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On spectral and photometric variability of the polar AN Ursae Majoris

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Abstract. We report the results of synchronous spectral and photometric observations of the AM Her–type system AN UMa made during an intermediate state of brightness ($16\overset{\rm m}{.}0 - 16\overset{\rm m}{.}5$) in March, 1991 and by an order of magnitude lower ($17\overset{\rm m}{.}0 - 17\overset{\rm m}{.}5$) in January, 1992 with the TV scanner and the photometer NEPh at the secondary focus of the 6 m telescope of the Special Astrophysical Observatory RAS. From 100 spectra with an average time resolution of 300 s, and a spectral resolution of ≈ 2 Å, in a wavelength range of ≈ 4000 – 5000 ÅÅ the variation of equivalent widths, profiles, halfwidths and radial velocities of emission hydrogen and HeII 4686 Å lines with phase of the orbital period was traced. The presence of significant variations of the parameters of spectral lines and of the system brightness in the B filter at times of 5–20 minutes ($\delta T = 12$ min) is shown. Significant variations of equivalent widths and HeII 4686 Å line intensity with orbital phase are revealed, depending on the photometric state of AN UMa. The strongest variations turned out the spectral variations in the emission lines around or at the phases of the main and secondary minima in the light curve of the system. We detected a difference in the behaviour of emission lines in different secondary photometric minima. Possible reasons of the detected spectral and photometric variability are discussed.

Key words: accretion – stars: individual: AN UMa – stars: binaries: general – stars: cataclysmic variables – X-rays: stars

1. Introduction

The AM Herculis-type stars (polars) are a subclass of cataclysmic variables which contain a synchronously rotating magnetized white dwarf (WD) with the magnetic field strength ($B \approx 10 - 230$ MG) which accretes matter from a low-mass companion. The matter emerging from the secondary to the main component does not form an accretion disk around it. A strong magnetic field of the main component prevents the formation of such an accretion disk, controls the gas motion and transfers it to the magnetic poles of the WD. In the polar regions of WD, energy release is caused by the process of accretion. The spectral region of the released energy is very wide: from hard X-ray to far infrared region. One of the most important features of polars is a great value of intrinsic linear and circular polarization of their optical radiation (Tapia, 1977a). Details about these systems can be found in the surveys of their observational data (Cropper, 1990; Vojkhanskaya, 1990; Chanmugam, 1992).

As a polar, AN Ursae Majoris was discovered in February, 1977 by Krzeminski and Serkowski (1977 a,b), who found record for that time circular (from 9 to 35%) and linear (from 0 to 11%) polarizations of optical radiation, which changed their values with a period equal to the orbital period ≈ 1.9 hours.

The magnetic field of AN UMa turned out to be very large ($B = 35.8 \pm 1.0$ MG) and it was measured from cyclotron bands in the spectrum of the system (Cropper et al., 1988).

Information about polarization observations of AN UMa is presented in the papers by Krzeminski, Serkowski (1977a,b); Efimov and Shakhovskoy (1981); Downes, Urbanski (1978); Liebert et al. (1982). The linear polarization has a sharp and wide peak at the moment of maximum on the light curves. The height of the peak is ≈ 10%, whereas the width is ≈ 0.2 P. Outside the peaks the polarization is 1-2%. Occasionally there appear secondary peaks up to 4-5% (Efimov, Shakhovskoy, 1981). The circular polarization is negative during the whole period. It reaches a maximum value at the moment of minimum on the light curves and minimum of linear polarization. As the brightness dropped to 19^m, the circular polarization curve did not change, but its amplitude increased two times (Liebert et al., 1982).

The system was observed in the ultraviolet range as well (Szkody et al., 1988; Mukai et al., 1993). Weak and variable emission lines CIV and HeII were present in the spectrum.

The light curves in the soft X-ray range obtained in different years are markedly different (Hearn, Marshall, 1979; Szkody et al., 1981; Osborne, 1987; Ramsay, Mason, 1994).

Information about spectral observations in different states of the system is given in the papers by Bond, Tifft (1974); Tapia (1977b); Greenstein et al. (1977); Liebert et al. (1982); Schneider, Young (1980); Williams, 1983; Vojkhanskaya (1986); Szkody et al. (1988); Bonnet-Bidaud et al. (1996). The brightness of AN UMa decreased in 1979 to 19^m and its spectrum changed much (Liebert et al., 1982). However neither absorption of the secondary component nor Zeeman absorption were revealed in the spectrum.

In the present paper we give the results of synchronous spectral and photometrical observations of AN UMa done with the 6 m telescope with the aim of obtaining additional data on the spectral variability of the star depending on the state of its brightness. We present in the paper the results of investigation of variability of profiles, equivalent widths W_λ, central intensities R_c, halfwidths of emission lines and radial velocities of narrow and broad components of hydrogen lines and HeII 4686 Å with phase of the orbital period and analysis of the revealed spectral (long-term and rapid) variability depending on the photometric state of the system. The use of the photometric complex at the Nasmyth 1 focus has made it possible to study the properties of sufficiently short-term photometric and spectral variations of this object and come to understanding of the mechanisms of this variability. This paper is the continuation of a series of the already available papers on the investigation of this fascinating object (Bonnet-Bidaud et al., 1992; 1996).

2. Observations

The synchronous spectral and photometric observations of the polar AN UMa were carried out with the 6 m telescope in March, 1991 and January, 1992. The spectral observations were made with the 1000-channel television spectrophotometer (Somova et al., 1982; Drabek et al., 1986) placed at the secondary focus Nasmyth 1 of the 6 m telescope on the spectrograph SP-124 (Gusev et al., 1976; Afanasiev et al., 1991). The employed diffraction grating (1200 gr/mm, with a dispersion of 50 Å/mm and a spectral resolution of ≈ 2 Å)) recorded the spectra in the wavelength range 4000–5000 Å. The aperture of the diaphragm on the spectrograph was chosen to be 2″. The recording of information was performed in the frame-by-frame mode (Somov, 1988). The photometric measurements were made with the NEPh photometer installed also at the Nasmyth 1 focus of the 6 m telescope (Vikuliev et al., 1991). When obtaining the light curve in the B filter with a time resolution of 0.1 s, 50% of the star light was sent to the photometer, the other half of the light was fed to the scanner for spectral investigation. The photometer diaphragm was 12″. The photometric measurements were made with the aid of the standard stars 1136+486 N1 and Q0957 N2 (Neizvestny, 1995).

Table 1: *Log of the photometric and spectroscopic observations*

Date	Spectroscopy		Photometry		B
	Start (UT)	End (UT)	Start (UT)	End (UT)	
10.03.91	22:28	23:32	22.18	00.40	16.5
	23:36	00:50			
	01:44	02:33			
11.03.91	16:38	17:51	16.47	19.50	16.2
	17:55	19:10			
	19:14	20:04			
28.01.92	21:15	22:20	21.14	23.25	17.2
	22:26	22:31			
	22:42	23:22			
	00:33	01:46			

The log of observations is presented in Table 1, where the mean light values of the system on different nights are also indicated. The orbital phases quoted in this paper were computed using the new ephemeris derived by Bonnet-Bidaud et al. (1996): $T_o(HJD) = 2443190.9921(\pm2) + 0.07975282(\pm4)E$.

The phase $\phi = 0.0$ corresponds to the maximum of linear polarization. The wavelengths of spectra were calibrated using a He–Ar–Ne lamp. The programs of data reduction were written in the algorithmic language SIPRAN (Somov, 1986).

3. Results

3.1. The general view of the spectrum and the orbital light curves

The average spectrum of the polar AN UMa of March 10, 1991 is displayed in Fig. 1a. The spectrum is seen to be represented, as it is typical of AM Her systems, in high brightness state by emission lines of hydrogen, HeII 4686 Å, HeI, the blend of lines CIII–NIII 4640–4650 Å. As in other polars the emission lines have a narrow and broad components superimposed on each other. The form of the spectrum of March 11, 1991 is only slightly different from the spectrum presented in Fig. 1a.

Fig. 1b presents the summed spectrum of AN UMa taken on January 28 1992. Comparison of the spectra depicted in Fig. 1a,b points out that the form of the spectrum has changed. In the spectrum of January 28, 1992 a number of lines are absent: the blend CIII–NIII 4640–4650 Å, weak lines HeII and CII 4667 Å. For comparison in Table 2 are presented the average spectrophotometrical parameters of the emission lines on three nights.

Fig. 2 shows the light curves of AN UMa after the reduction performed (sky background subtraction and correction for extinction) for the three dates of our observations (Bonnet-Bidaud et al., 1996). The conversion from counts to values was executed using the UBVR corrections. Our measurement accuracy proved to be about $0\overset{\rm m}{.}1$.

In 1991 March the object was in the intermediate state of activity. The average B magnitude was $16\overset{\rm m}{.}2$–$16\overset{\rm m}{.}5$. In January 1992, the object was by a magnitude fainter and was likely to be around the low state.

Light variations of AN UMa with the orbital period are clearly seen on all nights of our observations (see Fig. 2). A wide dip of $0\overset{\rm m}{.}6$ lasts about half the period (in the phase interval 0.25–0.75). Krzeminski and Serkowski (1977a,b); Imamura and Steiman-Cameron (1986); Liebert et al. (1982) also pointed to the complexity of the AN UMa light curves. Our light curves (Fig. 2) show stable features at phases $\approx 0.25 - 0.3$ and $\approx 0.7 - 0.75$.

3.2. Line profiles

For studying the rapid variability of spectral lines at times of minutes — tens of minutes, we analyzed the spectra with an exposure of 300 s. In so doing, 28 spectra were taken on March 10, 1991, 36 spectra on March 11, 1991, and 35 ones on January 28, 1992. As to the way of recording and processing, all these data are homogeneous. Examining the spectra we see that the profiles of all lines show strong variations. The line profiles of AN UMa in individual spectra are nonsymmetric and they vary with phase of the orbital period. On March 10, 1991 all emission lines disappeared for 10 minutes in the range of phases from 2.67 to 2.80. This range of phases coincides with the secondary minimum of the system light. On March 10, 1991 around phases 1.69–1.99, the line HeII 4686 Å had two components.

For illustration, in Fig. 3 are presented the Hβ, Hγ, and HeII 4686 Å emission line profiles as a function of the orbital period phase on January 28, 1991. It can be seen from the figure that on a time scale of 5 minutes at phase 2.71 the line HeII 4686 Å becomes two-component; a new component appeared and the old line component remained, which was strong at phase 2.67. One can estimate the lifetime of the new component at 15 minutes. Note that the activity of AN UMa in this period was low ($\approx 17\overset{\rm m}{.}5$).

Table 2: *Mean spectrophotometric parameters of emission lines during a night*

Date	Line	EW (Å)	R_c	FWHM (Å)
10.03.91	$H\beta$	19(1)	1.7(0.1)	15(1)
	HeII 4686	18(0.8)	2.0(0.1)	14(1)
	HeI 4471	10(0.8)	0.9(0.05)	15(1)
	$H\gamma$	20(1)	1.9(0.09)	10(0.7)
	$H\delta$	27(1)	1.9(0.09)	12(1)
	HeI 4921	2(0.5)	0.5(0.04)	4(0.5)
11.03.91	$H\beta$	15(1.0)	1.6 (0.1)	11(0.7)
	HeII 4686	17(0.8)	1.8 (0.1)	10(0.6)
	HeI 4471	9(0.4)	0.9 (0.04)	13(0.9)
	$H\gamma$	18(0.8)	1.7 (0.07)	10(0.6)
	$H\delta$	21(1.0)	1.5 (0.06)	11(0.7)
28.01.92	$H\beta$	21.0(1)	1.7(0.1)	11(0.5)
	HeII 4686	15.0(0.6)	1.4(0.06)	10(0.6)
	HeI 4471	3.7(0.3)	0.5(0.03)	11(1.1)
	$H\gamma$	17.0(1.0)	1.6(0.07)	10(0.6)
	$H\delta$	11.6(0.5)	0.9(0.04)	11(1.0)
	HeI 4921	2.0(0.5)	0.3(0.02)	6(0.5)

3.3. Phase variations of equivalent widths and halfwidths of emission lines

To study spectral variations of emission lines during the orbital period, we used the same spectra with 300 s exposures. We have studied in the present paper the behaviour of the Balmer lines (Hβ, Hγ) and HeII 4686 Å as a whole without dividing them into separate components. We measured their equivalent widths W_λ, central intensities R_c, line widths at half-intensity (FWHM). The technique of measurement of these parameters is described in the paper by Kopylov et al. (1986). Typical errors of determination of the emission line parameters are also presented therein. The measurement errors of the equivalent widths of the lines with $W_\lambda \approx 20$ Å are $\approx 5\%$, for the central depths of lines $R_c \approx 5\%$ and $\approx 4\%$ for the halfwidths of lines. The errors for weaker lines can be about 10-15%.

We display in Fig. 4 the W_λ variations for the Balmer lines and HeII 4686 Å for March 11, 1991 and January 28, 1992 depending on the orbital period phase. It is seen from this figure that the equivalent widths of the emission lines change their values. These curves have different appearance for different dates of our observations. On March 11, 1991 the maxima of curves $W_\lambda - \phi$ fall at phases ≈ 0.7 and ≈ 1.2 (Fig. 4a,b). On January 28, 1992 the maximum values on the curves $W_\lambda - \phi$ for the Balmer

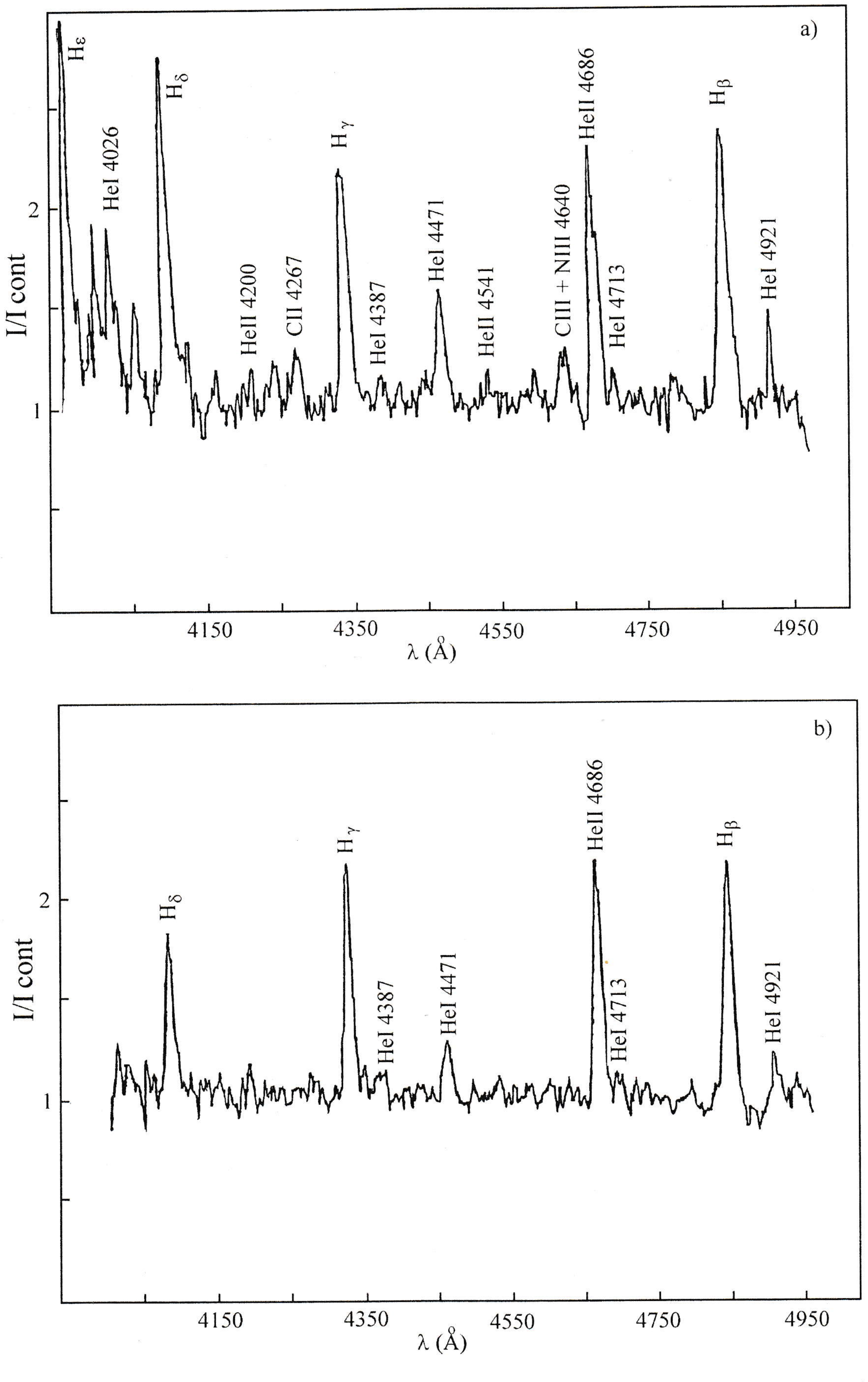

Figure 1: *The average spectrum of AN UMa obtained on March 10, 1991(a), on January 28, 1992 (b) and normalized to the continuous spectrum.*

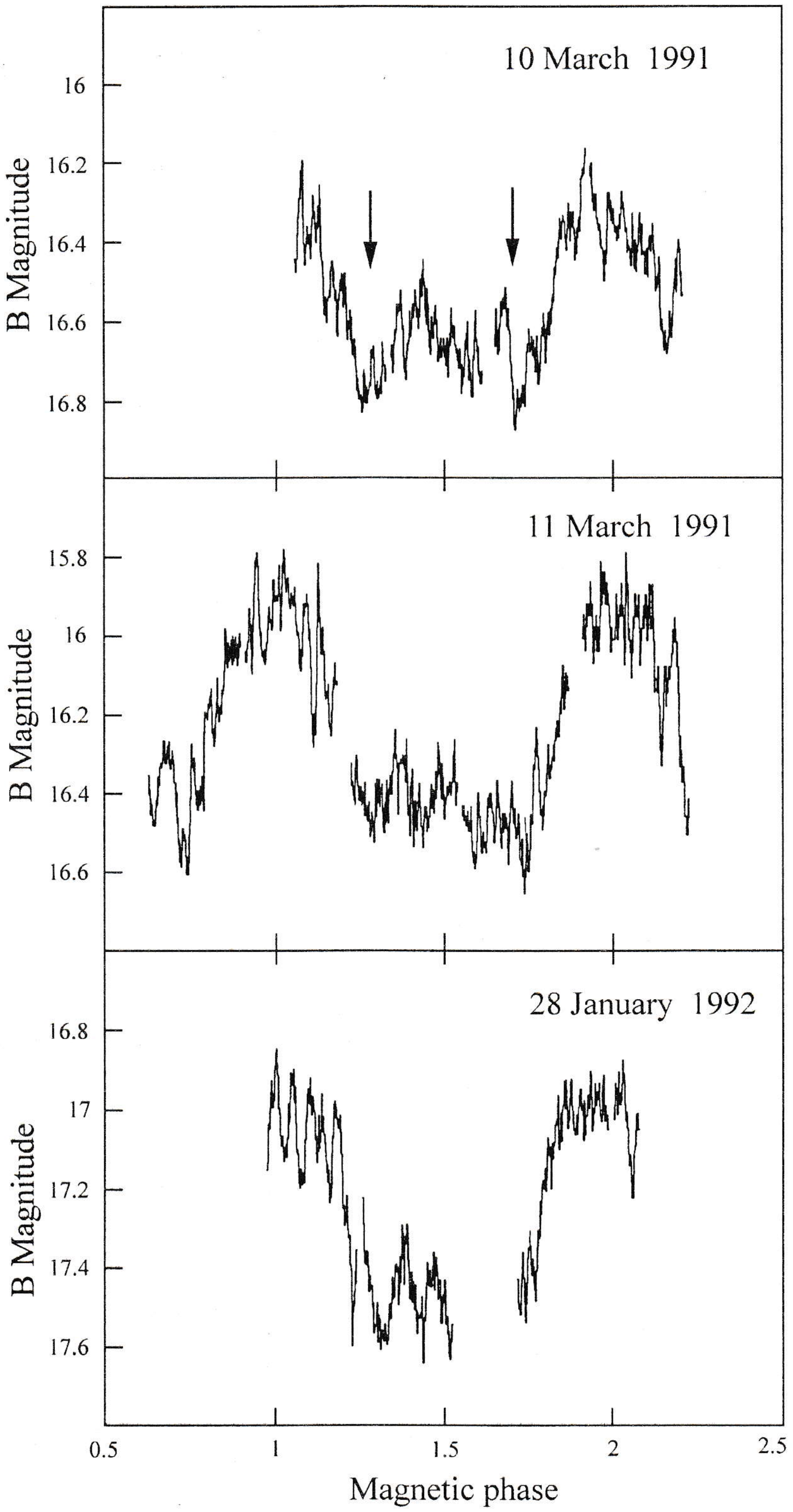

Figure 2: *The light curves of AN UMa in the B filter. The arrows indicate the photometric minima of the system* (≈ 0.25 − 0.3 — *main minimum, and* ≈ 0.7 − 0.75 — *secondary minimum.*

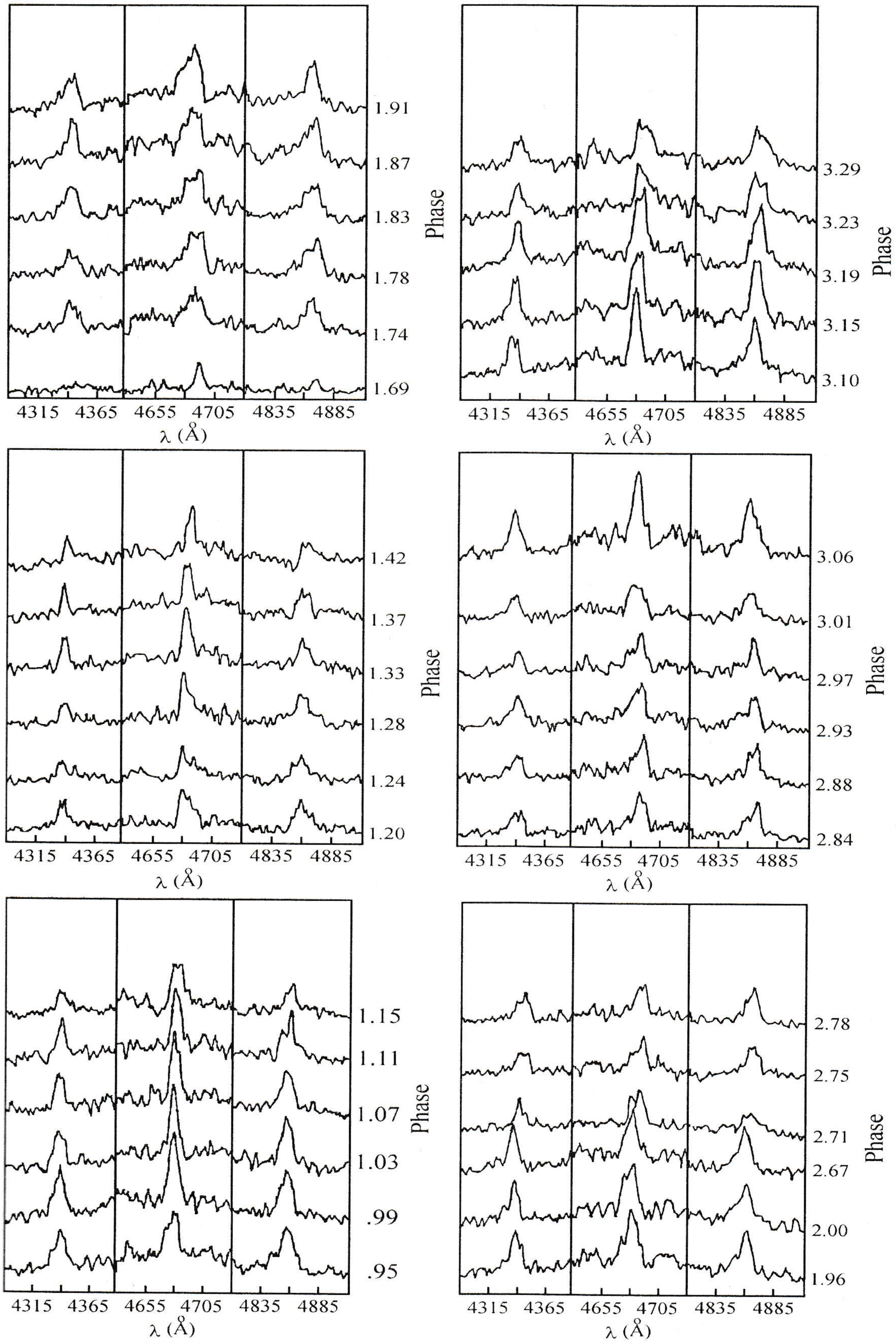

Figure 3: *The profiles of* Hβ, Hγ *and HeII 4686 Å (in intensities). The spectra are obtained on January 28, 1992. Magnetic phases are plotted on the Y-axis.*

lines are also at phases ≈ 0.7 and ≈ 1.2 (Fig. 4c), and the equivalent width of HeII remained practically unchanged (Fig. 4d). In this period the brightness state of the system was low ($17\overset{\rm m}{.}0 - 17\overset{\rm m}{.}5$). In the intermediate brightness state ($16\overset{\rm m}{.}0 - 16\overset{\rm m}{.}5$) W_λ of HeI changed strongly with phase of the orbital period and have two maxima at phases 0.7 and 1.2, the same as for the Balmer lines (Fig. 4a). Fig. 4 reveals great distinctions of the shapes of the curves from period to period during the night, and due to the brightness level of the system.

Fig. 5 displays the variations of the halfwidths of the lines Hβ, Hγ and HeII 4686 Å over 1991 March and January 28, 1992. It follows from Fig. 5 (b,c) that the maxima of the halfwidth of the Balmer lines Hβ and Hγ on March 11, 1991 fall at phases 0.7–0.8 and 0.2–0.3. The behaviour of the Hγ line halfwidth correlates basically with that of the Hβ halfwidth, some differences, however, can be seen. The maxima of the HeII 4686 Å line halfwidth fall also at phases 0.7–0.8 and 1.2–1.3 (Fig. 5a,f) on March 10, 1991.

3.4. Radial velocities

The true position of the regions of formation of emission lines in polars has been the subject of discussion until the present time. In the papers of many authors it was shown that the narrow peak and the wide base represent different regions of formation. The complex and variable line profiles observed in AN UMa largely impede analysis of velocities. In this paper the radial velocities of emission lines are measured from the center of gravity and the line peak. The resulting accuracy of determination of radial velocities is ±20 km/s. For weak lines this error may be twice as large. The data obtained were approximated by the least squares method of the curve of the form

$$V(\phi) = K \sin(2\pi(\phi - \phi_0)) + \gamma, \qquad (1)$$

where V is the radial velocity, γ is the gamma-velocity, ϕ is the orbital period phase (Bonnet-Bidaud et al., 1996), ϕ_0 is the cross phase of the sinusoid with the gamma-velocity when passing from the negative values of the velocity to the positive ones, K is the half-amplitude of the radial velocity curve.

The results of measurements of the radial velocity curve parameters for some emission lines are presented in Table 3, their errors are given in brackets. The parameter σ is equal to the root mean square deviation in km/s of all measurements from the sinusoid. The procedure of radial velocity measurements is noted: CGR — from the centre of gravity, peak — from the line peak. It is seen from Table 3 that the line HeII 4686 Å has the minimal error of deviation from the sinusoid on January 28, 1992.

It is clear from Table 3 that the difference of phases between the values of the radial velocity curves plotted from the broad components and from the line peaks was on the average (0.12 ± 0.01) P.

Sufficiently large scatter of points is seen on the radial velocity curves, measured from the line peaks. Vojkhanskaya (1986) has noted some deviations in radial velocity curves from the line peaks. Our data show strong deviations from the sinusoid in the vicinity of the main and secondary minima of the brightness curve of the system, near phase 0.

4. Analysis of results. Discussion

We have investigated AN UMA in two brightness states: the intermediate state of light ($16\overset{\rm m}{.}0 - 16\overset{\rm m}{.}5$) on March 10 and 11, 1991 and in a brightness state close to the low state ($17\overset{\rm m}{.}0 - 17\overset{\rm m}{.}5$) on January 28, 1992. The two different levels of the mean optical brightness state of AN UMa may be interpreted on the assumption that the accretion rate of matter onto the magnetic white dwarf is variable. Our studies have shown that AN UMa is a nonstationary object. This follows from the light curves in the B filter (Fig. 2), from the analysis of the emission line profiles in spectra with sufficiently high time resolution (300 s).

Efimov and Shakhovskoy (1981) pointed out that in spite of rather complex character of the light curves of AN UMa they have stable details indicating the drop in the star brightness in the phase interval 0.3–0.4 (main minimum) and around phase 0.8 (secondary minimum), which is consistent with the results of observations of Krzeminski and Serkowski (1977b). On our light curves (Fig. 2) one can clearly see stable details at phases 0.25-0.3 and ≈ 0.7 – 0.75. In all probability, these are the main and the secondary minima of the system brightness. On March 10, 1991 we detected a shift by 0.05–0.1 P of the position of the minima of the system brightness in comparison with the data interpreted previously. Besides, a phase shift of location of the secondary minimum of the light curve by 0.05 P from night to night is observed in March 1991 (Fig. 2). In the review of the observational data for systems of AM Her type (Vojkhanskaya, 1990) it was noted that the AN UMa light curves are unstable.

Maximum spectral variations occur just near the phases of photometric minima (variations of the line profiles, equivalent widths and halfwidths). It is seen from Fig. 4 that the emission line equivalent widths reach a maximum twice during the orbital period and are located near phases 0.7, 1.2, 1.7 and 2.2, i.e. the equivalent widths of all the lines increase at the moment of the secondary minimum of the light curve (phase 0.7) and close to the main minimum (0.25–0.3). The equivalent widths reach a minimum two times (≈ 0.9 – 1.0 and ≈ 0.4 – 0.5) which is close to the phase of maximum linear and circular polarization.

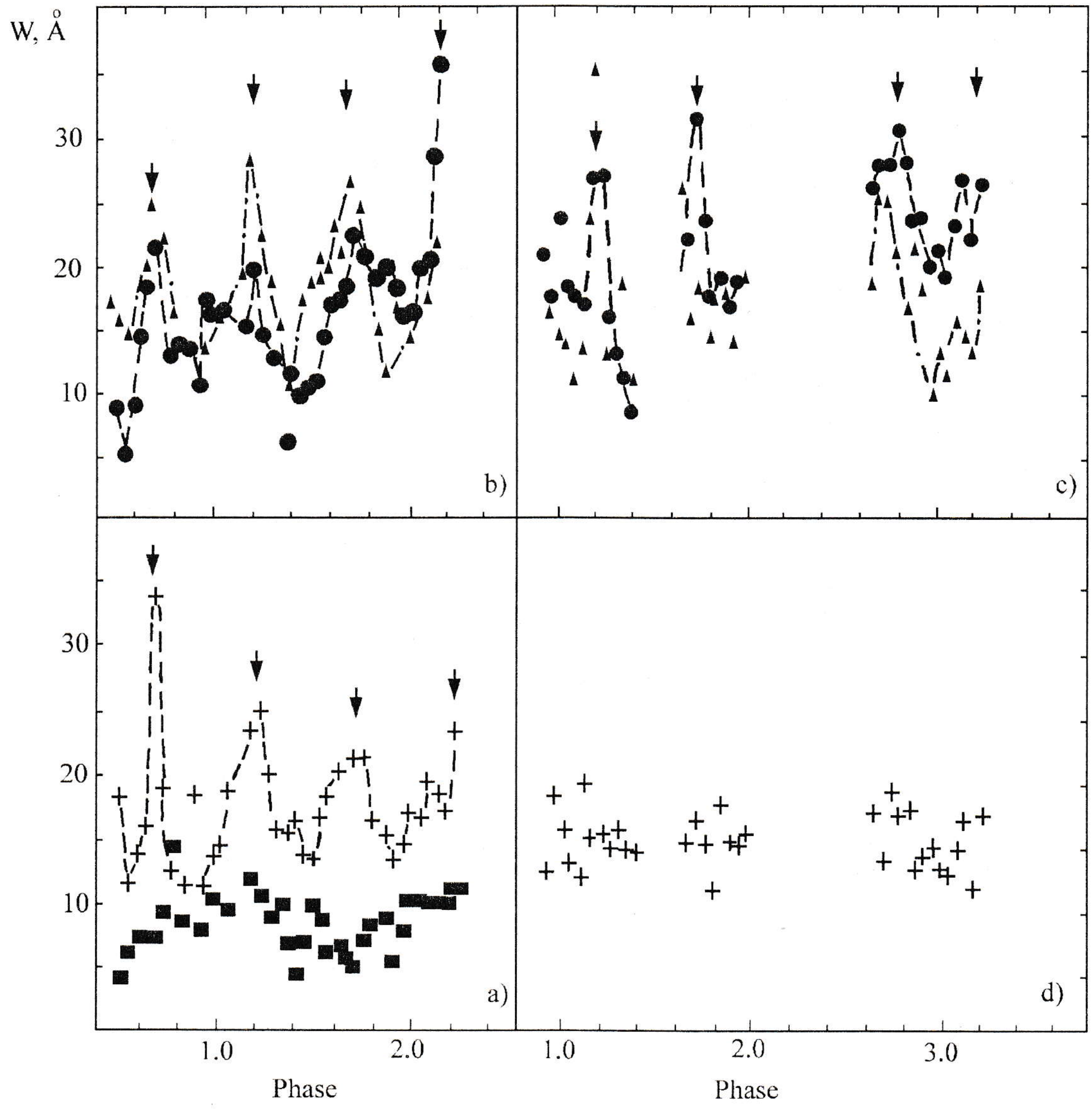

Figure 4: *a–d: The curves of the behaviour of equivalent widths of emission lines during the orbital cycle. (a) for the line HeII 4686 Å and HeI 4471 Å of March 11, 1991; (b) for* $H\gamma$ *and* $H\beta$ *of March 11, 1991; (c) for* $H\gamma$ *and* $H\beta$ *of January 28 1992; (d) for HeII 4686 Å of January 28, 1992. Filled circles -* $H\beta$*, triangles -* $H\gamma$*, crosses - HeII 4686 Å , squares - HeI 4471 Å. The errows indicate the maximum values in the curves.*

The results of synchronous spectral and photometric observations of AN UMa show the presence of significant rapid variations of parameters W_λ, R_c, FWHM and brightness of the system in the filter B at times 5–20 minutes ($\bar{\Delta T} = 12$ min). As it is mentioned above the spectral variations are especially strong near minima on the light curve. For instance, on March 10, 1991 the emission lines $H\beta$, $H\gamma$ and HeII 4686 Å diappeared for 10 minutes in the range of phases 2.76–2.80. The disappearance of the lines cannot be caused by the eclipse in the system since the system is not eclipsing. It may be due to obscuration of the accretion stream by the white dwarf itself, and probably due to the ifluence of the circumstellar matter ejected from the system as a nonhomogeneous wide shell (Vojkhanskaya and Gnedin, 1991). On January 28, 1992 the continuous spectrum weakened greatly at phase 1.69. On the same date, at phase 2.71 the line $H\beta$ became low-contrast and broad. It is likely that on this date in the secondary minimum the regions of formation of the line peaks and of the continuous spectrum are occulted.

Thus we have found a difference in the behaviour of emission lines in photometric minima of different periods (from obscuration of the continuous spectrum and emission line peaks to disappearance of emission lines in the spectrum).

On January 28, 1992 the HeII 4686 Å equivalent

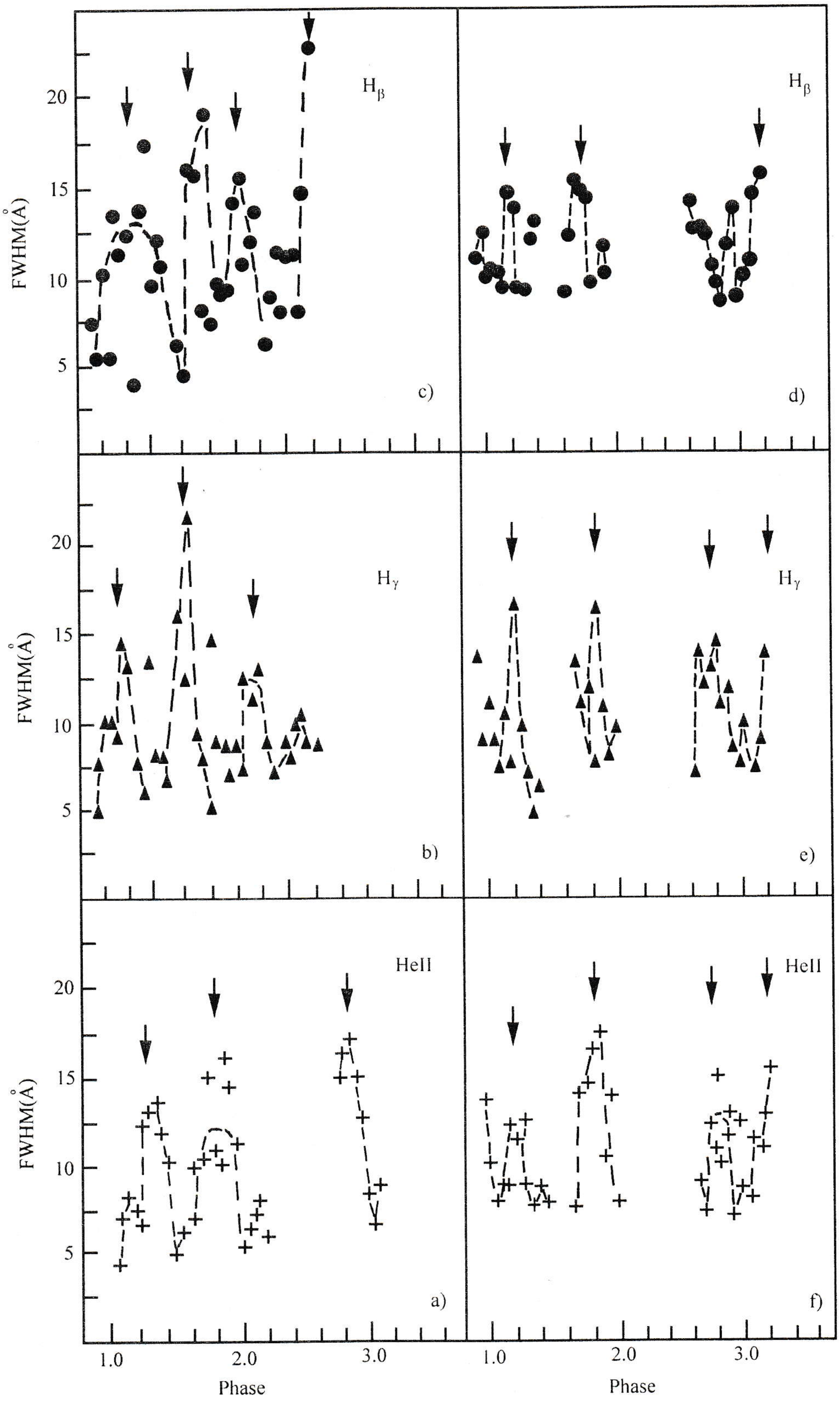

Figure 5: *a–f: The curves of variation of halfwidths of emission lines with phase of the orbital period. The arrows indicate the maximum values. (a) for HeII 4686 Å of March 10 , 1991; (b) for Hγ of March 11, 1991; (c) for Hβ of March 11, 1991; (d) for Hβ of January 28, 1992; (e) for Hγ of January 28, 1992; (f) for HeII 4686 Å of January 28, 1992. Crosses — HeII 4686 Å, triangles — Hγ, the filled circles — Hβ.*

Table 3: *Radial velocity sinusoidal parameters of the* $H\beta$, $H\gamma$ *and HeII 4686 Å line components*

Date	Line	$K(km/s)$	$\gamma(km/s)$	ϕ_0 J.M.B.B.	$\sigma(km/s)$
10.03.91	$H\beta$ CGR	268(26)	-13(21)	0.31 (.02)	105
	$H\beta$ peak	251(29)	62(24)	0.44 (.02)	121
	HeII 4686 CGR	322(16)	-107(13)	0.30 (.01)	64
	HeII 4686 peak	311(21)	-91(17)	0.43 (.01)	85
	$H\gamma$ CGR	325(19)	87(15)	0.29 (.01)	75
	$H\gamma$ peak	247(34)	2(29)	0.46 (.02)	142
11.03.91	$H\beta$ CGR	326(27)	-61(22)	0.31(.01)	111
	$H\beta$ peak	249(35)	56(29)	0.38(.02)	146
	HeII 4686 CGR	346(19)	-132(16)	0.31(.01)	80
	HeII 4686 peak	398(33)	-176(28)	0.38(.01)	139
	$H\gamma$ CGR	313(34)	74(28)	0.30(.02)	141
	$H\gamma$ peak	139(32)	106(27)	0.41(.04)	134
28.01.92	$H\beta$ CGR	205(23)	-38 (18)	0.36(.02)	88
	$H\beta$ peak	252(35)	-12(28)	0.47(.02)	141
	HeII 4686 CGR	274(16)	-103(12)	0.31(.01)	61
	HeII 4686 peak	330(30)	-123(23)	0.41(.01)	116
	$H\gamma$ CGR	284(27)	77(21)	0.27(.02)	106
	$H\gamma$ peak	168(31)	9(23)	0.41(.03)	118

width changed only slightly with phase of the orbital period and, on the average, is equal to 14 Å. It does not replicate the behaviour of HeII 4686 Å in the spectra of 1991. In contrast to this line, the behaviour of the equivalent widths of Hβ and Hγ on January 28, 1992 is consistent with that on March 11, 1991, and the maximum of the equivalent width for them is located also close to phases 0.7 and 0.2.

Different character of equivalent width variations during different orbital periods indicates that the quantity of line emitting matter, its distribution in space, and the degree of its excitation are time variable. This may suggest that the rate of accretion of matter in the system is variable. Attention to this fact was given by Vojkhanskaya (1986).

The emission line profiles show a complex structure and strong variability with phase of the orbital period. The bifurcation of the line HeII 4686 Å on January 28, 1992 is clearly observable at phases 2.71–2.78 on a time scale of 10 minutes. On a time scale of 5 minutes the line becomes two-component; a new component appears, and the line which is strong enough at phase 2.67 remains. A nonstationary accretion of matter in AN UMa, especially in the intermediate and low states of the system brightness, may be a mechanism of this kind of spectral variability. The blob model of accretion in polars becomes popular (Kuijpers, Pringle, 1982; Frank et al., 1988; Frank et al., 1992; King, 2000). It is known from the literature (Beardmore, Osborne, 1997) that from the variability of the flux in the X-ray and optical ranges at times of 70 s the parameters of the condensations (blobs) of accreted gas for the polar AM Her were determined: the length of the blob is $\approx 10^{10}$ cm, the radius is $6 \cdot 10^5 - 4 \cdot 10^6$ cm and the mass is $\approx 10^{16}$ g. These parameters are likely to be applicable to the gas blobs in the plasma of AN UMa.

From the data of Ferrario et al. (1989); Ferrario, Wickramasinghe (1990); Somova, Somov (1992), it was discovered in the polars that with one-pole accretion the halfwidths of emission lines vary with phase of the orbital period, having two maxima. It is seen from Fig. 5 that all the lines examined become the broadest in the time intervals coincident in phase with the minima on the light curves (main and secondary). It follows from the analysis of the halfwidths of lines in the case of AN UMa that accretion of matter is likely to occur in a similar manner.

Efimov and Shakhovskoj (1982) have shown that at AN UMA rotation only one magnetic pole is seen. The mean halfwidth of the emission Balmer lines on March 10, 1991 proved to be the largest, $\approx$ 900 km/s. Whereas on March 11, 1991 and January 28, 1992 the lines were narrower, $\approx$ 700 km/s. The difference of the profile halfwidths of the spectral lines on different dates may be associated with the fact that in the system AN UMa the power of the jet of the accreted matter varies.

The modeling of variations of radial velocities of narrow and broad emission line components has allowed the system parameters to be limited. The best solution was obtained for a white dwarf with a low mass ($M_{wd} = 0.4 - 0.6 M_{\odot}$), the inclination angle $i = 40^\circ - 60^\circ$, and the angle between the magnetic axis and the perpendicular to the orbital plane $\Theta_d = 25^\circ - 45^\circ$ (Bonnet-Bidaud et al., 1996).

5. Conclusions

As a result of the work done, the following has been discovered:

- there are considerable variations in Balmer and helium lines depending on the orbital period phase from period to period during a night, from night to night and depending on the state of brightness of the system. The phases at which the maxima of equivalent widths and central intensities fall are 0.2 and 0.7, which corresponds to the moment of the secondary minimum of brightness (phase 0.7) and close to the main minimum of brightness (0.25–0.3). Two minima of the equivalent widths are located near $\approx 0.4 - 0.5$ and $\approx 0.9 - 1.0$, which coincides or is close to the maximum of the circular and linear polarizations;
- dissimilar behaviour of the emission lines in the secondary minima of different periods has been revealed: from complete disappearance of all emission lines to eclipse of only peaks of emission lines and of the continuous spectrum;
- in the low state of the system brightness the equivalent widths of the line HeII 4686 Å in the spectrum vary little ($\approx$ 14 Å) during the entire orbital period, whereas in the intermediate state the equivalent widths and the central intensities of this line vary greately as in Balmer lines;
- the maxima of the halfwidths of the emission lines are in the range of phases 0.2–0.3 and 0.7–0.8, near the locations of the minima of the system light curves;
- as a result of synchronous spectral and photometric observations of AN UMa the presence is shown of significant rapid variations of the parameters FWHM, R_c, W_λ, system light in the B filter at times of 5–20 minutes ($\Delta T = 12$ min);
- in the low state of brightness of AN UMA (January 28, 1992) a two-component structure appeared in the line HeII 4686Å. On a time scale of 5 minutes a new component appeared. The lifetime of this component has been estimated to be 15 minutes. Nonstationary accretion of matter especially in the intermediate and low state of the system brightness may be the mechanism of this spectral variability.

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References

Afanasiev V.L., Lipovetsky V.A., Mikhailov V.P., Nazarov E.A., Shapovalova A.I., 1991, Astrofiz. Issled. (Izv. SAO), **31**, 128

Beardmore A.P., Osborne J.P., 1997, Mon. Not. R. Astron. Soc., **290**, 145

Bond H.E., Tifft W.G., 1974, Publ. Astr. Soc. Pacific, **86**, 981

Bonnet-Bidaud J.M., Mouchet M., Somova T.A., Somov N.N., 1992, IAU Circ., No. 5673

Bonnet-Bidaud J.M., Mouchet M., Somova T.A., Somov N.N., 1996, Astron. Astrophys., **306**, 199

Chanmugam G., 1992, ARA&A, **30**, 143

Cropper M., Mason K. O., Allington-Smith J. R., Branduardi-Raymont G., Charles P. A., Mittaz J.P.D., Mukai K., Murdin P.G., and Smale A.P., 1988, Mon. Not. R. Astron. Soc., **236**, 29

Cropper M., 1990, Space Sci. Rev., **54**, 195

Downes R.A., Urbanski J.L., 1978, Publ. Astr. Soc. Pacific, **90**, 458

Drabek S.V., Kopylov I.M., Somov N.N., Somova T.A., 1986, Astrofiz. Issled. (Izv. SAO), **22**, 64

Efimov Yu. S., Shakhovskoy N.M., 1981, Izv. KrAO, **64**, 55

Ferrario L., Wickramasinghe D.T., Tuohy I.R., 1989, Astrophys. J., **341**, 327

Ferrario L., Wickramasinghe D.T., 1990, Astrophys. J., **357**, 582

Frank J., King A.R., Lasota J.P., 1988, Astron. Astrophys., **193**, 113

Frank J., King A.R., Raine D.J.,, 1992, Accretion Power in Astrophysics (Cambridge, Cambridge Univ. Press), chap. 6

Greenstein J.L., Arp H.C., Shectman S., 1977, Publ. Astr. Soc. Pacific, **89**, 741

Gusev O.N., Zandin N.G., Lobachev M.V., 1976, Optico-Mekhanikal Promyshlennost', **12**, 63

Hearn D.R., Marshall F.J., 1979, Astrophys. J., **232**, L21

Imamura J.N., Steiman-Cameron T.Y., 1986, Astrophys. J., **311**, 786

King A.R., 2000, Astrophys. J., **541**, 306

Kopylov I.M., Somov N.N., Somova T.A., 1986, Astrofiz.Issled. (Izv. SAO), **22**, 77

Krzeminski W., Serkowski K., 1977a, IAU Circ., No. 3039

Krzeminski W., Serkowski K., 1977b, Astrophys. J., **216**, L45

Kuijpers J., Pringle J.E., 1982, Astron. Astrophys., **114**, L4

Liebert J., Tapia S., Bond H.E., Grauer A.D., 1982, Astrophys. J., **254**, 232

Mukai K., Vallerga J.V., Paerels F., 1993, Publ. Astr. Soc. Pacific, **105**, 387

Neizvestny S.I., 1995, in: Photometric systems and standard Stars, ed. Moletai Astronomical Observatory, 37

Osborne J., 1987, Astrophys. Space Sci., **130**, 207

Ramsay G., Mason K.O., 1994, Mon. Not. R. Astron. Soc., **270**, 692

Schneider D.P., Young P., 1980, Astrophys. J., **240**, 871

Somov N.N., 1986, Astrofiz. Issled. (Izv.SAO), **22**, 73

Somov N.N., 1988, Ph.D. Thesis, Nizhnij Arkhyz, SAO RAS, 26

Somova T.A., Somov N.N., Markelov S.V., Nebelitsky V.B., Spiridonova O.I., Fomenko A.F., 1982, in: Instrumentation for Astronomy with Large Optical Telescopes, ed. C.M. Humphries, Reidel, 283
Somova T.A., Somov N.N., 1992, Soobshch. Spets. Astrofiz. Obs., **69**, 21
Szkody P., Schmidt E., Cross L., Schommer R., 1981, Astrophys. J., **246**, 223
Szkody P., Downes R., Mateo M., 1988, Publ. Astr. Soc. Pacific, **100**, 362
Tapia S., 1977a, Astrophys. J., **212**, L125
Tapia S., 1977b, IAU Circ., 3049
Vikuliev N., Zinkovsky V., Levitan B., Nazarenko A., Neizvestny S., 1991, Astrofiz. Issld. (Izv. SAO) **33**, 158
Vojkhanskaya N.F., 1990, Astrofiz. Issled. (Izv.SAO), **30**, 3
Vojkhanskaya N.F., 1986, Astron. Zh., **63**, 516
Vojkhanskaya N.F., Gnedin Yu.N., Astrofiz. Issled. (Izv.SAO), **33**, 71
Williams G., 1983, Astrophys. J. Suppl. Ser., **53**, 523