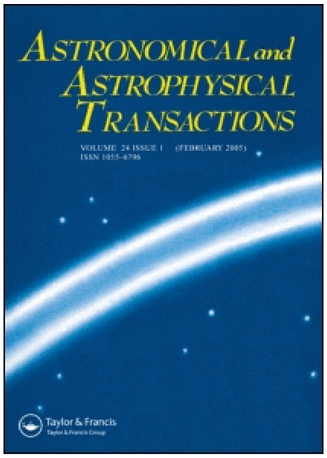

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OPTICAL SPECTRAL VARIABILITY OF NGC 4151 DURING 1990

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We use the intensive optical spectral monitoring of NGC 4151 obtained during the LAG campaign in January–June 1990, to investigate the profile and intensity variations of Hα and Hβ emission lines. The continuum light curve values were supplemented with photoelectrical photometry (11 dates) obtained at the Crimean observatory of the Sternberg Astronomical Institute by V. M. Lyuty. Cross-correlation analysis shows that the time delay between continuum changes and variability of Hβ and Hα is about 4 ± 2 days. The error in the delay was found by applying cross-correlation analysis to a model series, with the same temporal distribution, power spectrum, and signal-to-noise ratio as the actual data. This value of time delay is much lower than was found in other papers for other epochs. We can note two variabilly components in these changes in the lines: one fast and one slow. The amplitude of the slow component relative to the fast component is higher for Hα then for Hβ. The year 1990 was peculiar for NGC 4151 because the object returned to the state which was typical before 1980. The very strong dip in the covering factor was deduced from X-ray observations for the first half of 1990. During this interval interesting peaks were observed in the red wings of Hα and Hβ, which were previously observed very rarely. The same peak was seen in the UV line CIV during the first half of 1990. Intensities of the peaks changed in correlation with the continuum and line variability. We noted some differences in the behaviors of these peaks in Hα and Hβ. The results obtained are briefly discussed.

KEY WORDS AGNS, optical spectral variability, time delays

1 INTRODUCTION

NGC 4151 is one of the nearest and intrinsically weakest galaxies of the Seyfert class. The high degree of variability and extreme brightness in IR, optical, ultraviolet, X-rays and γ-rays make this object very popular for monitoring observations across all the electromagnetic spectrum.

In many publications, NGC 4151 was presented as a typical example of a tupe 1 Seyfert nucleus (Sy 1). From the fall of 1980, the UV permitted emission lines have been almost the same as the forbidden lines, suggesting a classification closer to Sy 2 (Elvius, 1983). In the spring of 1984 the same disappearance of the broad

Sy 2 (Elvius, 1983). In the spring of 1984 the same disappearance of the broad optical allowed lines was found (Lyuty, Oknyanskij and Chuvaev, 1984; Penston and Perez, 1984).

Hereafter, we shall call the 1980–1988 interval the "low state" although, in fact, there have been occasions when the nucleus brightened up in this period. After 1989–1990 NGC 4151 returned to its previously typical "active state" optical brightness level and spectral line profiles (Ayani and Maehara, 1991; Oknyanskij, Lyuty and Chuvaev, 1991, 1994).

NGC 4151 was one of the first known objects which can change type of Sy class so quickly. In recent years, the number of such Seyfert nuclei known has grown and is now about a dozen or more. We may therefore presume that many (if not all) of the variable nuclei in Seyfert galaxies undergo these sort of changes quite frequently (Oknyanskij *et al.*, 1991). It would seem that there must be some sort of general mechanism for these strong changes in AGNs. We have few chances to see several of these kind of changes in any one SyG during 10–20 years, but we can try to find repeated behavior of any parameters before, during and after these changes in different objects. These facts can be useful for understanding these peculiar changes and the nature of AGN in general.

During 1990 the spectrum of NGC 4151 was rather atypical, with a strong emission peak in the red wing of Hα and Hβ profiles (Boksenberg *et al.*, 1992; Oknyanskij, 1994), which decreased next year, when other blue peaks appeared. These peculiar variations in the line profiles might correlate with observed extremal variations of X-ray covering factor (Yaqoob *et al.*, 1993). Boksenberg *et al.* (1992) noted that in January 1985 the same red peak was present in the profile of the ultraviolet line CIV, however in March 1990 this line was quite symmetrical.

The purpose of the present work was to investigate the flux and profile variability of Hα and Hβ lines, and try to find the time delays between the continuum and line fluxes. We combined the results of these investigations with the results of other investigations during recent times or a long time ago before revealing some repeated peculiarities in behavior of these object. We also try to note the same peculiarities in other objects, which have the same extremal peculiarities. We hope to use the results of this analysis to get some new information about the geometrical or/and physical nature of NGC 4151 and AGNs in general.

2 DATA AND RESULTS

2.1 Data Reductions

NGC 4151 was observed during the LAG* monitoring program between January and June 1990. A total of 24 spectra covering the Hα and the Hβ were obtained during this period (Perez *et al.*, 1995). The line intensities in this paper were obtained by using an automatic scaling algorithm (van Groningen and Wanders, 1992) based on minimizing narrow-line residuals in difference spectra. This method, however, yields

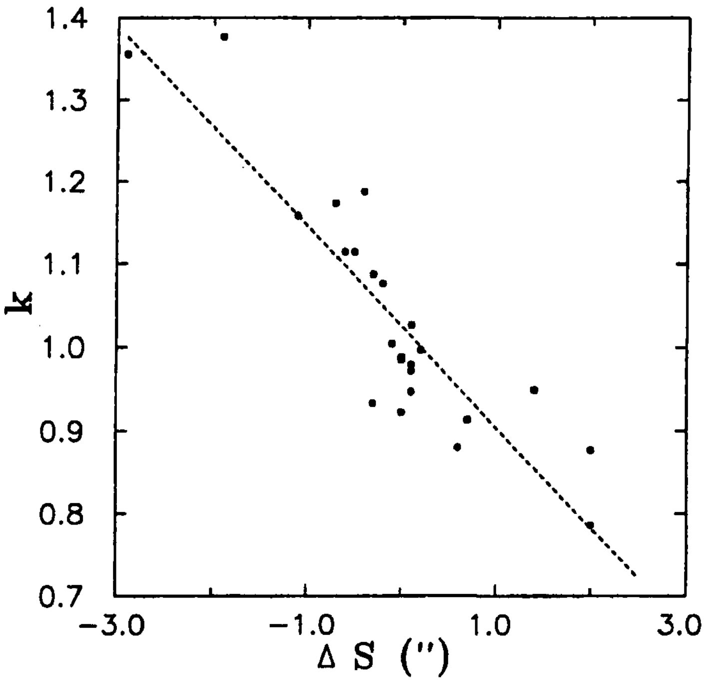

Figure 1 Example of seeing effect for Hα measurements (see text).

correct results only if the narrow-line region is a point source, which is not the case for NGC 4151. Variations in seeing can then introduce considerable errors, if no corrections are applied to compensate for the different spatial extensions. Perez *et al.* tried to correct for seeing effects, however, a significant seeing-dependent error remains (Robertson, 1994). One of the possible reasons for this is that Perez *et al.* used the contrinuum image taken in March 1988 when the nuclear continuum was several times fainter than during the LAG program. For this reason we performed new measurements and corrections of the spectra, by using a more straight forward method.

In addition we used data from the intensive ground-based photometrical program (Lyuty, 1973, 1977), which was kindly given to us before publication. We use these data to increase the amount of continuum measurements for the time series.

The fluxes of the Balmer lines were obtained by measuring the relative intensities Hβ/[OIII]λ4959 and Hα/([OI]λ6300+[SI](λλ6717+31). We assumed the forbidden line fluxes to be constant during the experiment (the standard assumption for this type of work).

To estimate the random error of these measurements we performed this work several times (both of us) independently and get a value of the error of about 3% for intensities. We use as a continuum light curve values 1/[OIII]λ4959 (with a random error of about 5%).

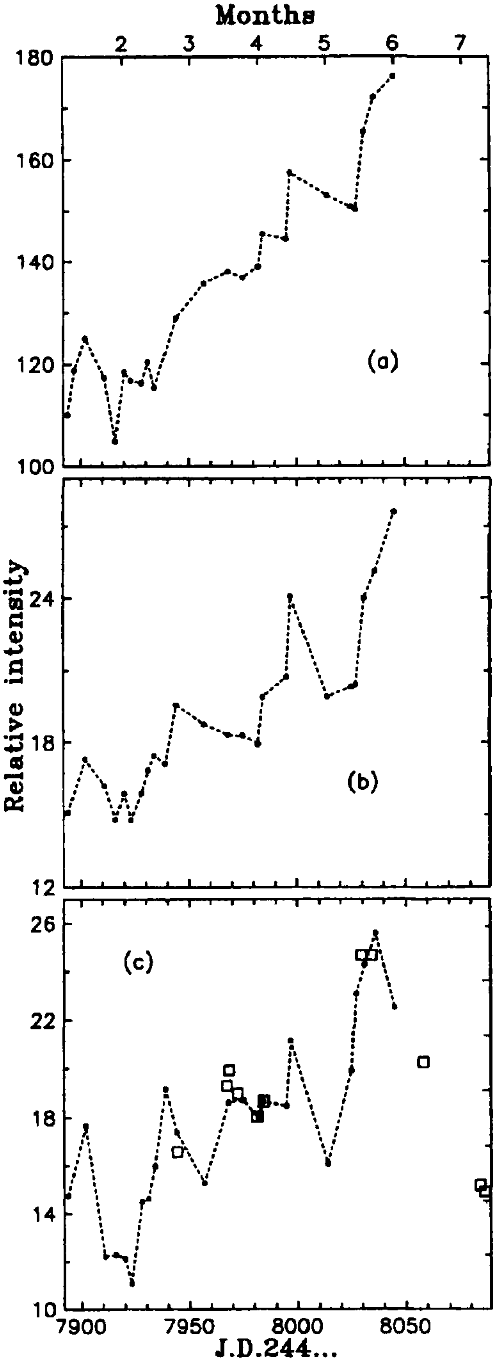

Figure 2 Light curves after reduction for seeing effect: *a*, Hα; *b*, Hβ; *c*, green continuum. (Boxes – continuum values obtained from Lyuty's photoelectrical measurements in filter B).

Our measurements of the line and continuum intensities (before any correction for seeing) correlate very well with the values obtained by Perez *et al.* (1995). The correlation coefficients are about 0.96–0.97 for the lines and about 0.99 for the green continuum. To estimate the seeing corrections we adopt a simple reduction method. We first calculate the flux ratios for all pairs of neighboring points in the light curves:

$$k_i = F_i/F_{i-1}, \tag{1}$$

and compare these to the differences in seeing between the two observations, S_i as listed by Perez *et al.* (1995)

$$\Delta S_i = S_i - S_{i-1}. \tag{2}$$

These two quantities correlate very well with each other, so a linear regression is used to find the best fit to the function

$$k = a\Delta S + b. \tag{3}$$

In Figure 1 we show as an example of this dependence the correlation between k_i and ΔS_i for Hα. The corrected fluxes F_i' can now be expressed as:

$$F_i' = F_i(1 - a(S_i - \bar{S})), \tag{4}$$

where $\bar{S} = 1\overset{''}{.}8$ is the mean seeing value.

We did not find a correlation between the continuum measurements and seeing. Corrected continuum values in Perez *et al.* are very badly correlated with data of Lyuty, but before the correction the correlation is very high. In spite of Perez *et al.*, these two facts give us opportunity do not make any correction for continuum measurements.

The light curves after the reduction for seeing effect are shown in the Figure 2.

2.2 Cross-Correlation Analysis

The correlations between the different emission components allow us to establish some of the physical properties of the emission regions. First of all, determination of the time lags between variability of the different emission components can give us useful information on the sizes and structures of AGN emission regions. For this purpose the cross-correlation technique (hereafter, CCF) for irregularly spaced data sets developed by Gaskell and Spark (1986) and refined by Gaskell and Peterson (1987) is most often used. We use a new version of this cross-correlation technique: the MCCF (Oknyanskij, 1994). The MCCF works as follows: to decrease the noise from interpolations (as used in the CCF), it takes into account only such points of the interpolated data which are close to real data points (not more than some assigned short time interval Max. In this paper, we shall use Max = 10 days). It is possible, that for some time shift we only have a few pairs of overlapping points or not even a single pair. As a rule, we excluded from analysis the time shifts for which the number of the overlapping points n are fewer than 10. If two data sets are not equivalent in accuracy and/or sampling we use only the best of them

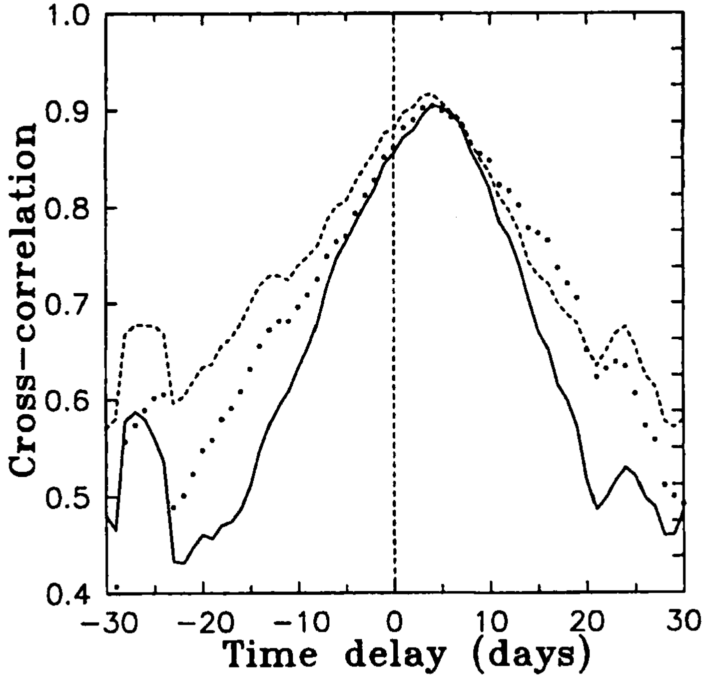

Figure 3 Cross-correlation functions MCCF for Hα (dashed) and Hβ (solid) (Perez *et al.* (1995) measurements with our correction for seeng effect) from green continuum (see Figure 2c). Points, MCCF for Hα (our measurements corrected for seeing) from the green continuum.

for interpolation. If the two data sets are similar in quality we calculate the two MCCFs, and then get the mean value of these.

Results of the MCCF calculations of the Hα and Hβ series with the blue continuum are presented in Figure 3. This figure shows that the time delay between the continuum and lines is about four days. To obtain an estimate of the error we applied the MCCF method to a large number of model series, with the same temporal distribution, power spectrum, and signal-to-noise ratio as the actual data (see Oknyankij, 1993). It was found that the standard error is about two days.

The time delay between the continuum and the Balmer lines that we find, 4 ± 2 days is significantly shorter than the delay which have been found in other papers and for other periods of time.

2.3 Variable Structure in the Line Profiles

The behavior of red peaks in Hα and Hβ lines, which was observed during January–June is evidence in favor of possible profile variations. The visual analysis of these line profile gave us evidence to discuss possible variations in the peaks relative to other parts of lines. This fact can be illustrated by Figure 4. It is clear that the

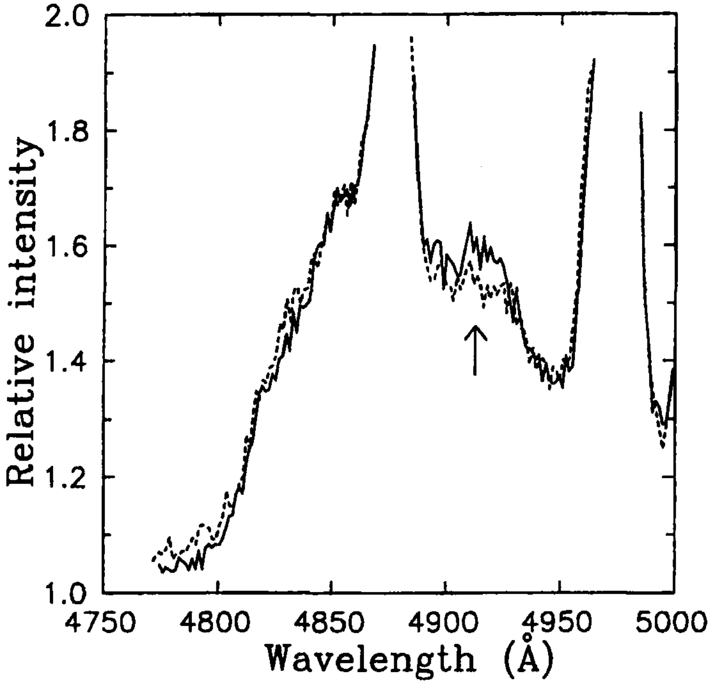

Figure 4 Profiles of Hβ in two dates (solid line, 13.05.90; dashed, 16.02.90).

intensity of the peaks changed between the two times (February 13 and May 16), while all the other parts of the Hβ profile were more or less identical. We measured the relative intensity in a 30Å region of Hα and in a 50Å region of Hα profiles where these peaks are seen. In the following we assume that the narrow component of Hβ has an intensity of about 0.2 relative to [OIII]λ4959 and the narrow component of Hα and several narrow lines blended with this line have an intensity about 2.68 relative to ([OI]λ6300+[SI]$\lambda\lambda$6717+31) (We take mean values for the narrow line intensities from two papers: Boksenberg *et al.* (1975) and Osterbrock and Koski, (1976)). Intensities of these parts of Hα and Hβ changed slowly in correlation with the continuum and line variability. We can note some differences in behavior of these two peaks. Intensity of the peak in Hβ compared to the full broad component slowly increased during the investigated interval and reach a maximumin April–May, however several fast dips were observed. The behavior of the peak in Hα is another. The profile of the line was brighter in the first part of the observed period and was comparatively weak in May–June.

Boksenberg *et al.* (1992) noted that in 1985 the red peak in Hα) correlated well with the same peak in the CIV line, but by the end of March 1990 the CIV line was almost symmetrical. To check this result we used the IUE archive and compared the profiles of CIV and Hβ for several close dates. In contrast with Boksenberg *et al.* we found evidence of the same features in the red wing of CIV as in the Balmer

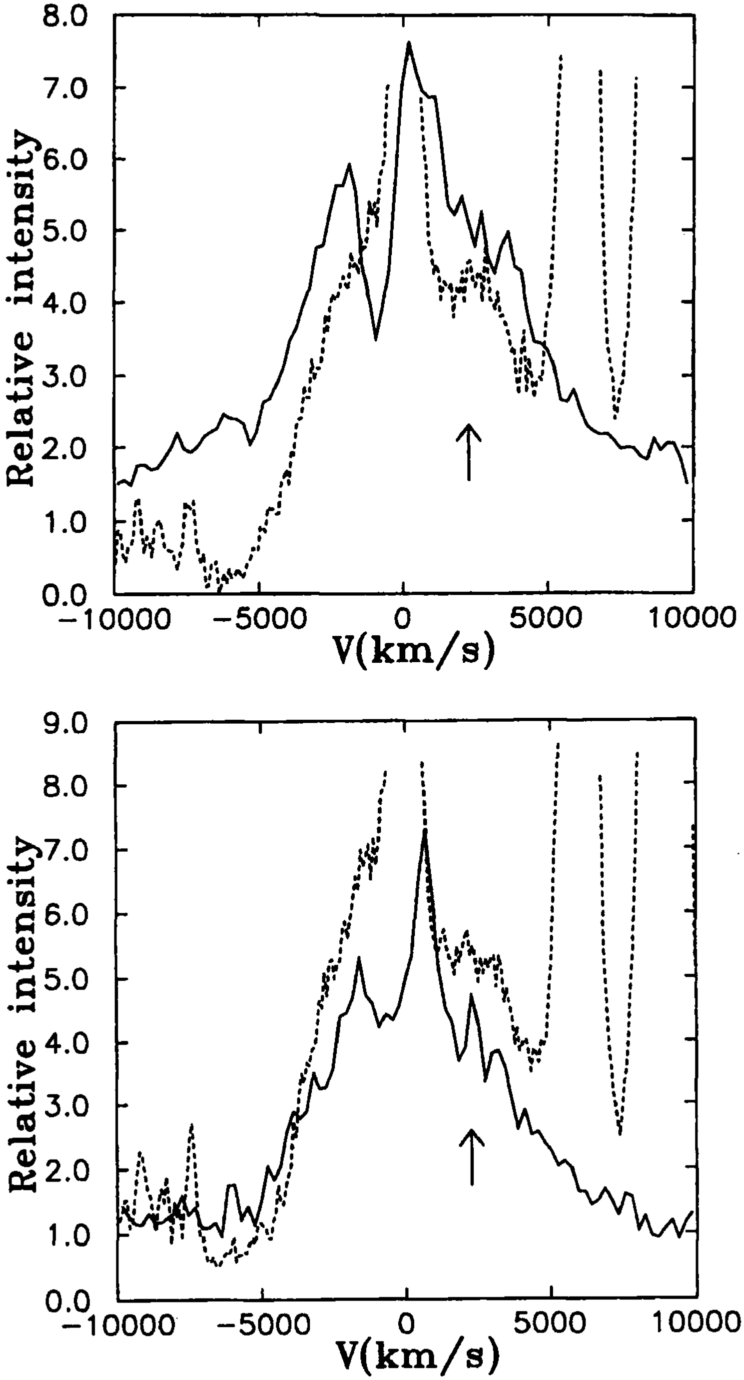

Figure 5 Peaks in CIV (dashed) and Hβ (solid) in close dates *a*, 25.02.90 and 16.02.90; *b*, 12.04.90 and 15.04.90).

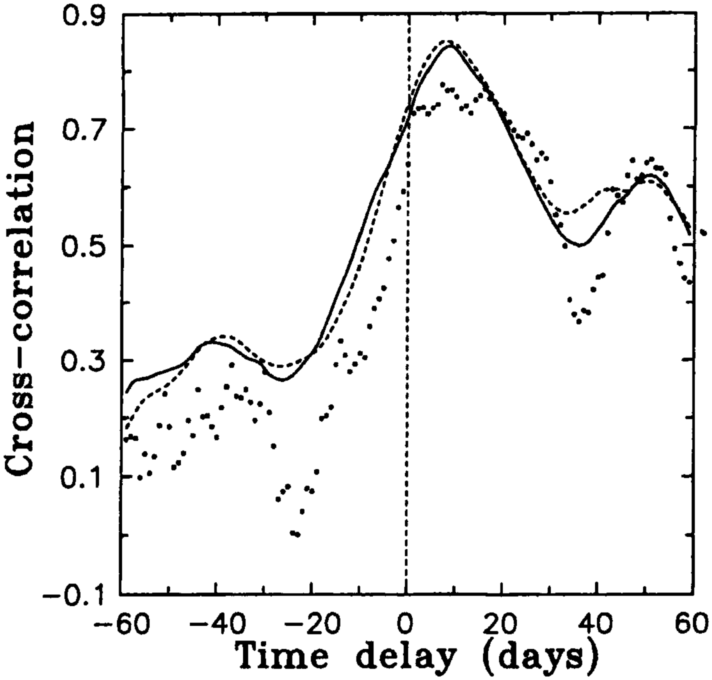

Figure 6 Cross-correlation functions for Maoz *et al.* data. (Solid, for Hβ; dashed, for Hα from continuum (full line interpolation). Points, MCCF for Hα from continuum with MAX = 5 days.

lines (see Figure 5) however at the end of March these peaks were very weak in the profiles of the lines.

2.4 Comparison with Previous Observations

To compare our results directly with those of Maoz *et al.* (1991), we also calculated the MCCF of their data. As shown in Figure 6, our cross-correlation function differs from that obtained by Maoz *et al.* (1991) for 1988, who use a different correlation method, i.e., they interpolate the line intensities to obtain regularly spaced data. In our opinion, this line interpolation is equal to filtering out high frequencies and can decrease the quality of the cross-correlation analysis. As shown in Figure 6 the time delay in 1988 was about nine days rather than four days. This conclusion does not depend on the method used.

Evidence in favor of a bigger time delay value in the previous time interval 1983–1986 is the MCCF for the Hβ (Peterson and Cota, 1988; Oknyanskij *et al.*, 1991, 1994) and the optical blue continuum (Lyuty) presented in Figure 7. There is a very clear peak in the MCCF with a 12 days time delay. About the same values for the Balmer line delays have been found several times before (Antonucci and Cohen, 1983; Chuvaev and Oknyanskij, 1987). We can conclude that if our result about

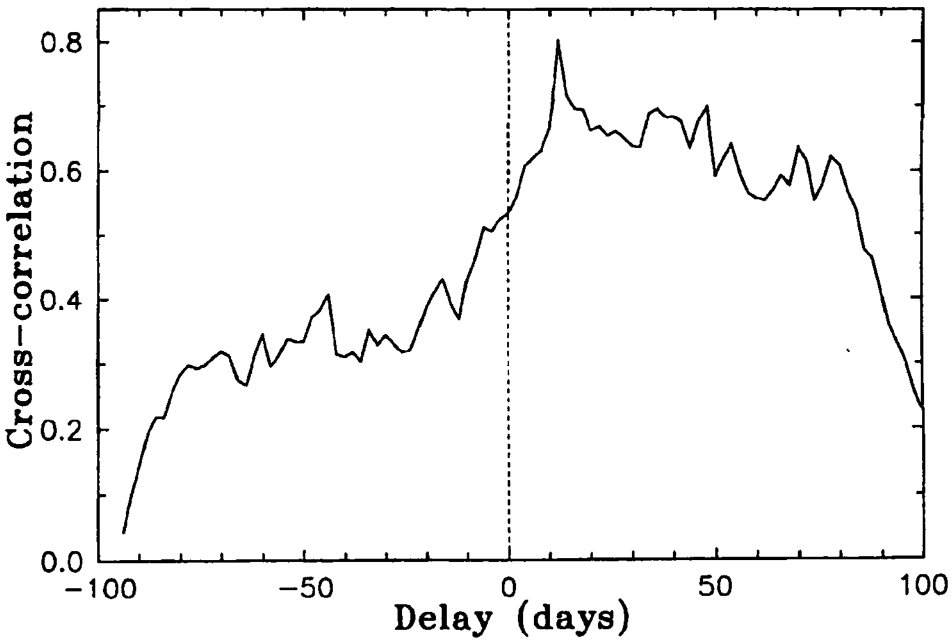

Figure 7 Cross-correlation MCCF for Hβ from blue continuum for 1983–1988 (Peterson and Cota, 1988; Oknyanskij *et al.*, 1991, 1994).

four days time delay in 1990 is correct, it is a very unique case in the variability of NGC 4151. This unique case correlates with another one observed in this object during 1990 – very strong dip in the X-ray covering factor (Yaqoob, 1993). These two unique observational facts together with the appearance of the same red peaks in the CIV and in the Balmer lines might be connected in some way. We must note that the red peaks in the Balmer line were seen during 1985 and 1990 from the spectral data of K. K. Chuvaev. These results in accord with the CCD spectral data give us confidence in the published results from the photographical data on the peaks in the red and blue wings of Balmer lines during 1975–1978 (Oknyanskij and Chuvaev, 1987) and 1990–1991 (Oknyanskij, 1994). It is interesting to note that in 1991 a decrease of the red peak and the appearance of new blue peak in Hβ were abserved during summer 1991. This blue peak is present in the spectrum which was obtained from the HST at the end of May 1991 (Boksenberg *et al.*, 1995). In previous cases (in 1975–1978) these blue and red peaks had about the same appearance and appeared in the about the same places of the line profiles as in 1990–1991.

3 DISCUSSION

The phenomena of transitions from one Seyfert type to another during several years or months has not been explained yet. The unified picture of AGN says that the type of an object depends on its orientation with respect to the line of sight. A thick torus or an accretion disk obscures part of the nuclear continuum source and broad line region, depending on its orientation. In this picture, Seyfert 2's are observed close to the plane of the torus, while Seyfert 1's are observed along the axis. Seyfert 1.8's and 1.9's are intermediate cases where we observe the torus under a larger angle than in Seyfert 2's but still close to edge-on (e.g. Antonucci, 1993). This model seems appropriate for NGC 1068 (Antonucci and Miller, 1985) and several other objects (Miller, 1988) with BLRs which are not directly observed but whose existence can be inferred indirectly. However, this picture offers no explanation for those objects that change from one Seyfert type to the other on short time scales, and other explanations have to be invoked. One possibility is that the change of type is caused by some dust clouds which temporally block our line of sight to the nucleus (e.g. Goodrich, 1989).

Of the more than a dozen Seyfert nuclei which exhibit similar variations in spectral type as NGC 4151, only NGC 5548 has been investigated very intensively. It was found that the time delay for the optical Balmer lines in NGC 5548 changed and was smaller during and just after the low state of the nucleus (Peterson *et al.*, 1994). This object is similar to NGC 4151 in the sense that it also shows secondary peaks in the optical broad lines. We wish to draw the attention to the fact that about of 50% or more of the objects, which are known to display changes of spectral type, also have similarly structured line ptofiles. These are NGC 4151 (Chuvaev and Oknyanskij, 1989), 3C 390.3 (Perez *et al.*, 1988), Mkn 6 (Chuvaev, 1991), NGC 5548 (Loska *et al.*, 1986), NGC 7603, Mkn 1218, Mkn 728 (Goodrich, 1989, 1995), Mkn 1018 (Cohen *et al.*, 1986). It is appreciably more often than for all AGNs, although the statistics are rather poor, of course. Also selection effects may play a role, in the sense that most of these objects were observed more intensively than the "average" AGN. Eracleus and Halpern (1994) found that about 32% of the radio-loud QSOs and BLRGs have peculiar broad line profiles. Objects with weak radio emission usually have smoother broad-line profiles (e.g. Steiner, 1981). Some of the objects mentioned above are radio sources (for example 3C390.30, but several are not (for example NGC 4151).

Several ideas have been put forward to explain the occurrence of double peaks in the broad emission lines: complex double-stream, or bipolar, distribution of outflowing BLR clouds; variation of the ionizing continuum or changes in orientation of the radiating cones; the presence of a large hot spot on the relativistic accretion disc, spiral shock structure in an accretion disk (Chakarbarti and Wiita, 1993); supermassive binary black holes (e.g. Eracleous and Halpern, 1994), elliptical ADs (Eracleous *et al.*, 1995). In the following discussion, we will assume that all the aforementioned peculiarities of NGC 4151 (e.g. spectral type changes, appearance and disappearance of peaks in the profiles, variable time delays) are common occurrences in Seyfert galaxies. If this simple conclusion is right we can try to find some preliminary explanation of our results without invaking any exotic peculiarities in NGC 4151. The most common model for a central object in AGNs is a suppemassive black hole with AD. It is not clear if an emission line can arise in AD, but it is expected from some theoretical publications (Collin–Souffrin *et al.*, 1980). The

AD model is a very fruitful idea, because it has a lot of scope for the explanation of different common AGN properties. Moreover, we can have too many very different explanations from this model for the peaks in line profiles, because in the AD model it is very easy to expect different kinds of anisotropy: in radiation, matter flow, brightness of AD and so on. Can we get some restrictions from our results for this spread of opportunities? The key question is if we can prefer one of two type of models for the double-peaked emission: bipolar flow, jets or emission from AD. We found from modeling that partial obscuration of emission clouds beyond AD can explain asymmetry in the locations of double peaks (for both possibilities: inflow or outflow streams). This explanation is valid only if the far side of the BLR is not completely obscured by a sick AD, since in the other case only one-sided peaks would be observed in general. We did not find any systematic difference in time delay for the peaks and other parts of line profiles, however from the double jet or stream model it is expected that the time delay between blue and red peaks is about weeks or even years (see the discussion of Livio and Pringle, 1995).

Finally we can conclude that the simple double stream model should be rejected. So only one opportunity can save this type of model, if one part of the clouds (perhaps more dense) falls to the central source and other ones (thinner) are ejected (Tsuruta, 1977). The systematic asymmetry in locations of the double peaks can be due to the fact that failing sick clouds radiate emission lines closer to the central source where the systemat radial velocity is higher than farther way, where (not so sick) clouds could be radiated.

Other types of models have problems also. First of all, it is difficult to explain the observational results in a simple model with radiation of all the broad lines in AD. In these models we can expect a brighter blue peak, but for NGC 4151 and some other objects it is not correct. If a double peak radiates from the double jet structure it is not clear why we cannot sometimes see one (or both) of these components. It is difficult to explain the appearance of the same peaks in profiles of CIV and Balmer lines. If we involve the more complex idea of an AD with the hot spot and strong anisotropy of the radiation field then we can get a preliminary explanation. The peak which are seen in different emission lines can be connected with emission from the matter above the same hot spot in AD. Different emission lines are radiated from different heights under the AD symmetry plane. Why can we see this peculiarity in the profiles of line only temporarilly. For a different reason. For example, only when hot sports are induced by stars passing near the disk. These cases can correlate with increasing the level of the continuum. For any case for NGC 4151 it is correct, because the periods of the peak appearances correlate with high intensity of the continuum in 1975–1978 (Chuvaev and Oknyanskij, 1987), 1985 and 1990. This scheme however has one obvious problem: it is impossible to understand the appearance of peaks at about the same places during the long period of time (1975–1991). Another possible explanation is some change in the BLR obscuration. If we observe AD and BLR throwing some ensemble of sick (dust) clouds, we can see an internal part of AD with hot spots only temporarilly. This is a possible explanation too. This simple idea can explain the correlation of the covering factor from the X-ray results, with the increase of the continuum level and the appearance of peaks in lines, decreasing the value of the time delay. Detailed discussion of obtained results is beyond the scope of this publication.

4 SUMMARY AND CONCLUSIONS

(1) We investigated flux and profile variability of the Hα and Hβ lines during January–June 1990 on the basis of spectral data obtained during the LAG program;

(2) Cross-correlation analysis shows that the time delay between continuum and Hα and Hβ variability is about 4 ± 2 days. This value is much lower than was found in other papers for other times;

(3) We note that the return of NGC 4151 to an active state in 1990 was accompanied by several peculiarities: low values of time delays, peaks in Hα, Hβ and CIV lines, a strong dip in the X-ray covering factor;

(4) Simple UM (Unification Model) of AGNs can not explain properties of Seyfert galaxies which can change the spectral class. More complex models are needed which possibly involve hot spots in AD, change in the BLR obscuration by dust clouds and so on;

(5) We conclude that many (if not all) of the variable nuclei in SyGs undergo changes of spectral class quite frequently.

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