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Optical variability of NGC 4151 during past 100 years

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Abstract. We present historical optical light curve of NGC 4151 over 1906–2007 based on our photographic and photoelectric data as well as other published photometrical data reduced to the same system.

We have found quasi-periodic component about 15.6 years in the 100-year light curve and that is close to our old result.

We present results of optical spectrophotometry during 1972–1991 using the monitoring data of K.K. Chuvaev.

We have performed the cross-correlation analysis to find out time delays between continuum and line variations.

1 Introduction

NGC 4151 is one of the brightest and best studied Seyfert-1 AGN galaxies. NGC 4151 is a ~12th (V) mag Barred Spiral galaxy (d ~ 16 Mpc) with a highly luminous and active nucleus. Because of its brightness and complex variability at about all the wavelengths, NGC 4151 has become the "number one example" for Active Galactic Nucleus (AGN) galaxies and has been the subject of numerous studies that cover wavelengths from gamma rays to radio. These studies show variability on all the time scales, from minutes to years. Like other AGNs, NGC 4151 is a powerful X-ray source with very strong UV, optical and IR emissions that are best explained by accretion processes occurring in the disk in proximity to its assumed supermassive $\sim 10^7 - 10^9 M_{\odot}$ black hole nucleus.

2 Photometrical variability

Optical variability of NGC 4151 was discovered by Fitch, Pacholczyk and Wayman (1967). Just since this time the variability of this object as well as of other AGNs has been intensively investigated.

We present the historical light curve of NGC 4151 over 1906–2007. The light curve (Fig. 1) is primarily based on our published photoelectric data (1968–2007, about 1040 nightly mean measurements) and photographic estimates (mostly Odessa and Moscow plates taken in 1906–1982, about 350 measurements). Additionally, we include all the data obtained prior to 1968 and published by other authors (de Vaucouleurs and de Vaucouleurs, 1968; Sandage, 1966; Wisniewski and Kleinmann, 1967; Fitch et al., 1967; Barnes, 1968; in total, 19 photoelectric observations from 1958–1967, reduced by us to the same diaphragm aperture as that used in our measurements) as well as photographic data of

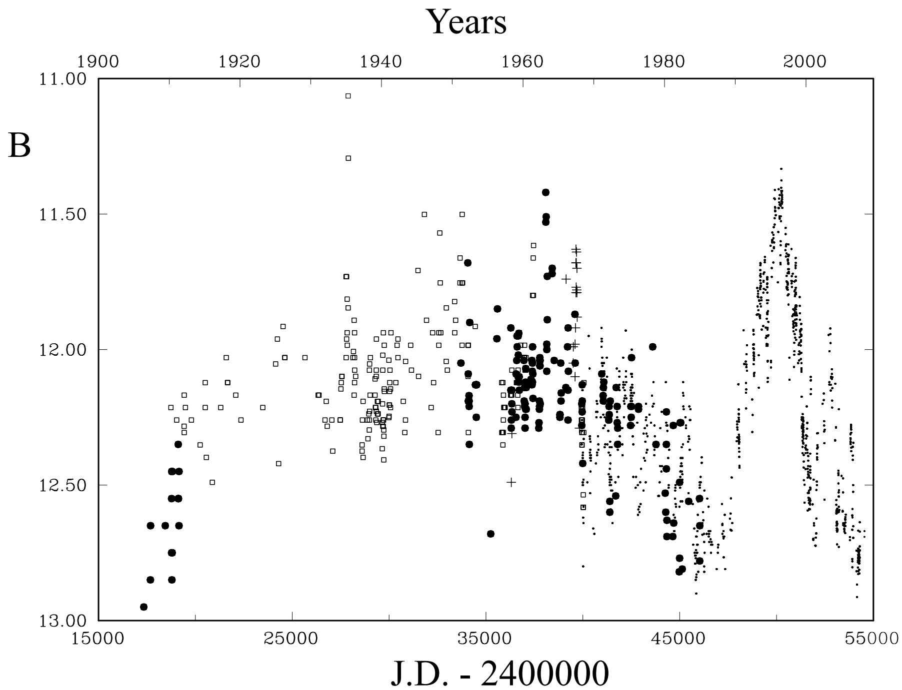

Fig. 1. The observed light curve of the NGC 4151 nucleus over 1906–2007. The dots are Lyuty's photoelectric data; crosses are photoelectric measurements before 1968; filed circles are Oknyanskij's photographic data; squares are photographic data by Pacholczyk et al.

Pacholczyk et al. (1983) (Harvard and Steward observatories' patrol plates taken in 1910–1968, about 210 measurements). All these data were reduced to a uniform photometric system. As it is clear seen in Fig. 1 there are several variability time scales (tens of days, several years, decades, and so on) in the light curve of NGC 4151. For additional references and details see Lyutyi and Oknyanskii (1981, 1987), Lyuty (2005, 2006), Oknyanskij (1978, 1983).

Applying Fourier (CLEAN) algorithm, we find a periodic component about 15.6 years (5700 days) in the 100-year light curve. 30 years ago nearly the same "period" was first revealed from Odessa photometric data (Oknyanskij, 1977, 1978).

3 Spectral variability

First spectral observations of NGC 4151 were done by Campbell and Moore (1918). Broad emission lines in the spectrum of the object were discovered by Seyfert (1943). Spectral variability of emission line H_α in NGC 4151 was discovered in 1972 (Lyutyi and Cherepashchuk, 1973). After this discovery the long-term spectral monitoring of NGC 4151 and other AGNs has been started at CrAO (Pronik and Chuvaev, 1972). See details on results of the spectrophotometrical investigations of NGC 4151 based on data by Oknyanskii, Lyutyi and Chuvaev (1984, 1991, 1994), Oknyanskii and Chuvaev (1989). Here we present variations of H_β intensity during 1972–1991 (Fig. 2) on the base of the spectral monitoring ($\sim$ 170 mean per night values for H_β intensity). This plot includes some published data of other authors as well as our published before and some unpublished data over the period 1972–1973 and 1991. As it is clear seen in the Fig. 2 variations of the line and optical continuum are very similar. Variations in the profiles of the Balmer lines were also studied. There is a strong correlation between the AGN's spectral type and brightness. The broad component of H_β was almost disappeared at the deep minimum in 1984. Additionally some transient emission components were found in the profiles (Chuvaev and Oknaynskii,

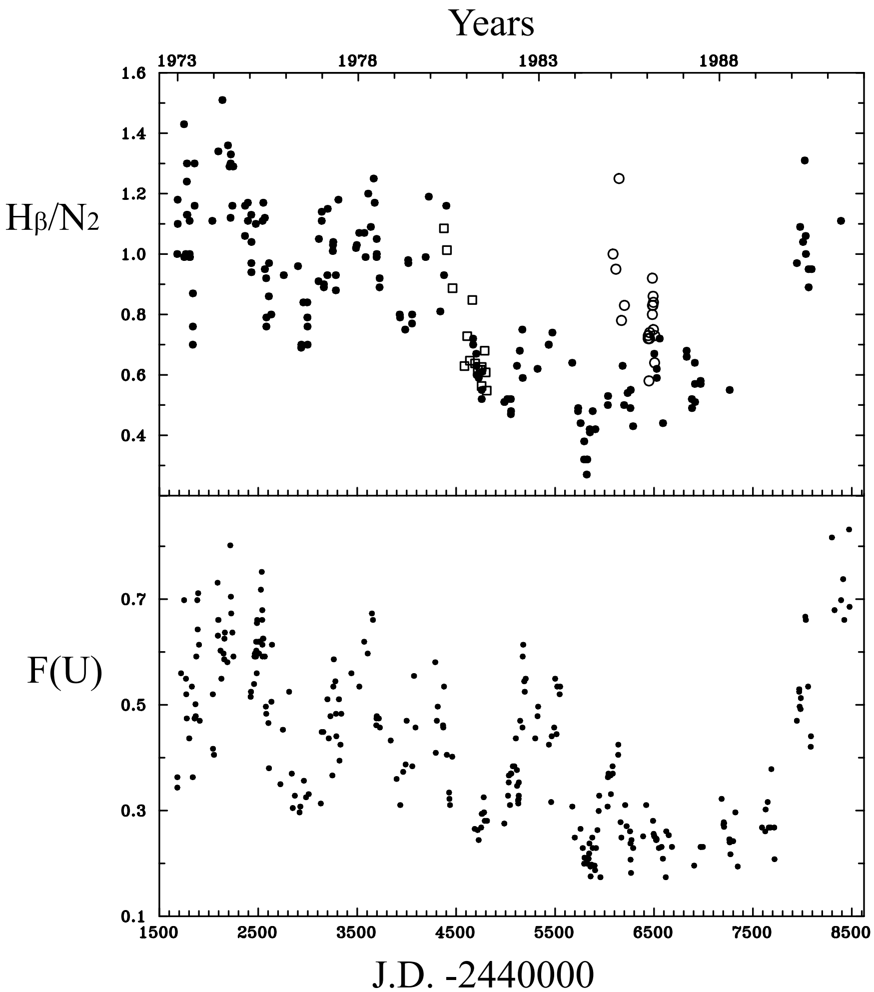

Fig. 2. The observed variations of relative intensity of H_β/N_2 over 1972–1991. Filed circles are our data; open circles – Peterson and Cota (1988); boxes – Antonucci and Cohen (1983). Bottom: Observed optical continuum light curve in relative flux, F(U) = 1 corresponds to U = 10^m

1989). The similar emission peaks in H_α and H_β profiles independently were found then by Oknyanskij and van Groningen (1997, 1999). See our results for the emission lines for the H_α spectral region (Chuvaev and Oknyanskii, 1988; Oknyanskii, Lyutyi and Chuvaev, 1991).

4 Cross-correlation analysis

We were using cross-correlation analysis to study possible time delays between H_β and optical continuum variations. See details about our method MCCF for this type analysis in case of data sets with gaps (Oknyanskii, 1993). At the start of our investigations the expected time delays for H_β and H_α were rather no less than several weeks. The results with time delays about a few days were considered as wrong and associated with some systematic errors and/or gaps in the data sets. Meanwhile some more precise spectral data gave time delay for H_β 4 ± 2 days (Oknyanskij and van Groningen, 1997) and more over the lag 0–3 days for H_β was found by Kaspi et al. (1996). This is in contrast to the past results in which a time lag of 9±2 days was found (Maoz et al., 1991). At the same time the delay for the CIV λ1549 and Mg II λ2798 lines of about 4 days was found by Clavel et al. (1990). As it was shown by Maoz

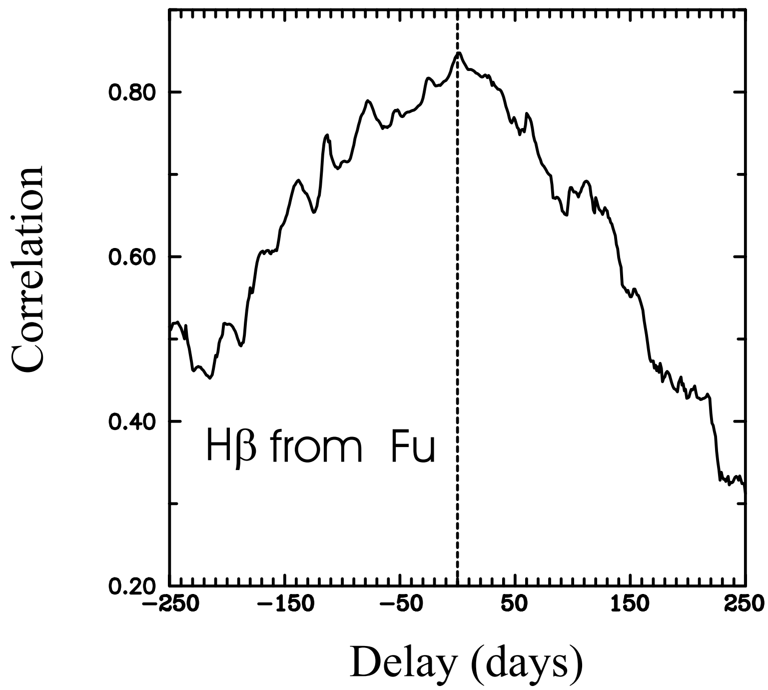

Fig. 3. Cross-correlation function for H_β and optical (U) flux variations during the high bright state of the object during 1974–1981

and Netzer (1988) obtained time delays can be much less than real size of emission line region and depend significantly on its geometry, orientation and optical continuum time scales. So our result about the very short time delay (formally 1–2 days) (Fig. 3) for H_β during 1974–1981 looks like not so surprising now. As it was found for the low state of the object during 1983–1990 (Oknyanskij, Lyutyi and Chuvaev, 1994) the time delay in H_β flux variations relative U flux was 12±5 days. The difference in time delays for these two intervals may be related to the different variability time scale of ionizing continuum or real changes in the BLR size and emission clouds distribution.

5 Conclusions

We present historical optical light curve of NGC 4151 over 1906–2007.

Applying Fourier (CLEAN algorithm) we have found periodic component 15.4 years in the 100-year light curve. 30 years ago about the same "period" was first revealed from Odessa's photometric data (Oknyanskij, 1977, 1977). 14–16-year circles seen in the light curve probably correspond to some accretion dynamic time.

We present historical spectral monitoring data (based on K.K. Chuvaev monitoring) for the period from 1972 to 1991. During this interval we found change of spectral type from Sy1.5 to Sy1.9 in 1984 when the strong minimum of continuum occurred, and then returned to the type Sy1.5.

H_β and H_α broad components and optical continuum variations are strongly correlated. The time delay value is not the same for different states of luminosity.

Forbidden lines have been found not variable with possible exclusion for coronal line [FeX].

There are transient emission features in profile of H_β and H_α broad components. This fact have been confirmed by the independent data.

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