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The variability of the broad component of the He II λ4686 line in NGC 4151

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Abstract. We present the results of the observations of NGC 4151 obtained from 1986 to 1990 with the TV scanner of the 6-meter telescope of the Special Astrophysical Observatory. Spectra averaged over periods of 2 - 3 months show changes in the asymmetry of the broad component of HeII λ4686 line over this observing period. The broad component of Hγ however does not show similar variations. We discuss the reasons which could be responsible for these observations.

Key words: galaxies: individual: NGC 4151 – galaxies: nuclei – galaxies: Seyfert

1. Introduction

The galaxy NGC 4151 is the most frequently observed object among the nearby Seyfert galaxies. Variability of NGC 4151 has been studied in various energy bands. In December 1993, when the galaxy was near the peak of its historical brightness it was monitored intensively with IUE,ROSAT,ASCA,CGRO and ground-based optical telescopes (Grenshaw et al. 1997; Kaspi at al. 1997; Warwick at al. 1997; Edelson et al. 1997). During this campaign NGC 4151 showed different scales of variability in different wave-bands. Strong variability was seen in the medium energy X-ray (1-2 keV) with weaker variations in hard X-ray (100 keV) and in the UV and optical range of the spectrum. The soft ($<$ 1 keV) X-ray showed no detectable variability. In the summary paper of this campaign (Edelson et al. 1997) the authors came to the conclusion that the reprocessing model can predict the strong observed correlation between UV and X-ray variability. However, the results of this campaign can also be interpreted in terms of UV emission from a disk which is partially illuminated by a X-ray source and also heated by internal viscosity and accretion.

Optical spectra of NGC 4151 have been obtained repeatedly over much longer periods and therefore can provide us with information about long-term variability. Indeed during 1963-65, the broad component of H_β had a red depression (Oke & Sargent,1968). In 1970, a strong blue depression took place (Anderson,1970), which started to decrease in 1974 (Boksenberg et al.,1975). In 1976-80 the line was almost constant, and in 1980-84 both wings decreased almost disappearing in May 1984 (Lyutyi et al.,1984). The wings reappeared in 1985 (Peterson, 1985). There is as yet no satisfactory explanation for the 10-15 year variations of the asymmetry of the H_β line. Similar changes, which could be caused by the evolution of the BLR over a long time- scale (years), have been observed in NGC5548 (Wanders & Peterson 1996). The analysis of other BLR lines on such long-time scale has not been attempted. Thus in spite of the multi-wave band data accumulated over the last 20-30 years, the nature of the nucleus remains poorly understood. Analysis of the variability of the profiles and intensities of different lines on long - time scale may give new and important results for understanding the structure of the nuclear region of NGC 4151.

In this paper we present the results of the optical spectral observations of NGC 4151 made at the 6m telescope of SAO. The paper is organized as follow: the observations and data reduction techniques are discussed in Sect. 2. The analysis of the variations of the profiles of the broad component of the HeII λ4686Å and Hγ lines is given in Sect. 3 and discussion of the results and conclusions are given in the Sects. 4 and 5 respectively.

2. Observations and data processing

A series of spectral observations of the nucleus of the Seyfert galaxy NGC 4151 were made with the 1024 channel TV spectral scanner of the 6-m telescope. The observations were made with a rectangular aperture of width of 1.0 arcsec and height of 4 arcsec, this corresponds to linear dimensions of 37.5 pc and 150 pc respectively (H_0 = 75 km/s Mpc) at NGC 4151.

The nucleus of the NGC 4151 was observed repeatedly between 1986 and 1990 in the spectral range 3900Å to 4950Å. The spectra were obtained with a dispersion of 1 Å/channel

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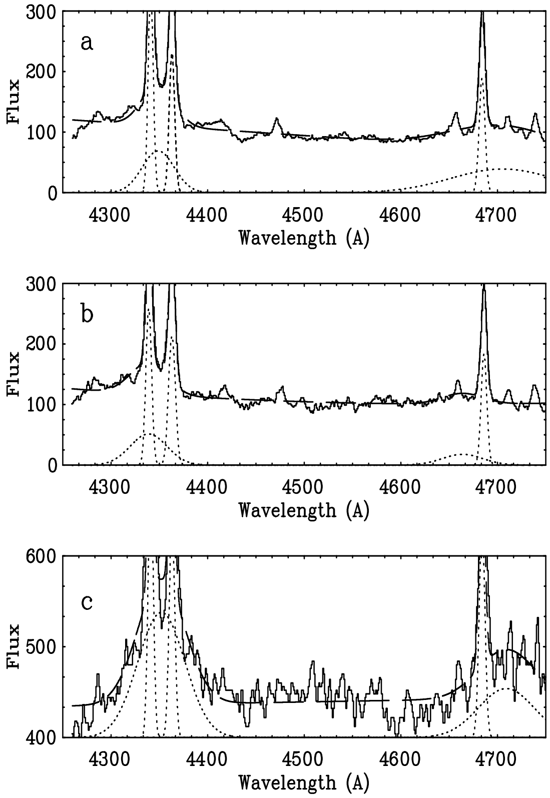

Fig. 1a–c. The mean spectra of NGC 4151 at three different epochs, **a** JD 2446521.5, **b** JD 2447221.5 and **c** JD 2447983.5. The spectrum is plotted as a histogram, the full line is the fit of Gaussians for the narrow and the broad components of Hγ and HeII line respectively. The Gaussians are shown separately in dotted lines.

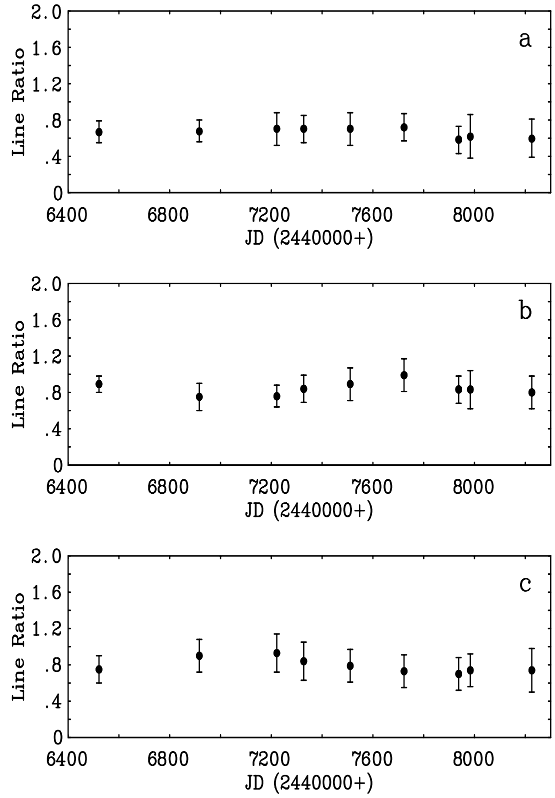

Fig. 2a–c. The variation of the flux of the narrow components, **a** HeIIλ4686/Hγ; **b** /HeIIλ4686/[OIII]λ4363 and **c** [OIII]λ4363/Hγ with 3 σ error-bar.

and a spectral resolution of ≈ 2 Å. The signal- to-noise ratio in the individual spectra is between 10-25. The exposure time was different for each spectrum as this was dictated by the seeing conditions. The average integration time of a spectrum was a few tens of minutes. In order to improve the signal-to-noise ratio of the data the spectra obtained during consecutive 2-3 month period were co-added. Unfortunately due to gaps in the observations the number of co-added spectra are different in each period. The co-added spectra were limited to 2-3 month period as over this time scale the evolution of the BLR is expected to be small. The dates of observations , the average Julian date and the number of co-added spectra (N) are given in Table 1.

The individual spectra were processed in the usual manner: flat field corrections, sky subtraction and wavelength calibration using the the Figaro software package (Shortridge 1993) and the package of data reduction developed for the 6-m telescope spectra. Differential extinction effects were also removed. The aim of this study is to investigate the profiles of the broad Hγ λ4340Å and the broad HeIIλ4686Å lines. The Hγ line is a blend of a narrow and a broad component of this line and the narrow [OIII]λ4363 line. Similarly, the HeII line is also a blend of a narrow and a broad component. In addition there are two narrow [ArIV]λ 4711,4740Å lines and an unidentified line at λ4654Å superposed on the broad component of HeII line. In order to investigate the broad components of these two lines, the blends were deconvolved with multi-component Gaussian fits using the Longslit 2D-Spec spectral analysis software (Wilkins & Axon 1992). The spectra were first shifted to the rest frame and the continuum was subtracted by fitting a first order polynomial to the line free continuum windows on either side of the two emission lines. The Hγ blend was fitted by a narrow and a broad Gaussian and a narrow Gaussian for [OIII] line. Similarly, the HeII blend was fitted by a narrow and a broad Gaussian and narrow Gaussians for the [ArIV] lines and the λ4654Å line. Both Hγ and HeII blends were fitted simultaneously and all parameters were kept free. Best-fit models were found by χ^2 minimization and the errors in the fitted parameters were taken from the fitting software. The fitting procedure returned the emission-line flux, the line FWHM and the position of the peak of the lines. The wavelength of the narrow lines was in agreement with the rest position of these lines. After the initial processing, all spectra were normalized to the intensity of the narrow component of HeIIλ 4686 line.

Three typical examples of averaged spectra are shown in Fig.1. In this figure we have also shown the Gaussian fits to the narrow and the broad components of these lines. The spectrum at JD 2447221.5 (b) illustrated the extreme blue shift of the HeII line and the spectrum at JD 2447983.5 illustrates the extreme

Table 1. The log of observations and parameters of Gaussian fit to the broad component of H_γ and HeII line.

Date	JD	N	H_γ			HeII		
			λ_P Å	FW km s^{-1}	Flux	λ_P Å	FW km s^{-1}	Flux
March-April 1986	6521.5	17	4348.8± 1.20	2690± 079	2.20± 0.2	4688.9± 1.45	5426± 331	1.25± 0.1
April-May 1987	6916.5	16	4345.3± 0.86	2453± 172	1.69± 0.3			
February-March 1988	7221.5	16	4338.0± 1.84	3097± 344	1.59± 0.2	4663.0± 2.90	3162± 478	0.42± 0.1
June 1988	7327.5	3	4344.6± 0.91	3185± 146	1.57± 0.2			
December 1988	7510.5	3	4335.0± 3.02	3744± 462	2.25± 0.3	4696.0± 2.84	4215± 784	1.32± 0.2
July 1989	7722.5	3	4344.2± 1.35	5369± 411	2.63± 0.2	4709.0± 2.58	1050± 96	0.49± 0.2
January-March1990	7937.5	13	4341.0± 0.73	4921± 170	4.64± 0.3	4710.0± 2.96	5639± 782	1.04± 0.2
April 1990	7983.5	7	4343.0± 0.92	6155± 374	5.10± 0.4	4706.0± 2.12	4420± 499	2.09± 0.2
November-December 1990	8225.5	7	4338.0± 0.83	4754± 266	4.86± 0.3	4697.5± 3.10	3860± 661	0.82± 0.2

N	The number of co-added spectra
JD	Julian date 2440000+
λ_P	Wavelength of the Gaussian peak
FW	Full Width at half maximum of the Gaussian
Flux	Line flux in arbitrary units

red shift of this line. In Table 1 the wavelength of the peak of the Gaussian, the FWHM of the Gaussian and the flux of the broad component of H_γ and HeII line respectively are given for all epochs considered here.

3. Variation of the asymmetry of the broad components lines

In order to check the accuracy of data reduction and normalization we have compared the following intensity ratios of the narrow components of lines: HeIIλ4686/Hγ; HeIIλ4686/[OIII]λ4363 and [OIII]λ4363/Hγ. The ratios for the epochs given in Table 1 are shown in Fig.1. As expected there ratios show no significant change over the 5 year monitoring period.

We parameterise the asymmetry of the broad HeII and Hγ lines by the peak wavelength of the broad Gaussian fitted to the blends. The agreement between the fitted wavelength and the rest wavelength of the narrow components gives us confidence that the observed changes in the peak wavelengths of the broad components are not an artifact of the fitting procedure. The peak wavelength and the integrated flux of the two broad components are shown in Fig.3. Significant changes have taken place in the asymmetry of the HeII line while there is only a gradual and a small change in the asymmetry of Hγ line. However, the change in the integrated line flux is exactly opposite with no significant change in the flux of HeII line but an increase by almost a factor of three in the flux of Hγ line in the period from 1986 to 1990.

4. Discussion

The photometry of NGC 4151 over the entire period covered in this study, is not available but the continuum intensity in Jan-Mar 1990 was high compared to the intensity in Mar-Apr 1986 (Oknyansky et al. 1991). Similarly, an increase in the 2-10 keV X-ray flux has been observed from 1987 to 1990 (Yaqoob et al. 1993). In addition, examination of all the low-dispersion IUE spectra of NGC 4151 shows that the intensity of the CIV line also varied during the 1988-1990 period. In November 1988 - January 1989 the intensity of the blue and red wing was similar, but in February 1990-April 1990 the red wing was stronger than the blue one (Ulrich et al.,1991). This strength of the red wing of the CIV line in February 1990-April 1990 coincides with the strength of the red wing of the HeII line detected in this study. This similarity in the shapes of broad components of these two lines, which have very different optical depth characteristics, suggests that the observed profiles of these lines are not a consequence of anisotropic emission of the lines but the clouds emitting these lines must have a similar kinematic environment. It is difficult to explain the change in the HeII line in terms of the changes in the FeII lines because the strong FeII lines are on the long-wavelength side of H_β line (Wills et al.,1985).

In the ‘standard’ model (not generally accepted) of the BLR in AGNs the ‘High Ionization Lines (HIL)’ like the HeII line, and the ‘Low Ionization Lines (LIL)’ like the Hγ line, are emitted from two different zones which also have a different geometry, the two zones are Keplerian clouds and an accretion disc respectively (Collin-Souffrin et al. 1982; Collin-Souffrin 1987; Netzer 1987;) The differences in the observed changes in the HeII line and the Hγ line may reflect the different locations in which these lines form. The reverberation mapping of NGC 4151 (Clavel et al. 1990) suggests that in this AGN the reaction time of the HIL zone (and also that of the LIL zone) to a change in the luminosity of the central engine is a few days. The long time scale of the changes described in this paper suggests either slow but sustained changes in the central engine or global changes in the population and/or the kinematics of the HIL clouds. However, the lack of significant change in the intensity of the HeII line suggests that there has been no signif-

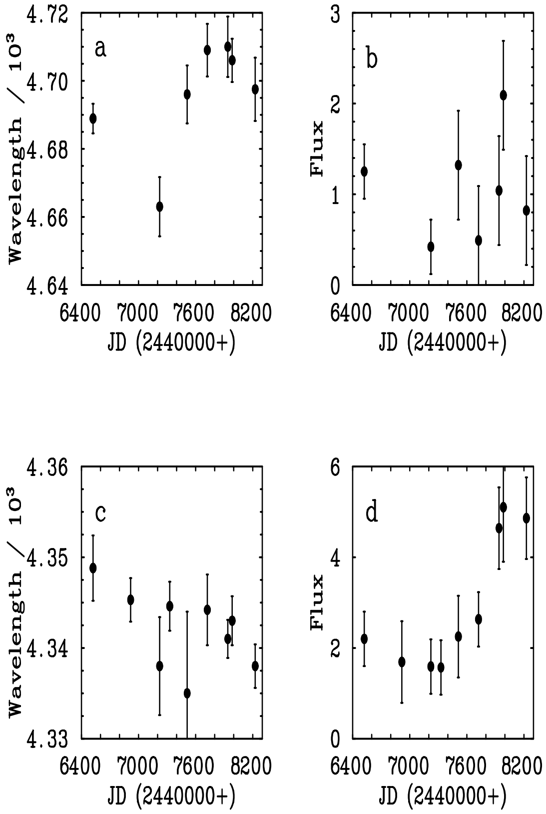

Fig. 3a–d. Central wavelengths of broad component of lines and fluxes (relative to the flux of the narrow component of HeIIλ4686 line) with 3 σ error-bar. HeII in panel **a** and **b**, H_γ line in panel **c** and **d**.

icant change in the luminosity of the central engine at energies higher than 54 eV and the observed asymmetry of this line is more likely to be a consequence of a change in the kinematics of the HIL clouds emitting this line. The lack of change in the asymmetry of Hγ line suggests little or no change in the kinematics of the LIL clouds in the disc. The small change in the intensity of this line may be a consequence of a change in the viscous dissipation in the LIL zone in the disc. Extensive modelling with self-consistent models of both the HIL and LIL zones is necessary to investigate the changes in the HeII and the Hγ lines described in this paper.

5. Conclusions

The results of the observations of the NGC 4151 obtained between 1986 and 1991 show changes in the asymmetry of broad component of HeIIλ4686 line. There is no similar change in the asymmetry of Hγ line during this period. The change in the asymmetry of the HeII line is qualitatively similar to the change in the profile of the CIV line. It seems possible that the variations of the broad component of HeII line and nearly stable asymmetry of the broad component of Hγ during this period is a reflection of the long-term variations in the kinematics of the clouds in the HIL zone of the BLR of NGC 4151.

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