensities are in good agreement (within a factor of 2), except for the weakest lines ($I_{\text{Orion}} < 0.25$) for which our intensities are larger. A few of these lines were previously observed in the spectrum of NGC 4151 (Boksenberg et al. 1975). Several of them were not observed neither by Verner et al. (Orion) nor by Hamann (1994) (KK Oph); however their radiative transition probabilities computed by Quinet et al. (1996) are relatively large.

3.2.2. Fitting the spectrum around $H\alpha$ and $H\beta$

We fitted the red spectrum (6250–6740 Å) with Gaussian components. The broad $H\alpha$ is well fitted by three Gaussians H1, H2 and H3; their velocities are 51, -98 and 29 km s^{-1} respectively and their $FWHM$ 1730, 3400 and 11600 km s^{-1} . The relative peak intensity of these three components is 1.00, 0.40 and 0.04. The He I $\lambda 6678$ line has a weak broad (1730 km s^{-1} $FWHM$) component (H1), with $\lambda 6678/H\alpha = 0.9\%$; broad lines (H1) of He I $\lambda 5876$ and $\lambda 7065$ are also present ($\lambda 5876/H\alpha = 2.1\%$, $\lambda 7065/H\alpha = 2.4\%$); $\lambda 5876$ has also a broader (3400 km s^{-1} $FWHM$) component (H2) with $\lambda 5876/H\alpha = 5.5\%$. A broad (H1) line is required at $\lambda 6371$ that we identify with Si II $\lambda 6371$.

We showed in a preceding paper (Véron-Cetty et al. 2001) that the Balmer lines of NLS1s are better fitted with a single Lorentzian profile than with a single Gaussian profile. Our new high signal-to-noise spectrum shows that, at least in the case of HS 0328+05, this is not satisfactory and that a fit involving several Gaussians is needed (see Fig. 6).

We analysed in detail the blue spectrum in the range 4780 to 5120 Å which contains the $H\beta$ and [O III] lines.

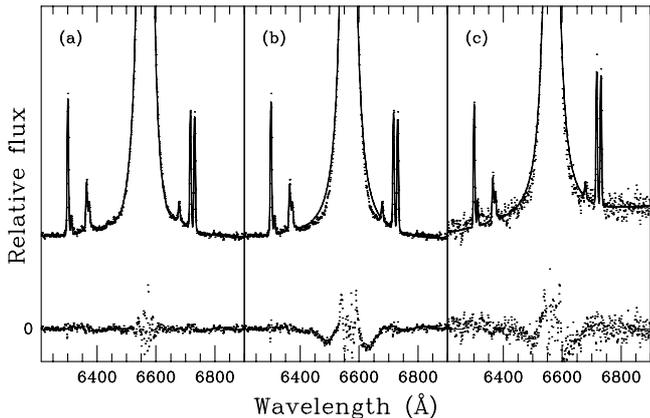


Fig. 6. Fit of the spectrum of HS 0328+05 in the range 6210 to 6900 Å. The broad H α component has been fitted with three Gaussian profiles **a)**, with a single Lorentzian **b)**. **c)** is the lower signal-to-noise ratio spectrum obtained with the OHP 1.93-m telescope fitted with a single Lorentzian. The high signal-to-noise reached with the NTT spectrum shows that the single Lorentzian fit is no longer acceptable.

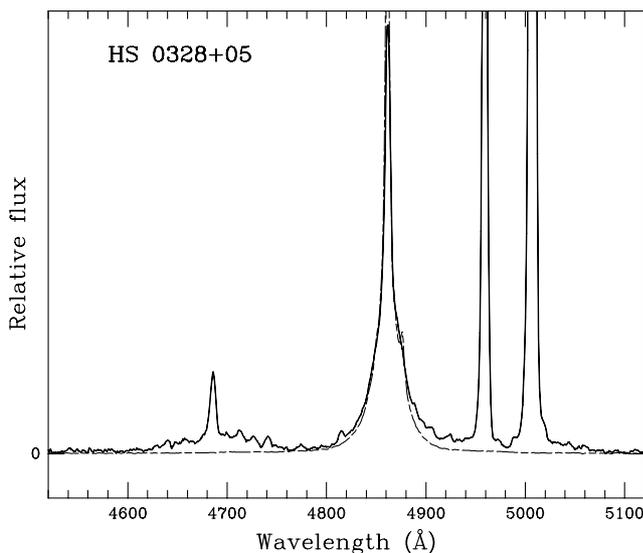


Fig. 7. The solid line is the blue spectrum of HS 0328+05 after subtraction of the Fe II emission; the dashed line is the H α profile moved to the wavelength of H β . The excess of emission redward of H β is obvious.

Figure 7 shows the H α profile superposed on the H β profile. The presence of an excess of emission in the red wings of H β and [O III] λ 5007 is clearly visible. These broad emission features, centered at $\sim\lambda$ 4890 and $\sim\lambda$ 5050, are separated by a significant deep at $\sim\lambda$ 4980 suggesting that they are two distinct features.

We have divided the H α profile by the H β profile; the H α /H β ratio is ~ 4 at the line center but drops quickly to ~ 1 in the region of the red wing (4880–4940 Å), an unlikely value for the Balmer decrement. It seems therefore that the feature seen as a red wing to H β cannot be due to H β emission.

For the blue spectrum, we made a fit with Gaussian components including, for H β , two broad components having the velocity and *FWHM* of the two main broad components of H α (H1 and H2); their intensity was let free; we found the Balmer decrement for these two components to be equal to 5.5 and 3.7 respectively. If the third, very broad, component (H3) had a Balmer decrement larger than three, it would not be detectable at H β .

We found necessary to include two broad Gaussian components to each of the He I lines λ 4922 and λ 5016, having the velocity and width of the narrowest broad Balmer profiles H1 and H2 respectively; their intensity with respect to the H β components is 8.1% and 3.8% respectively for H1 and 2.0% and 18.7% for H2.

We tried to identify all narrow lines in the range 4780 to 5120 Å. In addition to the [Fe II] lines listed in Table 1, we have identified two narrow permitted Fe II (42) lines: λ 4924, λ 5018, as well as [Fe VII] λ 4893, λ 4942 and λ 4989, three lines in multiplet 2F with relatively large radiative transition probabilities, and [Fe VI] λ 4967 and λ 4972 (2F), two lines with relatively strong predicted intensities (Garstang et al. 1978).

Several [Fe IV] lines have been observed in the spectrum of RR Tel (Thackeray 1954; Edlen 1969; Crawford et al. 1999); five of these lines (λ 4868, λ 4900, λ 4903, λ 4906 and λ 4918), from the same multiplet a^4G-a^4F , are within the spectral range of interest and were included in our model, improving the fit.

We have identified the line [Ca VII] λ 4940 which had previously been detected in the spectrum of RR Tel (Thackeray 1974; McKenna et al. 1997).

Our fit requires a line at λ 4932.5 (λ 4932/ λ 5007 = 0.003); Crawford (1999) observed a line at λ 4930.5 in the spectrum of RR Tel and identified it with [O III] λ 4931.0; however the three [O III] lines at λ 5007, λ 4959 and λ 4931 are from a triplet originating from the same upper level; the transition probabilities are such that λ 4931/ λ 5007 = 9×10^{-5} while the value observed in RR Tel is equal to 0.02, or 220 times larger than the theoretical value; we consider therefore that this line is unidentified.

We have found another unidentified line at λ 4896.8. There is also a weak line at $\sim\lambda$ 5058; Si II λ 5056 is not a good fit.

The narrow lines found in the range 4780 to 5120 Å are listed in Table 2. They were all included in our fit assuming that they have the same velocity and width (4.9 Å *FWHM*).

In the range 4915 to 4955 Å the emission excess is well fitted by a number of narrow emission lines ([Fe IV] λ 4918, He I λ 4922, Fe II (42) λ 4924, [Ca VII] λ 4940, [Fe VII] λ 4942, [Fe II] (20F) λ 4947, 4951 and an unidentified line at λ 4932.5 and by the broad components of He I λ 4922 (see Fig. 8). We also find no need for a broad redshifted component to the [O III] lines.

Table 2. Narrow emission lines identified in the range from 4780 to 5120 Å. Column 1: line identification, Col. 2: laboratory wavelength, Col. 3: relative observed intensity in HS 0328+05, Col. 4: intensity in RR Tel (Crawford et al. 1999).

iden	λ_{lab} (Å)	I_{HS}	$I_{\text{RR Tel}}$
[Fe II] (20F)	4814.5	0.69	0.367
H β	4861.3	32.10	30.550
[Fe IV]	4868.0	0.55	0.115
[Fe II] (20F)	4874.5	0.95	0.088
[Fe III] (2F)	4881.0	0.67	0.039
[Fe II] (4F)	4889.6	1.36	0.189
[Fe VII] (2F)	4893.4	0.21	1.250
?	4896.8	1.08	
[Fe IV]	4900.0	0.27	0.056
[Fe IV]	4903.5	0.32	0.068
[Fe II] (20F)	4905.3	0.49	0.145
[Fe IV]	4906.7	0.75	0.185
[Fe IV]	4918.1	0.32	0.078
He I (48)	4921.8	0.13	0.185
Fe II (42)	4923.9	0.98	0.128
?	4932.5	0.88	0.873
[Ca VII] (1F)	4940.3	1.02	3.063
[Fe VII] (2F)	4942.5	0.43	2.472
[Fe II] (20F)	4947.4	0.67	0.039
[Fe II] (20F)	4950.7	0.32	0.056
[O III] (1F)	4958.9	91.00	22.390
[Fe VI] (2F)	4967.1	0.65	0.579
[Fe VI] (2F)	4972.5	0.75	0.719
[Fe II] (20F)	4973.4	0.22	
[Fe VII] (2F)	4988.6	0.54	1.854
[O III] (1F)	5006.8	273.00	39.360
He I (4)	5015.7	0.75	0.328
Fe II (42)	5018.4	0.70	0.180
[Fe II] (20F)	5020.2	0.34	0.086
[Fe II] (20F)	5043.5	0.38	0.031
?	5058.0	0.40	
[Fe II] (19F)	5111.6	0.30	0.114

4. Results and discussion

4.1. He I $\lambda 4922$ and $\lambda 5016$

Broad He I emission lines are observed in AGNs: $\lambda 3188$ (Baldwin et al. 1980), $\lambda 4471$ (van Groningen & de Bruyn 1989; Feldman & MacAlpine 1978), $\lambda 5876$ and $\lambda 7065$ (Feldman & MacAlpine 1978; Morris & Ward 1988) and $\lambda 10830$ (LeVan et al. 1984). The He I lines at $\lambda 4471$, $\lambda 4922$, $\lambda 5016$, $\lambda 5876$ and $\lambda 6678$ have been detected in the NLS1 galaxy Mark 110 (Kollatschny et al. 2001).

The broad He I $\lambda 4471$ line is usually weak in Seyfert 1s ($\lambda 4471/\lambda 5876 \sim 0.1$) implying $n_e \sim 10^9 \text{ cm}^{-3}$ (Feldman & MacAlpine 1978; Almog & Netzer 1989).

Van Groningen & de Bruyn (1989) concluded that the $\lambda 5016$ line emission could contribute only a small fraction of the “red shelf” observed in Seyfert 1s; this

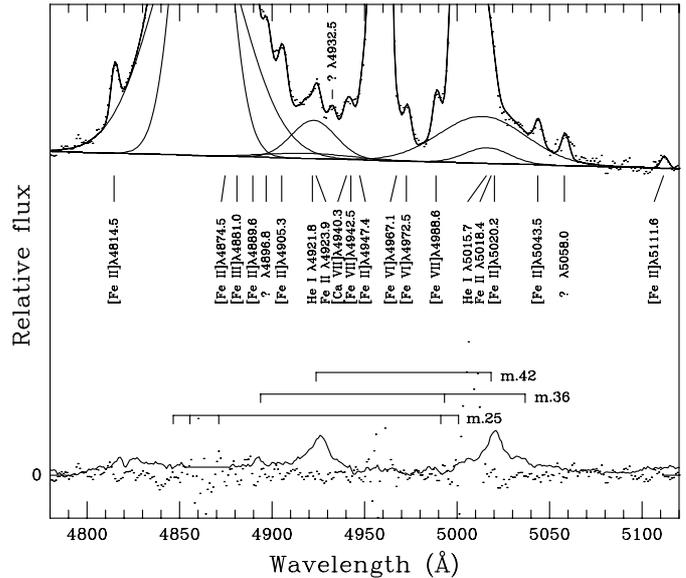


Fig. 8. Fit of the spectrum of HS 0328+05 in the range 4780 to 5120 Å. The figure shows the data (after subtraction of the Fe II emission), the fit and the broad individual components (H β and He I $\lambda\lambda 4922$, 5016). A number of narrow emission lines have been identified, many of them being due to iron. The “red shelf” is well fitted by a combination of narrow lines and broad He I $\lambda 4922$ and $\lambda 5016$ components. The bottom solid line shows the Fe II spectrum subtracted from the original spectrum while the dotted line shows the residuals.

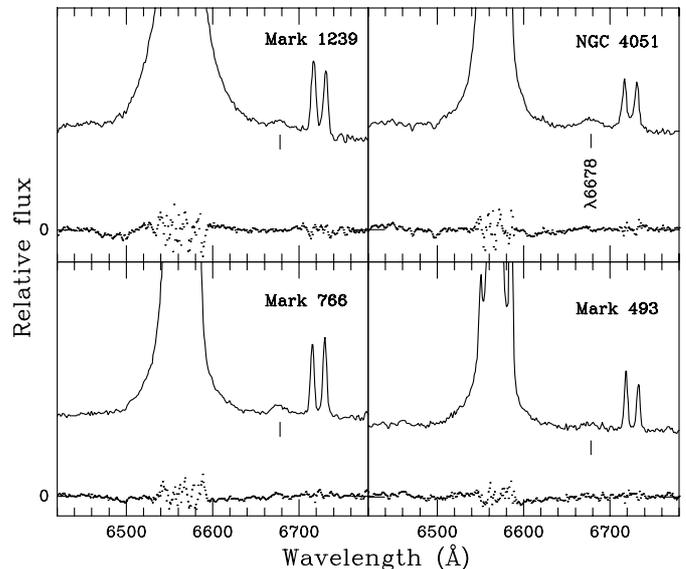


Fig. 9. The He I $\lambda 6678$ line observed in four NLS1s galaxies.

statement was based on the assumption that $\lambda 5016$ should not be stronger than $\lambda 6678$ and that the strength of this last line is typically 0.6–0.8% of that of H α . Erkens et al. (1997) have however observed broad $\lambda 6678$ in a number of Seyfert 1s with an intensity relative to H α in the range 1.2–7.2%. We have detected this line in several NLS1s with an intensity relative to H α in the range 0.8–2.6% (Mark 1239: 0.8%; NGC 4051: 2.6%; Mark 766: 1.7%; Mark 493: 1.2%) (see Fig. 9).

In the case of Mark 110, Kollatschny et al. (2001) convincingly showed that the red wing of [O III] λ 5007 is due to a broad He I λ 5016 line.

In the spectrum of RXS J01177+3637 and HS 0328+05, we have found He I lines emitted by the two broad Balmer line emission clouds; their relative intensities are listed in Tables 3 and 4.

In the case of HS 0328+05, we can set an upper limit to the intensity of a broad λ 4471 component corresponding to λ 4471/ λ 5876 = 0.15.

Table 3. Intensity relative to $H\alpha$ of the He I lines observed in the spectrum of RXS J01177+3637.

λ (Å)	FWHM (km s ⁻¹)	
	2150	6100
4713		6%
4922		10%
5016	1.8%	7%
5876	4.1%	12%
6678	2.0%	9%
7065	2.6%	

Table 4. Intensity relative to $H\alpha$ of the He I lines observed in the spectrum of HS 0328+05.

λ (Å)	FWHM (km s ⁻¹)	
	1730	3400
4922	2.7%	1%
5016	1.1%	6%
5876	2.1%	5%
6678	0.9%	
7065	2.4%	

At very high densities ($n_e > 10^{13}$ cm⁻³), the He I lines may become very strong relative to the Balmer lines (Stockman et al. 1977); the Fe II emission region has a density which can almost reach this value ($10^{10} < n_e < 10^{11} - 10^{12}$ cm⁻³) (Collin-Souffrin et al. 1980, 1988; Kwan et al. 1995).

4.2. $H\beta$ wing

The wing to the red of $H\beta$ has often been assumed to be $H\beta$ emission coming from the same region as the [O III] wings with a low λ 5007/ $H\beta$ ratio (close to unity) implying a relatively high density ($10^7 - 10^8$ cm⁻³) (Meyers & Peterson 1985; van Groningen & de Bruyn 1989). Van Groningen & de Bruyn (1989) found no evidence for major differences between the $H\beta$ and $H\gamma$ profiles in a number of Seyfert 1s; they also found that the wings detected on the long wavelength side of the [O III] lines have a clear counterpart in the Balmer lines.

However, although the broad $H\beta$ line in Akn 120 has a red wing, the other Balmer lines do not show such a feature which, consequently, must be due to elements other than hydrogen (Foltz et al. 1983; Doroshenko et al. 1999).

In the spectra of RXS J01177+3637 and HS 0328+05, neither $H\beta$ nor the [O III] lines have a broad redshifted component.

5. Conclusion

The detailed study of the spectrum of two Seyfert 1s showing a “red shelf” shows that it is mainly due, in addition to the Fe II multiplet 42, to the presence of relatively strong He I λ 4922 and λ 5016 broad lines. In HS 0328+05, there is also a non negligible contribution to the $H\beta$ red wing of a number of narrow emission lines.

There is no evidence for the presence of a broad redshifted component in $H\beta$ or [O III] in any of these two objects.

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