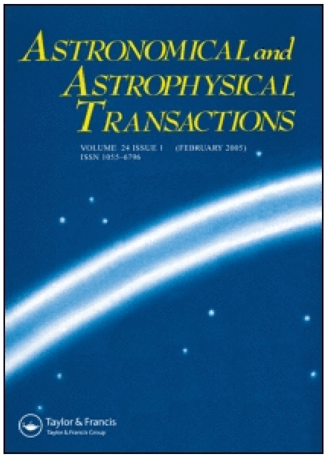

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FORBIDDEN LINE VARIABILITY IN ACTIVE GALACTIC NUCLEI

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A number of review papers and new data on line variability in the spectra of about a dozen active galactic nuclei permit us to suppose that the characteristics of forbidden line variability are similar to those of permitted lines. Using the well-known mechanisms of forbidden line excitation in HII regions, calculations of the volume dimensions were made for a number of parameters T_e and n_e and luminosity $\mathscr{L}_{7959+5007} = 10^{41}\,\mathrm{erg\,s^{-1}}$. The results of calculations permit estimation of volume dimensions of about (1,0–1,5) light months for the NGC 1275 nucleus [O111] envelope. Parameters $T_e = 28{,}000$ K, $n_e = 10^7\,\mathrm{cm^{-3}}$ and $\mathscr{L}_{7959+5007} = 10^{42}\,\mathrm{erg\,s^{-1}}$ corresponding to the active stage of the nucleus were used.

KEY WORDS Galaxies, active nuclei-galaxies, line variability

The problems of active galactic nuclei (AGN) were not the main trends of the investigations of S. A. Kaplan and S. B. Pikel'ner, though their contribution to the general understanding and culture of astrophysical study influences this region too. Their discussions in this field were very significant. Some of the problems under study are reflected in their papers and books: S. B. Pikel'ner (1965, 1976), E. A. Dibay, S. A. Kaplan (1976).

Our estimates of AGN gaseous envelope dimensions are based on the variability of emission lines H_α, H_β, CIII, CIV. Previously these dimensions were determined roughly because the time intervals between accidental observations were months and years, but now specially organized monitoring enables obtaining the time variability and the time of delay of the variability compared to that of central sources more exactly.

Since the time of relaxation of gas emission is small, the observed delay of gas events compared to those of continuum sources defines the distance of gas (clouds, jets) from the central source. Recent determinations of such time delay for NGC 4151 and NGC 5548 show that the broad line gas has a distance from the nuclei of galaxies of only several light days $\sim 10^{16}$ cm. The density of this gas must be very high $\geqslant 10^{10}\,\mathrm{cm^{-3}}$.

The question is what are the density and the distances of the forbidden line gas from the central source. Are they equal correspondingly to 10^2–$10^3\,\mathrm{cm^{-3}}$ and 100 pc ($3 \cdot 10^{20}$ cm) or is the density much higher (for [O111] lines 4959 + 5007 AA it is $3 \cdot 10^6\,\mathrm{cm^{-3}}$) and the distance 10^{17}–10^{18} cm. It is easy to see that the [O111] line luminosity in both cases is the same. It is not excluded that both cases take place simultaneously.

In favour of the existence of a dense inner zone of narrow lines there is an important argument: the gas density estimated by [O111] line intensity relations for all AGN equals to the critical density or even higher ($\sim 10^7\,cm^{-3}$). It is quite natural to suppose that the gas density decreases not so steeply from $10^{10}\,cm^{-3}$ in the central regions to $10^2\,cm^{-3}$ in the outer ones, but there are regions of intermediate densities between these zones of extreme density. The correct proof of such a gas structure will be obtained when the observations have a resolution of $0\rlap{.}''02$. Another proof can be shown now using the variability of forbidden lines.

The observational evidence of forbidden line variation in Seyferts and other AGN are compiled in review papers: V. Lyutyi and V. Pronik (1975), I. Pronik (1980a; 1987), M. Penston (1982), B. Peterson (1988) and others. An incomplete list of AGN whose spectra observations indicate the possible variability of forbidden lines includes NGC 1275, NGC 1566, NGC 3227, NGC 3516, NGC 4151, NGC 5548, NGC 7469, Akn 120, F 427 and 3C 390.3. I. Pronik (1992) considered the spectral material on 11 QSO published by W. Zheng *et al.* (1986, 1987, 1988) and assumed that the forbidden lines 4959 A and 5007 A [O111] vary in these objects, too. But this assumption is still to be verified.

According to the above review papers, the characteristics of forbidden line variability are rather like those of permitted ones. The most part of these observations concerns the lines [O111] 4959 A (N_2) and 5007 A (N_1). All the review material permits us to assume:

1. Time scale variability in most cases is several years, but months and weeks should not be excluded.

2. The amplitude variations are from a tenth of a magnitude to several times. W. Zheng reports in the Atlantic meeting in 1990 that [O111] flux 3C 390.3 nucleus spectrum decreased between 1975 and 1985 by about 1,5 magnitude.

3. The flux variability is followed by line profile variation.

4. There is a correlation between the forbidden line variable fluxes and continuum ones. In W. Zheng's report such a correlation was shown for [O111] 5007 A, [NeIII] 3869 A and [011] 3727 A lines. I. Pronik assumed the correlation of variable [O111] and continuum fluxes in 11 QSO (1992).

5. The data on time delay in forbidden line variation from continuum are more scanty than for permitted lines. In Figure 1 the time variation of relative intensities of forbidden lines is plotted according to I. Pronik (1980) (bottom) and continuum of NGC 1275 nucleus according to V. Lyutyi (1980) (top). As shown by V. Lyutyi, the period between 1970 and 1976 was the most active in UBV flux variability of the NGC 1275 nucleus: there were many bright flares. Figure 1 shows flux variations obtained for diaphragm 5″ from V. Lyutyi data: the flares $\sim \Delta U(5'')$ in the considered active period reach 2^m.

Figure 1 demonstrates that the time scales of continuum flares in the active stage of the NGC 1275 nucleus coincide with those of forbidden line relative intensities. The last can be considered as a result of a temperature increase in the forbidden line emission zones. So one can suppose that increasing UV flux is followed by increasing of electron temperature T_e of the forbidden lines emitting gas. But peaks in the continuum and relative intensities of forbidden lines are shifted with respect to one another: in 1971–1975 forbidden lines delayed continuum by about 6 months and in 1976–1977 by about 10 months. This event looks very much like the observed in VLBI radio observations at a 1,3 cm wavelength where radiolobes move relative to the nucleus of the galaxy.

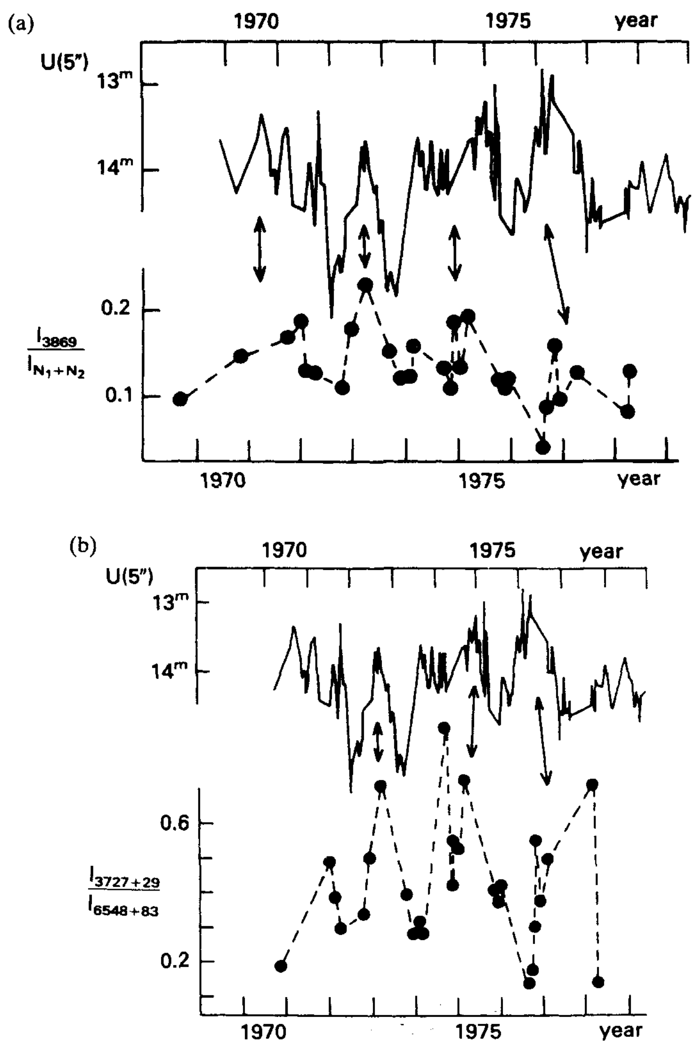

Figure 1 The comparison of forbidden line relative intensities (bottom) and continuum time variations (top) for the NGC 1275 nucleus: a, [0111] lines, b, [011] lines (see text).

Time scale moving in optical regions is the same as in radio regions (Marr *et al.* 1989). So Figure 1 permits us to suppose that the region emitting forbidden lines in the NGC 1275 nucleus during its active stage has a bright feature resembling the jet-like radiolobes. An assumption of this kind was made earlier after analysing histograms of the distribution of NGC 1275 nucleus [O111] fluxes (I. Pronik *et al.*, 1990).

6. The correlation of [O111] 4959 + 5007 A and H_β fluxes was obtained by I. Pronik *et al.* (1990) during the observation of the NGC 1275 nucleus in 1982–1987 and by I. Pronik (1992) for 11 QSO using the data of W. Zheng *et al.*

Table 1 Relations $\lg \mathscr{L}_{[\mathrm{OIII}]} \sim \lg \mathscr{L}_\beta$ for three groups of QSO and NGC 1275 nucleus (I. Pronik)

Objects, types	$\left(\frac{\mathscr{L}_{5007}}{\mathscr{L}_\beta}\right)$	*Observational relations*	*Coefficient of correlation*
NGC 1275, Sy 2	3,1	$\lg \mathscr{L}_{[\mathrm{OIII}]} \sim (1{,}03 \pm 0{,}03) \lg \mathscr{L}_\beta$	$0{,}96 \pm 0{,}01$
QSO,1	1,6	$\lg \mathscr{L}_{[\mathrm{OIII}]} \sim (1{,}00 \pm 0{,}34) \lg \mathscr{L}_\beta$	$0{,}72 \pm 0{,}17$
QSO,2	0,4	$\lg \mathscr{L}_{[\mathrm{OIII}]} \sim (1{,}17 \pm 0{,}02) \lg \mathscr{L}_\beta$	$0{,}98 \pm 0{,}01$
QSO,3	0,2	$\lg \mathscr{L}_{[\mathrm{OIII}]} \sim (1{,}36 \pm 0{,}04) \lg \mathscr{L}_\beta$	$0{,}96 \pm 0{,}02$

(1986, 1987, 1988). The character of the correlations for QSO is found to be dependent on I_{5007}/I_β. These relations are shown in Table 1. As we see the relation for QSO having the greatest value of I_{5007}/I_β is the same as for NGC 1275.

7. Using the relative forbidden line intensities $I_{3869}/I_{4959+5007}$, $I_{4363}/I_{4959+5007}$ and $I_{6717+31}/I_{4069+76}$, $I_{3726+29}/I_{6716+31}$ I. Pronik (1980, b) obtained the intervals of T_e and n_e in variable gaseous envelopes of NGC 1275 by Seaton's method of cross curves: $8000\,\mathrm{K} \leq T_e \leq 28{,}000\,\mathrm{K}$, $10^6\,\mathrm{cm}^{-3} \leq n_e \leq 10^7\,\mathrm{cm}^{-3}$ for the [O111] zone and $5000\,\mathrm{K} \leq T_e \leq 20{,}000\,\mathrm{K}$, $10^3\,\mathrm{cm}^{-3} \leq n_e \leq 10^5\,\mathrm{cm}^{-3}$ for [011] zone. But for the region emitting 4363 Å [O111] line $n_e \sim 10^9\,\mathrm{cm}^{-3}$ was suggested.

Until now there has been no general theory explaining the forbidden line variation in a time scale of years and months. But it is well known that the lifetime of atoms and ions on the metastable levels for the brightest forbidden lines observed in the near UV and optical regions of the spectrum are about seconds and hours (see Table 1, obtained according to the values of the possbility of spontaneous transitions A_{21}, compiled by S. Kaplan and S. Pikel'ner (1963). So one can expect the time scale of forbidden line variability is of order of magnitude of hours and weeks. But the mechanism of excitation was still open to discussion. N. Bochkarev (1987) and S. Fabrika (1987) proposed two possible mechanisms responsible for rapid variation of forbidden line emissivity. In the first case the heavy element plasma column densities change by phase transfer between two thermally stable fluids. In the second, the optically thick gas in forbidden lines [O111] 4959 Å and 5007 Å was considered. But it is important to explain not only the volume unit emissivity variation but the whole gas volume, too.

Observations show that physical conditions in the gaseous AGN envelopes are very complex. There are regions of neutral and ionized hydrogen. The mechanisms of forbidden line excitation can be different in these regions. For regions of neutral hydrogen V. Pronik and I. Pronik (1987) proposed ionization of oxygen and other heavy elements by soft X-rays. Calculations showed that the emissivity of [O111] lines 4959 + 5007 ÅÅ in the regions of neutral hydrogen concentration of $10^8\,\mathrm{cm}^{-3}$ provides the total flux of these lines equal to 10^{41}–$10^{42}\,\mathrm{erg\,s}^{-1}$ (obtained for the NGC 1275 nucleus) in the volume of (1,0–1,5) light months dimensions.

In the AGN regions of ionized hydrogen, where the well known collisional excitation for the lines 4959 Å and 5007 Å O111 take place, the emissivity of unit volume in [O111] lines is:

$$\varepsilon = (4959 + 5007) = n(\mathrm{O111}) n_2/n_1 A_{21} h\nu_{12}\ \mathrm{erg\,s}^{-1}\,\mathrm{cm}^3,$$

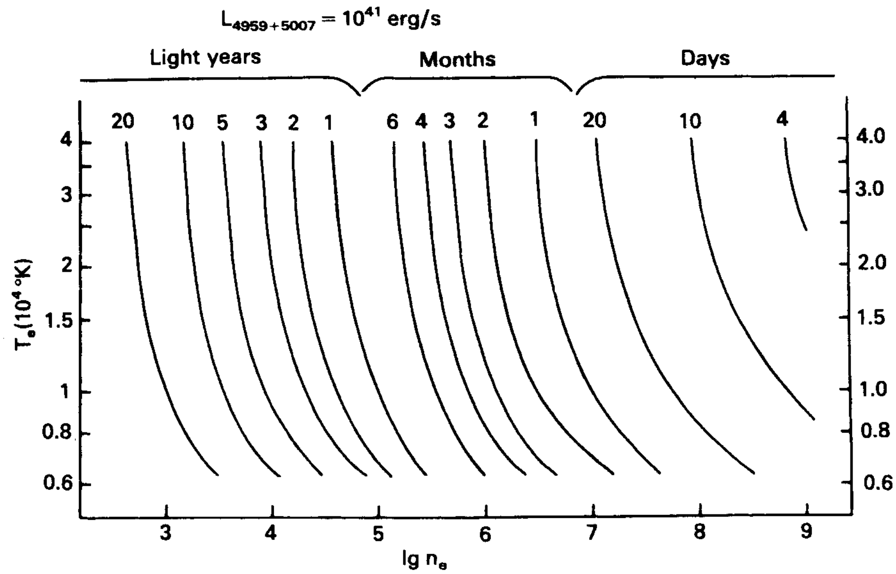

Figure 2 Dimensions of [O111] zones, emitting general flux $\mathscr{L}_{[O111]} = 10^{41}$ erg s^{-1} and having various values T_e and n_e (see text).

where n(O111) = number of O111 ions in 1 cm^3, n_2/n_1 = ratio of O111 ions at two levels, 2 (2p^2 ^{1}D$_2$) and 1 (2p^2 ^{3}P$_{0,1,2}$) A_{21} = is the probability of spontaneous transition equal to 0,028 sec^{-1}, and $h\nu$ = energy of one quantum equal to $4 \cdot 10^{-12}$ erg. A number of values $n_2/n_1 = f(T_e, n_e)$ are given by V. Pronik and I. Pronik (1987). Using these values one can calculate the emissivity of unit volume in [O111] lines and then the volume dimension of the gas of known luminosity $\mathscr{L}_{4959+5007}$. Figure 2 gives sets of series of volume dimensions emitting $\mathscr{L}_{[O111]} = 10^{41}$ erg s^{-1} and having different parameters T_e and n_e. For $\mathscr{L}_{[O111]} = 10^{42}$ erg s^{-1} the dimensions will be $\sqrt[3]{10} \sim 2$ times more. The calculations were made on the supposition that all atoms of oxygen are in the O111 ionization stage, the oxygen abundance is O/H = $6 \cdot 10^{-4}$ (C. Allen, 1955) and the filling factor is equal to 1.If one takes the values of T_e and n_e obtained for the NGC 1275 nucleus using the relative intensities of forbidden lines [O111] and [NeIII] obtained for NGC 1275 (see above): T_e = 28,000 K, $n_e = 10^7$ cm^{-3}, the dimensions of the [O111] region will be equal to about 20 light days (or 40 l.d. for $\mathscr{L}_{[O111]} = 10^{42}$ erg s^{-1}).

J. Tholine and D. Osterbrock about 15 years ago (1976) supposed that the forbidden lines [O111] 4363, 4959 and 5007 ÅÅ in the NGC 7603 nucleus are emitted in a one light year dimension region. Proceeding from the observed relation $\mathscr{L}_{4959+5007}/\mathscr{L}_{4363} = 11$ they adopted $T_e = 10^4$ K and $n_e = 10^6$ cm^{-3} for this region. But the combination of $\mathscr{L}_{4959+5007}/\mathscr{L}_{4363} = 11$ and $n_e = 10^6$ cm^{-3} is possible only if $T_e = 1{,}7 \cdot 10^4$ K. If we assume $T_e = 10^4$ K then the density must be very high. We believe that AGN forbidden line zones have not only high density but high temperature ($\geqslant 2 \cdot 10^4$ K) too.

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