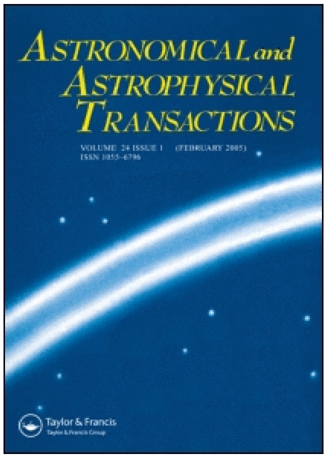

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NIGHT-TO-NIGHT VARIATION IN THE OPTICAL EMISSION LINES IN THE NUCLEAR SPECTRUM OF THE SEYFERT GALAXY NGC 3227

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Fifty-three spectrograms in the optical region (3700–7300 Å) with a spectral resolution of about 8 Å have been obtained for the Seyfert nucleus of the galaxy NGC 3227 with the 6 m telescope on 12–15 January 1977 while the nucleus was in the historically important epoch of its extreme maximum brightness. The width of the slit was $1''$, and the length of the box during the spectral measurements was $1.5''$. The data obtained by us and those compiled from literature showed that profiles of the Balmer lines Hα, Hβ and Hγ are different, demonstrating that the gas emitting these lines is highly self-absorbed. The profiles of the Balmer lines contain various components that kept their positions (radial velocities) over 10 years. The components can reflect long-lived flows or jets in the broad-line region (BLR). A blue bump at a radial velocity of $-5000\,\mathrm{km\,s^{-1}}$ in the Hγ profile was revealed. Variations in the intensities of the revealed components and broad wings of the emission lines Hβ and Hγ profiles were detected over 3 days. The same variations were observed by us earlier in the emission line profiles of the NGC 7469 nucleus spectrum. We suppose that the revealed night-to-night variability of the emission line spectra of the galaxies NGC 3227 and NGC 7469 is a result of short-time flares in the BLR. The dimension of the flare region is less than 0.2 of the whole BLR dimension. The density of the flare region is two to three orders of magnitude higher than that of the overall BLR. One of the possible explanations for the observed event can be proposed in the framework of a model of short-lived shocks in long-lived flows or jets.

KEYWORDS: galaxies, active galaxies, individual galaxies, NGC 3227, nuclei of galaxies, spectra of Seyfert galaxies, emission line variability

1 INTRODUCTION

NGC 3227 is a bright member of the NGC 3226–3227 pair of galaxies. The systematic velocity of the NGC 3227 equals $1175\,\mathrm{km\,s^{-1}}$ (Rubin and Ford, 1968). The interaction with the companion NGC 3226 can trigger fuelling of the active nucleus of the NGC 3227 (Gonzalez Delgado and Perez, 1997). There is a systematic expansion of the gas of the nucleus outwards with a velocity of $175\,\mathrm{km\,s^{-1}}$ (Rubin and Ford, 1968).

The NGC 3227 nucleus is characterized by a high brightness level of the nucleus compared with the environments. Gonzalez Delgado and Perez (1997) discussed spectral observations of the NGC 3227 nucleus made with a long slit on 10–13 March 1988. Their Figure 2 shows

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that the profile of the nucleus brightness in the $\lambda = 5960\,\text{Å}$ continuum through the major axis is very sharp; from the centre to the radius $R = 1''$ the brightness decreased by a factor of 5 and to $R = 2.5''$ by a factor of 20. The brightness of the Hα emission decreased from the nucleus rapidly, by a factor of about 30 in the range $0'' < R < 2.5''$. In this case the brightness of the NGC 3227 nucleus exceeds the brightness of the nucleus surroundings in an aperture of $1.5''$ by more than one order of magnitude.

The *UBV* variations in the NGC 3227 nucleus were revealed by de Vaucouleurs and de Vaucouleurs (1968) during observations in 1957–1967. The *UBV* light curve of the NGC 3227 nucleus compiled for 1967–1979 by Quisbert *et al.* (1989) showed that there was an essential increase in the nucleus brightness (ΔU of magnitude about) in 1975. The maximum brightness of the nucleus was observed during 1975–1977 (Figure 1). Variations in the optical brightness of the nucleus were observed in the 1980s and 1990s by Rosenblatt *et al.* (1992), Winge *et al.* (1995) and others.

NGC 3227 has a nucleus of variable Seyfert type (Pronik, 1987). It was a Sy2 type before 1974 (Dibaj and Pronik, 1967; Khachikian and Weedman, 1971, 1974; Adams and Weedman, 1975) and became a Sy1 type after 1974 (Osterbrock, 1977; Elvis *et al.*, 1978; Kodaira *et al.*, 1979; Pronik, 1983, 1987). The Seyfert type of NGC 3227 changed after brightening of the nucleus by ΔU of magnitude 1 at the beginning of 1975 (see Figure 1).

Rubin and Ford (1968) showed that the Balmer lines in the spectrum of the NGC 3227 nucleus are of a multicomponent nature. Figure 2 shows the profile of the Hβ line obtained by Rubin and Ford during the minimum brightness of the nucleus in 1967. One can see five components in the profile: 1, 2, 4 and 5 are the separate components and 3 is the shoulder of component 2.

The Balmer Hα, Hβ and Hγ decrements show that the gas emitting these lines is highly self-absorbed with an electron concentration $n_e \approx 10^{11}\,\text{cm}^{-3}$ (Anderson, 1970). The nuclear [O III] ($\lambda = 5007\,\text{Å}$) line profile is characterized by a blue shoulder and by wings extending in the range from -1300 to $+800\,\text{km}\,\text{s}^{-1}$ (Vrtilek and Carleton, 1985).

Indications of variations in the optical emission lines for NGC 3227 were first supposed by Wampler (1971) and later confirmed on time scales of months to years by Pronik (1971, 1983). Salamanca *et al.* (1994) and Winge *et al.* (1995) showed that the variable emission of the broad-line region (BLR) in the Hα and Hβ lines lags the continuum flux variation at $\lambda = 5000$–$6000\,\text{Å}$ by about 17 days. This gives the spatial scale of the BLR as about 17 light days (about 4.5×10^{16} cm).

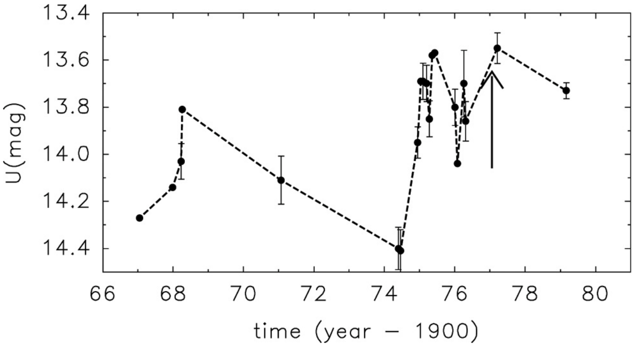

Figure 1. Light curve of the NGC 3227 nucleus according to Quisbert *et al.* (1989). The arrow corresponds to the dates of our observation: 12–15 January 1977.

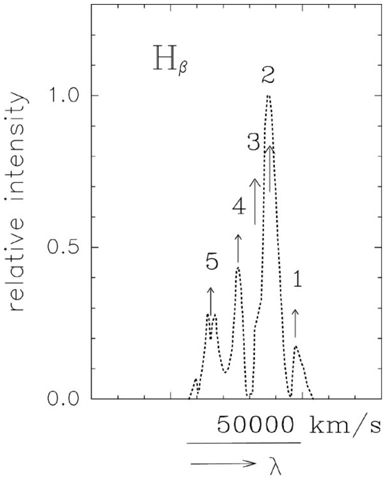

Figure 2. Multicomponent profile of the Hβ line obtained by Rubin and Ford (1968) on 8 March 1967. The arrows show the narrow components of the profile.

McAlary *et al.* (1988) and Rokaki *et al.* (1992) concluded that the profiles and the intensities of the broad emission lines Hα and Hβ and the ultraviolet (UV) continuum of the NGC 3227 nucleus can be explained in the framework of the accretion disc model.

The Seyfert galaxy NGC 3227 is known as a strong X-ray variable source. Its 2 keV flux varied during 2.8 h by a factor of 3; the 2–10 keV flux varied by a factor of 2 (Ptak *et al.*, 1994). These variations can influence the short-term UV and optical variations. A 2 day flare with a ΔU amplitude of magnitude 0.5 was recorded by Lyutyi (1977).

In this paper we discuss night-to-night variations in the optical emission line spectrum of the NGC 3227 nucleus obtained by us during observations for four nights with the 6 m telescope in 1977. Preliminary information was published by Pronik *et al.* (1999), Pronik and Metik (2003) and Pronik (2004).

2 OBSERVATIONS AND TREATMENT

53 spectrograms in the spectral region 3700–7300 Å were obtained for the NGC 3227 nucleus at the prime focus of the 6 m telescope on 12–15 January 1977 by V.L. Afanas'ev.

The high-speed spectrograph UAGS equipped with the three-stage image tube UM-92 with a multialkali photocathode was used. The image-tube unwidened spectrum was recorded on an A-600 film. The entrance slit width was about 1″. The resulting linear dispersion was about 95 Å mm^{-1}. The spectral resolution measured as the full width at half-maximum of the 6300 Å night sky line was about 8 Å. The seeing was 1–3″. Spectra were taken as series. One series contains one to three spectrograms. The duration of one series was about 5–25 min. There were two to three series of observations over each night. The exposures were 0.5–4 min.

The spectra of the star i Per were observed for flux calibration, using the same spectrograph set-up as for the nucleus of NGC 3227. The spectra of the planetary nebula IC 351 were observed to estimate the photometric errors.

A log of the observations is given in Table 1. From Table 1, one can see that there were ten series of observations of the NGC 3227 nucleus during four nights.

Table 1. A log of the observations.

Date of observations	*Number of series*	*Middle of the observational type (Universal Time) (h) (m)*	*Spectral wavelength range (Å)*	*Number of spectrograms n*	*Seeing (″)*
12–13 January 1977	1	23 40	3700–4900	3	1
	1		5800–7300	2	
	2	23 50	5800–7300	2	
	2		4000–5800	2	
	2		3700–4900	3	
13–14 January 1977	1	00 06	5800–7300	2	1–2
	1		4000–5800	1	
	1		3700–4900	1	
	2	00 28	5800–7300	1	
	2		3700–4900	1	
	3	00 44	3700–4900	1	
	3		4000–5800	2	
	3		5800–7300	2	
14–15 January 1977	1	23 45	3700–4900	1	2–3
	1		4000–5800	2	
	1		5800–7300	2	
	2	00 52	5800–7300	2	
	2		4000–5800	2	
	2		3700–4900	2	
	3	01 15	5800–7300	2	
	3		4000–5800	2	
	3		3700–4900	2	
15–16 January 1977	1	22 03	5800–7300	3	1.5
	1		4000–5800	2	
	1		3700–4900	1	
	2	23 20	3700–4900	3	
	2		4000–5800	1	
	2		5800–7300	3	

The spectra were recorded with projected dimensions of the entrance box on the film corresponding to 4 Å × 1.5″.

Figure 1 shows that our observations were performed during the maximum brightness of the nucleus, which was so high that its surroundings can be obtained only in the case when the nucleus is overexposed. The dimensions of the nucleus spectra along the slit length on the film were equal to the observational dimension.

Then the software package by B.A. Burnasheva was used to calculate the equivalent widths (EWs) and the profiles of the emission lines. The standard errors σ for the EW$_\lambda$ values of the emission lines were obtained by Merkulova and Pronik (1983) using the planetary nebula IC 351 spectra as equal to about 8%.

Details of the observations and the treatment have been given by Merkulova and Pronik (1983) and Pronik *et al.* (1997).

3 RESULTS

3.1 Equivalent widths

The EW$_\lambda$ values of the emission lines and blends Hδ + [S II], Hγ + [O III], Hβ, [O III] ($\lambda = 4959$ and 5007 Å), Hα+[N II] and [S II] ($\lambda = 6717$ and 6731 Å) were obtained using the spectra of the NGC 3227 nucleus observed on 12–15 January 1977.

The final results obtained for 56 EWs of the emission lines averaged for each series, EW$_\lambda$ and 24 EWs averaged for each night, EW$_\lambda$ are given in Table 2, which contains standard errors

Table 2. **EWs of the emission lines in the spectrum of the NGC 3227 nucleus on 12–15 January 1977. n_{ser}, number of spectrograms in the series; EW_{λ}, EWs averaged over the series of observations; σ, standard error; n_{night}, number of spectrograms obtained during the night; EW_{λ}, EWs averaged by night.**

			Series 1		*Series 2*		*Series 3*		*Averaged by night*	
Date of observations	*Wavelength of line λ (Å)*	*Ion*	n_{ser}	$EW_{\lambda} \pm \sigma$ (Å)	n_{ser}	$EW_{\lambda} \pm \sigma$ (Å)	n_{ser}	$EW_{\lambda} \pm \sigma$ (Å)	n_{night}	$EW_{\lambda} \pm \sigma$ (Å)
12–13 January 1977	4068 + 76, 4101	[S II] + Hδ	3	27.3 ± 1.1	3	31.4 ± 0.9	–	–	6	29.3 ± 1.2
	4340 + 63,	Hγ + [O III]	1	48.8	4	47.1 ± 3.8	–	–	5	47.3 ± 3.0
	4861	Hβ	–	–	2	97.9 ± 1.1	–	–	2	97.9 ± 1.1
	4959 + 5007	[O III]	–	–	2	115.7 ± 16.5	–	–	2	115.7 ± 16.5
	6563 + 6548+83	Hα + [N II]	2	472 ± 15	2	352 ± 47	–	–	4	412 ± 40
	6716 + 31	[S II]	2	26.4 ± 1.4	2	27.0 ± 0.7	–	–	4	26.7 ± 0.7
13–14 January 1977	4068 + 76, 4101	[S II] + Hδ	1	27.4	1	16.6	1	31.6	3	25.2 ± 4.5
	4340 + 63	Hγ + [O III]	4	44.1 ± 4.6	1	47.4	3	45.2 ± 5.2	8	44.9 ± 2.8
	4861	Hβ	1	50.7	–	–	2	73.9 ± 5.3	3	66.2 ± 8.3
	4959 + 5007	[O III]	1	77.3	–	–	2	88.6 ± 11.9	3	84.8 ± 7.8
	6563 + 6548 + 83	Hα + [N II]	2	474 ± 1	1	379	2	386 ± 28	5	420 ± 24
	6716 + 31	[S II]	2	36.4 ± 2.8	1	48.6	2	28.4 ± 2.8	5	35.6 ± 3.9
14–15 January 1977	4068 + 76, 4101	[S II] + Hδ	1	26.0	2	25.2 ± 5.9	2	30.2 ± 4.1	5	27.1 ± 2.6
	4340 + 63	Hγ + [O III]	1	49.8	4	40.2 ± 4.6	4	48.5 ± 3.8	9	45.0 ± 2.9
	4861	Hβ	2	66.6 ± 1.1	2	62.2 ± 4.5	2	74.8 ± 3.5	6	67.9 ± 2.8
	4959 + 5007	[O III]	2	138.4 ± 6.8	2	103.1 ± 3.1	2	136.7 ± 6.4	6	126.0 ± 8.7
	6563 + 6548 + 83	Hα + [N II]	2	548 ± 48	2	401 ± 39	2	389 ± 3	6	446 ± 36
	6716 + 31	[S II]	2	31.1 ± 5.8	2	26.7 ± 2.6	2	22.5 ± 4.2	6	26.8 ± 2.6
15–16 January 1977	4068 + 76, 4101	[S II] + Hδ	1	31.9	3	35.1 ± 3.8	–	–	4	34.3 ± 2.8
	4340 + 63	Hγ + [O III]	4	45.8 ± 2.4	4	43.4 ± 4.3	–	–	8	44.6 ± 2.3
	4861	Hβ	2	62.7 ± 0.0	1	85.3	–	–	3	70.2 ± 7.5
	4959 + 5007	[O III]	2	131.3 ± 9.4	1	127.0	–	–	3	129.9 ± 5.6
	6563 + 6548 + 83	Hα + [N II]	3	454 ± 68	3	445 ± 36	–	–	6	450 ± 29
	4716 + 31	[S II]	3	26.1 ± 1.5	3	34.2 ± 1.8	–	–	6	30.1 ± 2.0

σ of 42 EW_λ averaged by series for six emission lines and blends. Sample of 42 σ values is enough for the statistical considerations. We suppose that during one visit (one series) there was no EW variability and that the sample of σ follows the normal Gaussian distribution. In this case the most probable value of σ is equal to the average value obtained from members of the sample. The calculated average σ is equal to $(10 \pm 1)\%$. This is near to the value of σ obtained independently using the planetary nebula IC 351 spectra by Merkulova and Pronik (1983). For a discussion of the obtained data we adopted $\sigma = 10\%$.

Data averaged over four nights of our observations are presented in Table 3, which shows that there were 14–30 observations for each emission line carried out over four nights. The ratio of the standard deviation (SD) to σ for EW_λ of different lines were in the range 1.6–2.2. Using the F test or χ^2 test (mathematics given by Korn and Korn (1961)) we can obtain a confidence level of the difference between the distributions of SD and of σ to be above 99.9%. This result permits us to argue that a variation in EW_λ over four nights exists with a confidence level of 99.9%. The SD of these variations, $-\Delta\mathrm{EW}_\lambda$, was calculated as $(\Delta\mathrm{EW}_\lambda)^2 = (\mathrm{SD})^2 - \sigma^2$. The degree of variation (or variability index) was defined as $\Delta\mathrm{EW}_\lambda/\mathrm{EW}_\lambda$. The sixth column of Table 3 shows the degree of EW_λ variation over four nights, $\Delta\mathrm{EW}_\lambda/\mathrm{EW}_\lambda$, which is in the range of (10–20)%. This result permits us to suppose that there were variations in the flux of the continuum or/and variations in the emission lines during the four nights on a level of (10–20)%. Our data do not permit us to discern whether the observed variation in EW_λ is caused by variation in the flux of the emission lines or of the continuum. Additional independent night-to-night observations will be useful to clarify this question.

3.2 Relative intensities of the emission lines

The relative intensities I_λ/I_β of emission lines were calculated using the EW_λ averaged over the four nights of our observations and the spectral energy distribution (SED) of the continuum of the NGC 3227 nucleus given by Anderson (1970). We considered the relative intensities I/I_β of emission lines in the spectral region 4100–6700 Å. According to Quisbert *et al.* (1989) the variation in the SED of the NGC 3227 nucleus in this region is not high. When the magnitude of U is between 14.4 and 13.6 (i.e. the magnitude of ΔU is 0.84), B–V has a magnitude in the range 0.78–0.91 (i.e. the magnitude of $\Delta(B$–$V)$ is 0.12). In the case when the magnitude of ΔU is 0.84, the maximum error will be for the Hδ line relative intensity, which is not more than 10%. For the relative intensities of other emission lines, because of SED uncertainties the error will be negligible.

Table 3. EW_λ averaged over the whole period of observations (four nights) (12–15 January 1977): SD, standard deviation.

Wavelength of line λ (Å)	*Ion*	*Number of spectrograms n*	*EW_λ (Å)*	*SD/σ for EW_λ*	*$\Delta EW_\lambda/EW_\lambda$*	I_λ/I_β *Our results*	I_λ/I_β *Anderson (1970)*	I_λ/I_β *Osterbrock (1977)*
4068 + 76 + 4101	[S II] + H_δ	18	29.2 ± 1.3	2.0	0.17	0.30	0.35	–
4340 + 63	H_γ + [O III]	30	45.2 ± 1.3	1.6	0.12	0.51	0.53	0.26
4861	H_β	14	72.3 ± 3.7	1.9	0.16	1.0	1.0	1.0
4959 + 5007	[O III]	14	117 ± 6	1.9	0.16	1.65	2.59	1.76
6563 + 6548 + 83	H_α + [N II]	21	434 ± 16	1.7	0.14	7.67	8.17	5.37
6716 + 31	[S II]	21	31.0 ± 1.5	2.2	0.20	0.56	0.79	0.47

The relative intensities I_λ/I_β of emission lines obtained by us are shown in the seventh column of Table 3. The eighth and ninth columns give the relative intensities of emission lines obtained by Anderson (1970) and Osterbrock (1977) respectively. The data in these three columns of Table 3 show the similarity between the relative intensities of emission lines in the three cases. The relative intensities obtained by us correspond to an Sy1 type. This is in agreement with the high brightness level of the nucleus shown in Figure 1.

The neighbouring position of the Hβ and [O III] ($\lambda = 4959 + 5007$ Å) lines permits us to calculate the [O III]-to-Hβ flux ratio using the respective EW_λ from Table 2. The values of the [O III]-to-Hβ flux ratios for the eight series of observations are in the range 1.2–2.1. This variation is essentially more than 3σ, and we can speculate that there was variation in the flux of the Hβ line during the four nights of 12–15 January 1977 by about 50%.

3.3 Profiles of the emission lines

The profiles of the Hγ, Hβ and Hα Balmer lines on 12 January 1977 normalized to their peak intensity are presented in Figure 3. The figure shows the following.

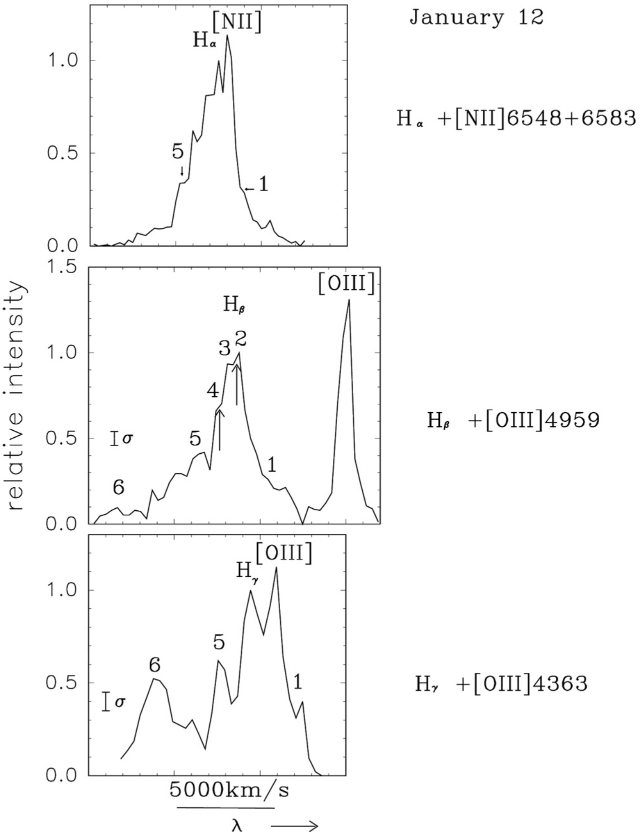

Figure 3. Profiles of the $H\alpha$, $H\beta$ and $H\gamma$ emission lines on 12 January 1977 normalized to the continuum and a peak intensity. The bars show mean SD σ for the average obtained by a series of profiles. The emission components of the profiles are labelled 1–6 (see text).

(i) The full width at zero intensity (FWZI) of the Balmer line profiles is equal to 10 000–11 000 km s^{-1}, which corresponds to the FWZI of a Sy1 type.

(ii) The shapes of the Balmer line profiles are different. The difference between the profiles of Hα and Hβ is less than the difference between the Hα and Hγ profiles.

(iii) The Balmer line profiles are asymmetric; the blue wings are broader than the red ones. The effect of the asymmetry increases with increasing number of lines in the Balmer series. The brightest and broadest blue wing is observed in the Hγ profile. Its width is more than 7000 km s^{-1}.

(iv) The Balmer line profiles show bright emission components. Five individual components in the Hβ line profile are numbered in Figure 3 as 1–5. The components shifted with respect to component 2 by +25, −6.5, −12 and −32 Å respectively (in velocity units of approximately +1500, −400, −725 and −2000 km s^{-1}). Components 1 and 5 can be identified in the Hγ profile and guessed in the Hα profile. There is a bright bump at the blue end of the Hγ profile (component 6 in Figure 3) shifted from component 2 by about −5000 km s^{-1}.

(v) The central core of the Hβ profile consists of components 2, 3 and 4. The short-wavelength component 4 and the long-wavelength component 2 are shown by arrows in Figure 3. The separation between components 2 and 4 equals 11.7 ± 0.8 Å (723 ± 52 km s^{-1}) and was calculated using eight spectrograms. Components 2 and 4 were not identified in the Hα profile because of blending with the [N II] ($\lambda = 6584$ Å) line. In the Hγ profile the components were not identified because of low dispersion.

(vi) Comparison of the Hγ, Hβ and Hα profiles in the spectrum of 12 January 1977 is shown in Figure 4a. The wings and components 1 and 5 became brighter compared

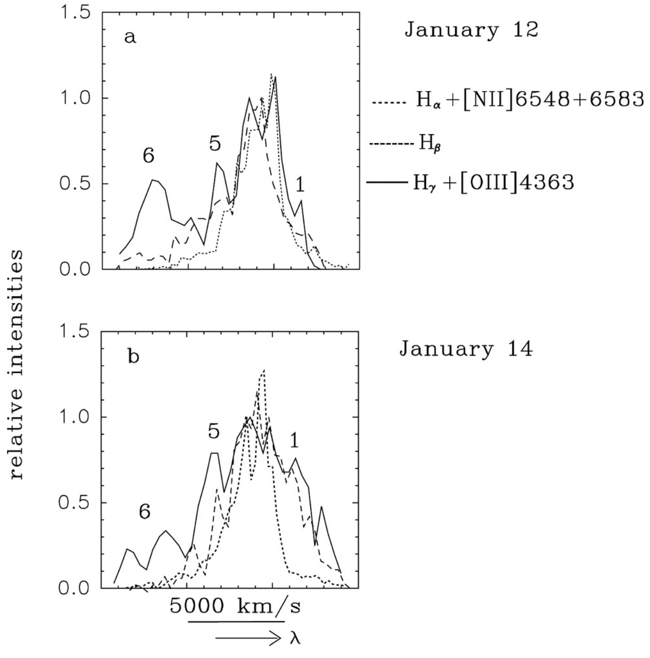

Figure 4. **Comparison of the profiles of the three Balmer lines of the NGC 3227 nucleus spectrum: a, obtained on 12 January 1977; b, obtained on 14 January 1977. The emission components labelled 1, 5 and 6 are the same as in Figure 3.**

with the line core with increasing line number in the Balmer series. The blue bump 6 at $-5000\,\mathrm{km\,s^{-1}}$ is clearly seen in the Hγ line profile; its sign is present in the Hβ profile and is absent in the Hα profile. To align the profiles of the Hα, Hβ and Hγ lines we use the lines [N II] ($\lambda = 6583\,\text{Å}$), [O III] ($\lambda = 4959\,\text{Å}$) and [O III] ($\lambda = 4363\,\text{Å}$), respectively.

Figure 5 gives a comparison of the Hβ and Hα profiles obtained on 12 January 1977 by us (solid curves) and on 8 March 1967 by Rubin and Ford (1968) (dashed curves). Figure 1 shows that the NGC 3227 nucleus had a minimum brightness on 8 March 1967 and a maximum brightness on 12 January 1977. The profiles of the Hα line shown in Figure 5 almost coincide for both dates; they differ only in the wings, being broader in 1977. Five individual components in the Hβ profile are clearly seen. Their positions coincide at both dates. One can see that for the minimum brightness of the nucleus in 1967 all components were clearly separated, but in 1977 during the maximum brightness of the nucleus all emission components are partly merged into a broad line profile. At the same time they kept their radial velocities over 10 years, from 1967 to 1977. Component 2 was the brightest of all components during the minimum brightness on 8 March 1968. Its position in velocity units is the nearest to the recession velocity of the galaxy in the Hβ line.

From Figure 5, one can conclude that the components of the Hβ line kept their radial velocities over 10 years, from 1967 to 1977.

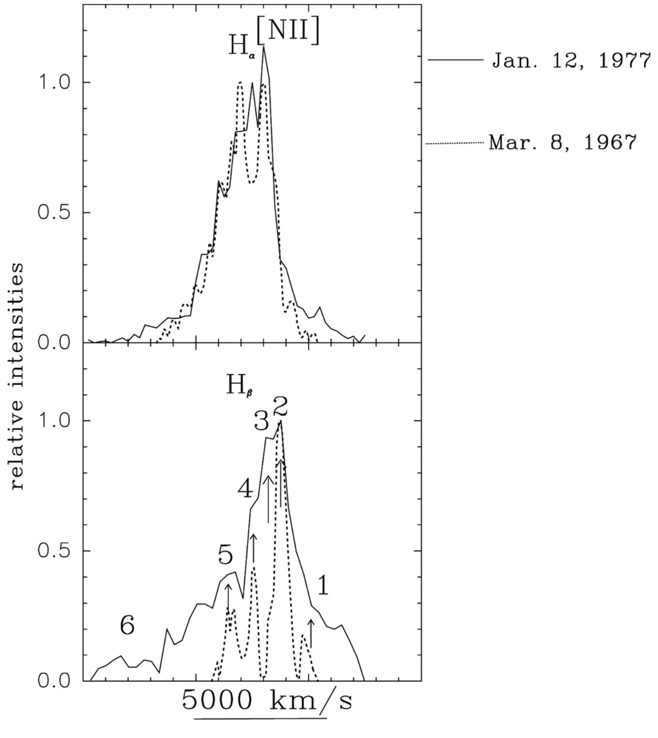

Figure 5. **Comparison of line profiles observed on 12 January 1977 by us (——) with the profiles obtained at the deep minimum of the nucleus on 8 March 1967 by Rubin and Ford (1968) (- - - -). The arrows show the common components of the Hβ emission line for these two dates. Emission components 1–6 as in Figure 3.**

4 SHORT–TERM VARIATION IN THE BALMER LINES

Figure 6a, b and c show a comparison of each of the Balmer line profiles observed on 12 and 14 January 1977 for Hα, Hβ and Hγ respectively. The error bars of the averaged profiles are the same as those shown in Figure 3. The intensity of the Hβ line profiles were scaled to a peak height of 1.0 using the peak of component 2. As shown above, its position in velocity units is the nearest to the recession velocity of the galaxy in the Hβ line. One can argue from Figures 4 and 6 that the shapes of the Balmer line profiles exhibit night-to-night evolution. The degree of variation increased with increasing line number in the Balmer series. The profile of the Hα line was almost constant, whereas the profile of the Hγ line was the most variable.

Variations in the shapes of the Hβ profile were found to be connected with the variations in EW_β. Figure 7 shows the intensity ratios of the Hβ line components versus EW_β. The intensities of the components were measured from the continuum level to their peak brightness. Three significant positive correlations are seen for flux ratios of 2/4, 2/1 and 2/5. The coefficients of the correlations are equal to 0.89 ± 0.08, 0.68 ± 0.19 and 0.62 ± 0.22 respectively, and the corresponding confidence levels of the correlations are equal to 0.998, 0.969 and 0.949. Components 4, 1 and 5 became brighter compared with the central component with decreasing EW_β. Therefore the three positive correlations revealed in Figure 7 exhibit an increase in linewidth with decrease in EW_β. If one supposes that the decrease in EW_β is caused mainly

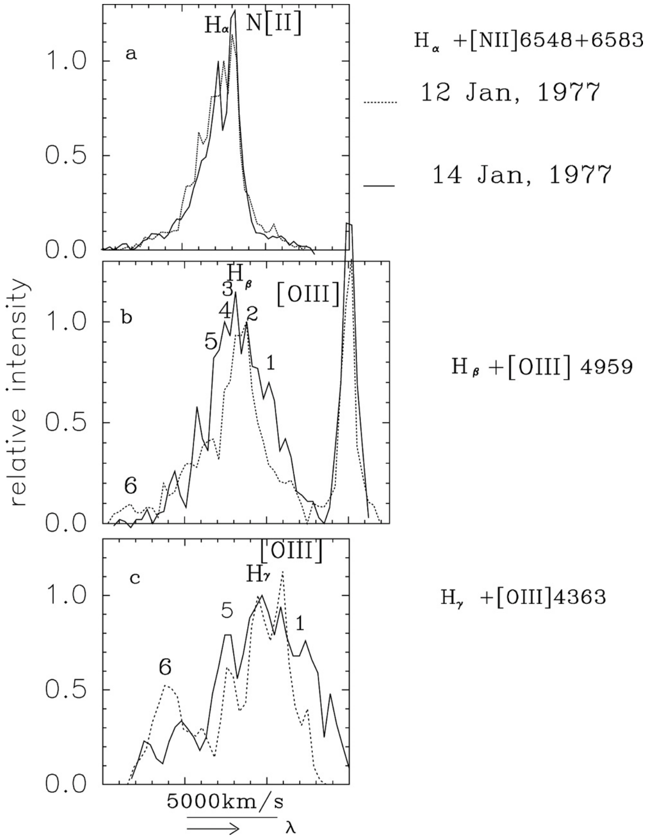

Figure 6. Comparison of the Balmer line profiles obtained on 12 and 14 January 1977: a, Hα; b, Hβ; c, Hγ. Components 1–6 are the same as in Figure 3.

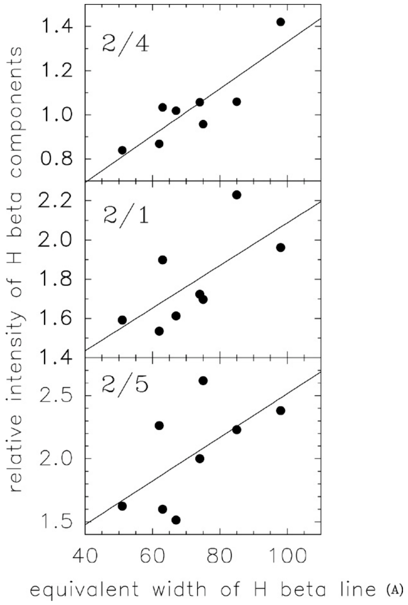

Figure 7. **Correlations of the relative intensities of the components of the Hβ line and its equivalent width. Components 1, 2, 4 and 5 are the same as in Figure 3.**

by the increasing continuum level, then an increase in the intensity of the continuum of the NGC 3227 nucleus is accompanied by an increase in the line breadth.

5 DISCUSSION

5.1 Summary account

The Seyfert galaxy NGC 3227 nucleus was observed in an historically important epoch during its extreme maximum brightness on 12–15 January 1977. Using 53 spectrograms taken with the 6 m telescope for the NGC 3227 nucleus we measured EW_λ, the relative intensities $\mathbf{I}_\lambda/I_\beta$ and the profiles of the emission lines and of Hδ, Hγ, Hβ, [O III] ($\lambda = 4959$ and 5007 Å), Hα + [N II] and [S II] ($\lambda = 6717$ and 6731 Å). Spectral data obtained by us and by Rubin and Ford (1968) for a low brightness of the nucleus permit us to draw the following conclusions.

(i) According to the values of I_λ/I_β averaged over four nights of our observations and the FWZI of profiles of the emission lines Hγ, Hβ and Hα are about 10 000 km s^{-1}, this indicated that on 12–15 January 1977 the NGC 3227 nucleus was an Sy 1 type.

(ii) The profiles of the Hγ, Hβ and Hα lines are different. The difference in the Balmer line profiles occurred both for high and low brightnesses of the nucleus. The intensity of the wings and emission details of the profiles became brighter with increasing line number in the Balmer series.

(iii) The profiles of the Balmer lines show asymmetry; the blue wings are broader than the red wings. The effect of asymmetry increases with increasing number of lines in the Balmer series. The brightest and the broadest blue wing (up to −7000 km s^{-1}) is observed in the Hγ line profile. The effect of blue asymmetry is greater for high than for low brightness of the nucleus.

(iv) There are bright emission components in the profiles of the Balmer lines. the five components of the Hβ line profile located in the central part of the profile between radial velocities $+1500$ and $-2000\,\mathrm{km\,s^{-1}}$ coincide with those observed on 8 March 1967 by Rubin and Ford (1968). As a result, the components kept their position over 10 years during 1967–1977. We observed the components in the inner approximately $1.5''$ (100 pc) region of the nucleus. During the minimum brightness on 8 March 1967 the Hβ line profile consisted of separate components; the underlying broad component had almost disappeared.

(v) The central core of the Hβ line profile consists of three components. The separation between the extreme components is 11.7 ± 0.8 Å or, in velocity units, $723 \pm 52\,\mathrm{km\,s^{-1}}$.

(vi) The neighbouring positions of Hβ and [O III] ($\lambda = 4959 + 5007$ Å) permits us to calculate the intensity ratios $I([\mathrm{O\ III}])/I(\mathrm{H}\beta)$ using the respective EW_λ values. The intensity ratio varied from 1.2 to 2.1. We speculate that there was variation in the flux of Hβ over the four nights of 12–15 January 1977 by about 50%.

(vii) The Balmer line profiles exhibit night-to-night variations from 12 to 14 January 1977. The degree of variation increases with increasing line number in the Balmer series. The profile of the Hα line was almost constant, whereas the profile of the Hγ line was the most variable.

(viii) Increases in the brightnesses of the emission components of hydrogen line profiles were observed from 12 January to 14 January 1977. On 14 January 1977 this effect became the most pronounced.

(ix) Variation in the relative intensities of the emission components of the Hβ line profile became brighter compared with to the central component when EW_β decreased. If one supposes that the decrease in EW_β is caused mainly by the increase in the continuum level, then the increase in the continuum intensity is accompanied by increases in the intensities of the three components with respect to the core component.

The observed results on the emission line profiles and EW_λ variations cannot be caused by seeing variations during the observations. As was shown in second paragraph of section 1, emission of the nucleus exceeded the emission of its surroundings in the aperture of our measurements ($1.5''$) by more than one order of magnitude.

5.2 *Preliminary interpretation*

5.2.1 Common characteristics of the broad-line region. There have been many optical observations of the variations in emission lines and continuum of the NGC 3227 nucleus on timescales of months and years; by Pronik (1971, 1983), Peterson *et al.* (1982, 1985), Stripe (1990), Rosenblatt *et al.* (1992, 1994), Salamanca *et al.* (1994), Winge *et al.* (1995) and others. It was shown that the variation in the emission of the BLR in the Hα and Hβ lines lags the flux variation in the $\lambda = 5000$–6000 Å continuum by about 17 days. According to this result, one can speculate that the dimension of the BLR is about 4.5×10^{16} cm.

The data obtained by us and compiled from literature showed that the profiles of the Balmer lines in the NGC 3227 nucleus spectrum contain variable components that kept their positions over 10 years. We observed the components in the inner approximately $1.5''$ (100 pc) region of the nucleus. This type of multicomponent profiles of the Balmer lines was observed by Barbieri *et al.* (1977) for the maximum brightness of NGC 7469; the components maintain their radial velocities over 20 years (Pronik *et al.*, 1997). The multicomponent profiles of the Balmer lines can reflect the ingredients in the gaseous structure of the BLR of the NGC 3227 and NGC 7469 nuclei, which change their brightness with time without changing their velocities. One can speculate that these narrow components of the Balmer emission line profiles are produced by long-lived gas streams and flows in the BLR.

The Balmer decrement for Hα, Hβ and Hγ show that the gas emitting these lines is highly self-absorbed, its electron concentration is $n_e \geq 10^{11}$ cm^{-3} (Anderson, 1970). Our data on the extremely different shapes of the Hα, Hβ and Hγ line profiles and the increase in the degree of variation from Hα to Hγ lines support the supposition of a high optical depth of the BLR gas.

The observed emission of the three Balmer lines in the case of a high optical depth can be caused by different gas layers located at different distances from the source of gas excitation. According to the theory, the coefficient of absorption for the Hα line is higher than for the Hβ and Hγ lines. Therefore, the observed optical depth for the Hα line is the highest, and the observed Hα light contains mainly the emission of the outer layers of the emitting gas. The coefficient of absorption for Hγ is lower, and the optical depth of the gas emitting in this line is smaller. Therefore, the observed Hγ light contains more emission from the inner gas layers. The difference in the shapes of the Balmer line profiles demonstrated the stratification of physical conditions in the BLR, which for other active Galactic nuclei (AGNs) was pointed out earlier by various workers for different active nuclei (see for example Gaskell and Sparke, (1986)).

The long-lived gas streams supposed by us to occur in the NGC 3227 nucleus do not contradict current models of AGNs involving the accretion disc. The BLR could be a gaseous envelope of the accretion disc; so the gas inside a biconical formation connected with this disc (Veilleux and Zheng, 1991). The signs of both the accretion disc and the gas outflow have been observed for the NGC 3227 nucleus by several researchers. Rokaki *et al.* (1992) showed that broad profiles of Hα and Hβ lines and the UV continuum in the spectrum of the NGC 3227 nucleus can be roughly fitted by an accretion disc model. The systematic expansion of gas from the nucleus outwards with a velocity of 175 km s^{-1} was obtained by Rubin and Ford (1968). The outflow of gas emitting the [O III] ($\lambda = 5007$ Å) line was reported by Vrtilek and Carleton (1985). Rosenblatt *et al.* (1994) discussed the observed asymmetry of the broad Hβ profile and suggested that radial motions exist in the BLR of the NGC 3227 nucleus.

5.2.2 Short-term variability in the broad-line region. The data on the profiles of the Hα, Hβ and Hγ lines that we observed permit us to argue that there was a flare in the region of emission lines of the NGC 3227 nucleus on 12–14 January 1977. We noted the following observational signs for the 3 day flare (see Figures 4 and 6).

On the first day, the distinction between the profiles of the Hα, Hβ and Hγ lines were less than in the following days.

On the second day, the blue core of the Hβ line profile, of the blue broad wings of the Hβ and Hγ profiles and of the emission component having a radial velocity of −2000 km s brightened in comparison with that of the profile core.

On the third day, further brightening of the blue core of the Hβ profile and of the blue wings of the Hβ and Hγ profiles occurred. The red wings of the Hβ and Hγ line profiles and of the components at radial velocities of +1500 and −2000 km s^{-1} also brightened in comparison with that of the profile core.

The observational data permit us to obtain several characteristics of the flare region.

(i) The dimension of the flare region was about 3 light days (about 7.7×10^{15} cm); that is, it was 0.2 or less of the whole BLR dimension (about 4.5×10^{16} cm).

(ii) The high confidence level of the brightness of the emission line component and EW$_\beta$ correlations shown in Figure 7 permit us to speculate that emission line variations lag behind the continuum variations by not more than 1 day, that is that radiation of the continuum and of the Balmer lines in the flare region are produced by almost the same region.

(iii) The variation in the Hγ line profile was more pronounced than the variation in the Hβ profile; it was almost not observed in the Hα profile. One can argue that in the flare region the emission has an inverse Balmer decrement. Fitting of our observational data to the grid of the theoretical models described by Gershberg and Shnoll (1974) permits us to suppose that the gas emitting the variable Balmer lines during the flare is ionized and excited mainly by a collision process. This gas must be opaque, hot and inhomogeneous because of physical conditions in the plasma with an electron temperature $T_e \approx 25\,000$ K and an electron concentration $n_e \approx 10^{12}$–10^{14} cm^{-3}. Thus the electron concentration in the flare region is by two or three orders of magnitude higher than that of the whole BLR concentration.

(iv) As the highest variations were observed Hγ profile and the lowest for the Hα profile we can speculate that the flare was located in the inner layers of the gas flare emitting the Balmer lines.

(v) At the beginning of the flare, most variations were registered in the blue part of the Hγ and Hβ line profiles. According to Vrtilek (1985) and Capriotti *et al.* (1982), such variations can signal the outflow of emitting material. Therefore, we suppose that during the flare there was expansion of gaseous clouds in the flare region. The shape of the Hα line profile did not change during the flare. So we speculate that the expansion of the inner layers did not reach the outer layers of the flare region.

(vi) During the 3 day flare we observed variations in the emission of not only the blue components of the Hγ profile but also the red components, with a lag of 1 day. One can speculate that the flare gas of positive radial velocity $+1500$ km s^{-1} is not screened out by the circumnuclear disc.

(vii) Night-to-night variations in the Balmer lines of the NGC 3227 nucleus have a remarkable similarity to the characteristics of the night-to-night variations in the same lines in the NGC 7469 nucleus (Pronik *et al.*, 1997). In the case of NGC 3227 we observed an increase in the flare and for NGC 7469 a decrease in the flare. The flare in NGC 7469 was observed during minimum brightness of its nucleus. The flare in NGC 3227 was observed during maximum brightness of its nucleus. Therefore, we speculate that short-time flares did not relate to the general brightness of the nuclei of these galaxies.

We suppose that the 3 day flares observed by us could be connected with shocks in small dense regions in a gas of long-lived outflows in the BLRs of the NGC 3227 and NGC 7469 nuclei.

6 CONCLUSIONS

(1) The data obtained from 53 spectrograms of the NGC 3227 nucleus observed on 12–15 January 1977 with the 6 m telescope combined with the previously published data showed that profiles of the Hα, Hβ and Hγ lines contain five variable emission components that kept their position relative to the central peak of the profile over 10 years. They appear to reflect the components of the BLR structure of the NGC 3227 nucleus which changed their brightness without changing the radial velocities and could be caused by long-lived gas flows or streams.

(2) The 3 day flares in the inner part of the BLR was observed on 12–14 January 1977. The most variable was the Hγ line profile whereas the Hα line profile was almost stable. We speculate that the flare was a result of a shock in flows or streams in the BLR. Electron densities inside the shocks are higher by two to three orders of magnitude compared with those in the overall BLR.

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