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INVESTIGATION OF FORBIDDEN LINE VARIABILITY IN SEYFERT GALAXY NUCLEI AT CRIMEAN OBSERVATORY IN 1971–2006

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RESUMEN

Desde 1971 se ha estudiado la variabilidad de líneas prohíbidas en núcleos de galaxias Seyfert en intervalos temporales de años a días en el Observatorio de Crimea. Los resultados nos han permitido proponer que la variabilidad de días-años es producida por distintas fuentes.

ABSTRACT

Variability of forbidden lines in Seyfert galaxies nuclei has been studied on timescales years-days at Crimean observatory since 1971. Results allow us to argue that days-years variability are caused by various sources.

Key Words: galaxies: active — galaxies: nuclei

1. INTRODUCTION

The first report on forbidden line variations was made by Bardin et al. (1967) for the Seyfert galaxy nucleus NGC 5548. Later on Andrillat & Souffrin (1968) published data on the forbidden line variability in the Seyfert galaxy NGC 3516. Below we present our data on the forbidden line variability in Seyfert nuclei obtained at the Crimean Observatory during the period 1971–2006. The first results were reviewed by Pronik (1987).

2. MONTHS - YEARS VARIABILITY

Photographic observations. Investigation of the forbidden line variability on the time scale of months-years has been carried out at the Crimean observatory since 1971. Spectra of NGC 1275, NGC 3227 and NGC 7469 nuclei were observed with the 2.6 m telescope of Crimean Observatory during 6, 11 and 1 years, respectively.

Observed ratios of forbidden line intensities and the theoretical method of intersecting curves by Siton, were used to calculate electron concentration n_e and electron temperature T_e of gas emitting forbidden lines. We used relative intensities of the emission forbidden lines: [O III] λ 4363 Å and (4959+5007) Å, [Ne III] λ 3869 Å, [O II] λ (3727+29) and [S II] λ (4069+76) Å and (6717+31) Å.

For the zone of [O III] and [Ne III] the intensity ratios (4959+5007)/3869 and 4363/(4959+5007) were used. **For NGC 1275** nucleus diapasons of T_e and n_e variations were obtained: 8000 K$\leq T_e \leq$28000 K, 10^6 cm$^{-3} \leq n_e \leq 8\times10^6$ cm^{-3}. Variable n_e and T_e in the [O III] zone showed an inverse relation.

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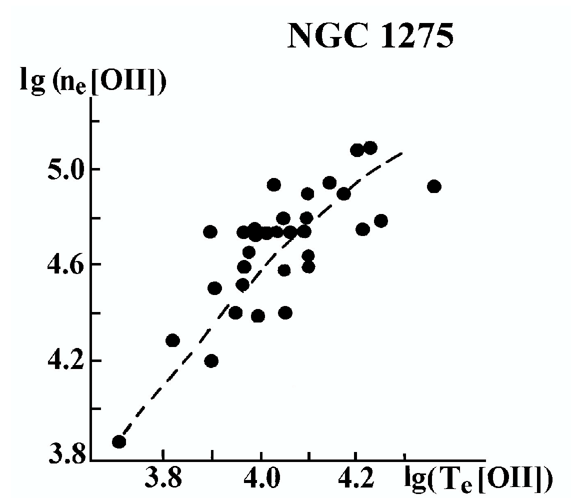

Fig. 1. log T_e vs. log n_e in the zone of [O II] lines in the NGC 1275 nucleus in the 1971–1976 monitoring.

For the zone of [O II] and [S II] the intensity ratios (3727+29)/(6717+31) and (6717+31)/(4069+76) give the intervals of variations 8000 K$\leq T_e \leq$20000 K and 2×10^4 cm$^{-3} \leq n_e \leq 10^5$ cm^{-3}. Figure 1 shows the direct relation of variables n_e and T_e in the [O II] zone for NGC 1275 (Pronik 1974, 1976).

Variability of n_e and T_e was also suspected for forbidden lines in **NGC 3227** (Pronik 1983) and **NGC 7469** (Pronik 1975) nuclei.

Spectral and UBV data obtained during 15 years (1973–1988) for the **NGC 7469** nucleus were compiled from the literature. Two direct relations of emission lines Hβ and [O III]λ 4959+5007Å fluxes were obtained. Relation for the high brightness of the nucleus (U(27$''$)$\leq 12^m75$) was shifted in comparison to the low brightness relation (U(27$''$)$\geq 12^m9$).

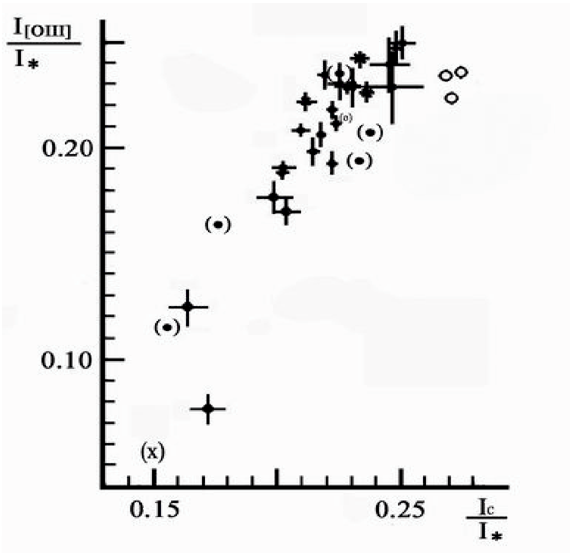

Fig. 2. Direct correlations of [O III] lines and the continuum flux in NGC 1275 nucleus in 1982–1987. I_* is the flux of the comparison star.

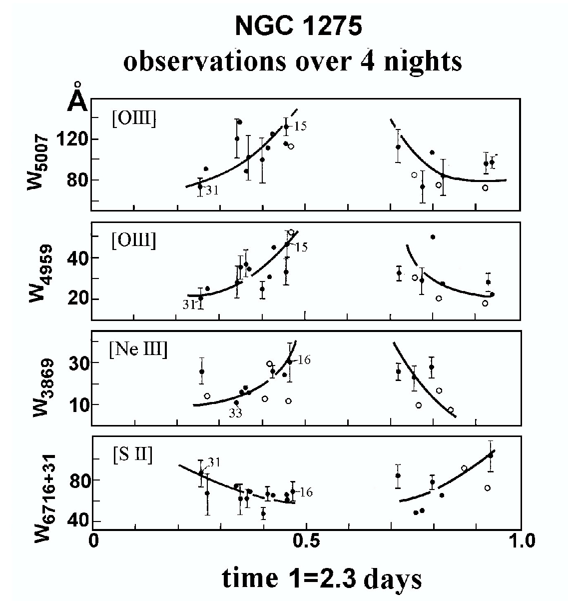

Fig. 3. Variation of the EW_λ lines in NGC 1275 nucleus with characteristc time 2.3 days in 12–14 January 1977.

The first one has systematically lower fluxes $F_{[O\ III]}$ for equal $F_{H\beta}$. Amplitudes of both $F_{H\beta}$ and $F_{[O\ III]}$ variations during 3 years were of the order of a factor of 2 (Pronik et al. 1996).

We analysed data on flux variations of [O III] and Hβ emission lines for 11 QSO obtained by Zheng et al. in 1986–1988. Data for 11 QSO covered three direct relations of variable luminosities $L_{H\beta}$ and $L_{[O\ III]}$ corresponding to three types of the QSO. Fluxes $F_{H\beta}$ and $F_{[O\ III]}$ varied on a scale of years by a factor $\sim$ 2.5 (Pronik 1992).

In 1982–1987 photoelectric observations of the NGC 1275 nucleus were carried out with the 1.25 m telescope of Crimean observatory with a $10''$ diaphragm and a spectrometer slit $\Delta\lambda$=80Å. During 35 nights three spectral regions were observed: the continuum near λ 5200 Å, and emission lines Hβ and [O III] λ 4959+5007 Å. This allowed us to obtain 379 flux values of each spectral region of the NGC 1275 nucleus. The estimated error in flux measurement was $\sim \pm4\%$.

In Figure 2 one can see a direct relation of emission lines [O III] λ 4959, 5007 Å and continuum fluxes. During 5 years fluxes of the continuum, Hβ and [O III] λ 4959+5007 Å emission lines varied by a factor of $\sim$2. Night-to-night variations of [O III] lines were suspected (Pronik et al. 1990).

3. NIGHT-TO-NIGHT VARIABILITY

Looking for the night-to-night emission line variations, spectra of NGC 1275, NGC 3227 and NGC 7469 nuclei were obtained with the 6 m telescope in January 12–15, 1977. The spectra obtained with a slit of $1''$ have a dispersion of 95Å/mm and a spectral resolution of 8Å. The box used during the spectra analysis was $1''\times1.5''$. The error (σ) of an equivalent width (EW) value for EW$\geq$10Å is σ=10–15%, while for EW$\leq$10Å is σ=15–20%.

For **the NGC 1275** nucleus 126 spectrograms were obtained. It was shown that profiles and EW_λ of both hydrogen and forbidden lines varied with a characteristic time of 2.3 days. Variation of EW of the lines [O III] λ 4959,5007 Å, [Ne III] λ 3869 Å and [S II] λ (6717+31) Å with 2.3 days characteristic time is shown in Figure 3. One can see that variations of $EW_{[Ne\ III]}$ and $EW_{[O\ III]}$ are inverse with the $EW_{[S\ II]}$ variation (Merkulova & Pronik 1985; Pronik 1987).

For **NGC 3227 and NGC 7469** nuclei 53 and 23 spectrograms were obtained, respectively. It was shown that in the spectra of both nuclei the EW of [O III] 5007 Å line varied inversely with the EW of [S II] 6717+31 Å. Opposite direction of $EW_{[O\ III]}$ and $EW_{[S\ II]}$ variability in the NGC 3227 nucleus during 3 days is shown in Figure 4 (Metik et al. 2006; Pronik, Metik, & Merkulova 1997).

Three-day flares were also revealed for both nuclei. During the flare:

1. The Hβ and Hγ profiles broadened when EW decreased.
2. The peak of the profile shifts to the blue.

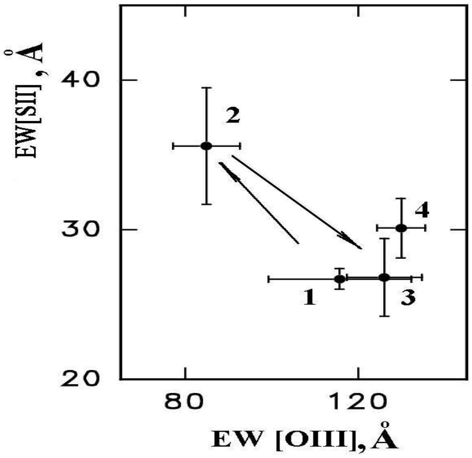

Fig. 4. Comparison of $EW_{[O\,III]}$ and $EW_{[S\,II]}$ variations in the NGC 3227 nucleus during January 12–15, 1977.

3. Variable lines have inverse Balmer decrement.

4. The degree of the variability increases with the number of the line in Balmer series.

5. In the NGC 3227 nucleus the flare was observed during the high brightness phase but in the NGC 7469 nucleus the flare was observed during the low brightness phase.

For the explanation of inverse Balmer decrement simultaneously with the $EW_mathrmH\beta$ decreasing during the 3-day flare in the NGC 3227 nucleus Pronik & Metik (2004) considered a grid of gas models by Gershberg & Shnol (1974). It was shown that a model of collision ionization and excitation of gas having a very dense and hot plasma $n_e \sim 10^{12}$ cm^{-3}, $T_e \sim$ 25000 K, is in good agreement with an inverse Balmer decrement simultaneously with EW_λ decreasing obtained for 3-day flare.

The explanation of forbidden line variations is a subject of special consideration. We propose only an idea, that the physical condition in [O III] and [O II] zones of 3-day flare is the same in the Balmer line region 3-day flare which is independent on the nucleus brightness. Lifetime of atoms and ions on the metastable levels giving optical forbidden lines are less than 7 hours. This allows night-to-night variation of optical forbidden lines. Calculation of Boyarchuk et al. (1969) showed that the emission of forbidden lines [O III] λ 4959, 5007 Å is possible in gas with n_e up to 10^{10} cm^{-3} and T_e up to 10^5 K.

According to Adams & Weedman (1975) the luminosity of NGC 1275, NGC 3227 and NGC 7469 nuclei in [O III] 4959+5000 Å lines are in the range 10^{41}–10^{42} erg s^{-1}. Using results published by Boyarchuk et al. (1969), V. Pronik calculated a grid of gas region sizes emitting [O III] 4959+5000Å lines, with a luminosity of 10^{41} erg s^{-1} but n_e, T_e are different (see Pronik & Pronik 1988, 1992). It was shown that a nucleus luminosity $L_{[O\,III]}=10^{41}$ erg s^{-1} can be provided by gas formation on scales from 20 light years up to 4 light days. For instance a hot, dense gas with $n_e \sim 10^9$ cm^{-3}, $T_e \sim 30000$ K with a size of 4 light days can be variable in [O III] lines as a 3-day flare.

Parameters n_e, T_e and the dimension of the gas region variable in [O III] lines is in good agreement with those obtained above for gas emitting 3-day hydrogen flares. We speculate that emission of both hydrogen and [O III] lines in 3-day flares can be produced in the same region. Such region can be connected with the shock waves in long-lived flows from the galaxy nuclei.

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