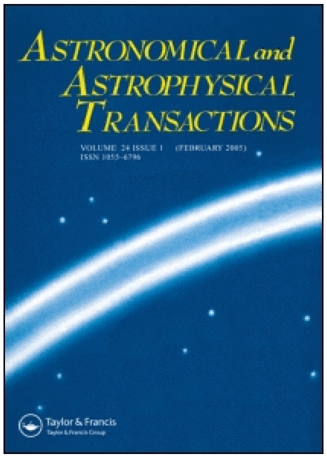

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SPECTROSCOPIC EVIDENCE OF SPORADIC GAS ACCRETION ONTO THE HERBIG Ae STARS WITH NON-PERIODIC ALGOL-TYPE MINIMA

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We present the results of simultaneous spectroscopic and photometric observations for six isolated Herbig Ae stars with non-periodic Algol-like minima: UX Ori, BF Ori, CQ Tau, SV Cep, VX Cas, and WW Vul. In all cases the Hα line has the profile typical for axially symmetric accretion. In the spectra of five stars (CQ Tau is the exception) the strong He I 5876 Å line has been observed in absorption which is not typical of normal A stars. In three cases: UX Ori, VX Cas, and WW Vul, variability of this line is found. We did not observe any correlation between the strength of this line and the brightness of the stars.

These observational facts are considered as evidence for gas accretion, which is probably an important property of young stars with non-periodic Algol-type minima.

KEY WORDS Gas accretion, Herbig Ae stars

1 INTRODUCTION

The stars with non-periodic Algol-like brightness minima are a small subclass of young stars, its prototype being UX Ori. Polarimetric observations of these stars in deep minima showed (see Grinin *et al.*, 1991; Grinin, 1992 and references therein) that their unusual variability was caused by the existence of young protoplanetary disks seen edge-on or at a small inclination to the line-of-sight. When occulting a star by opaque dust fragments (clouds), the direct stellar radiation weakens and the scattered light of the circumstellar (CS) dust disk becomes a dominant source of the radiation. Such disks are unresolved with a telescope due to the large distances to these stars (many of them are in Orion and Taurus). Nevertheless, we can suppose their orientation (edge-on) owing to the high linear polarization observed in deep minima and two-component Hα emission line profiles usually observed in their spectra. On the basis of these arguments, it was suggested in papers quoted above that the brightness variations occurred due to such an orientation.

In this paper we present the results of spectroscopic observations carried out for several photometrically most active stars of this type in the regions of Hα and He

Table 1. The program stars

Star	*Sp*	ΔV
WW Vul	A0,3e V	$10^m_.3$–$13^m_.6$
VX Cas	A0,3e V	10.0–13.3
BF Ori	A5e	10.3–13.5
UX Ori	A3e, III	8.7–12.8
CQ Tau	A8e, V	9.9–11.6
SV Cep	A0e, III	10.3–12.1

I 5876 Å lines. Their names, spectral types and ranges of brightness variation (on the basis of Herbig and Bell (1989) catalogue) are given in Table 1.

Except CQ Tau, these stars have early A spectral Types. They satisfy all criteria suggested by Herbig (1960) for selecting young stars of intermediate masses, except one: they have no associated nebulosity. For this reason, they were included neither in the original list by Herbig (1960) nor in the subsequent lists by Finkenzeller and Mundt (1984) and Hamann and Persson (1992) and turned out of interest of spectroscopists studying the spectra of Herbig Ae/Be stars. Thus, spectroscopic observations of these stars in the literature are mainly restricted to Hα line (Zajtseva and Kolotilov, 1973; Kolotilov, 1977; Finkenzeller and Mundt, 1984). An exception is BF Ori whose spectrum was studied recently in detail by Welty *et al.* (1992).

2 OBSERVATIONS

The observations of selected stars were carried out at the Crimean Astrophysical Observatory from January 1992 to March 1993. The spectroscopic observations were obtained with the SPEM spectrograph equipped with a CCD detector attached to the 2.6 m telescope in Nasmyth's focus. Spectral resolution was $\approx 1,0$ Å per pixel. Table 2 gives details of these observations. The spectra obtained were reduced using the numerical code elaborated by S. A. Sergeev.

The synchronous photometric UBVRI observations were carried out with the 1.25 m telescope equipped with the photopolarimeter of Helsinki University (Piirola, 1975). The results were reduced into Johnson's photometric system. Table 2 gives the magnitudes of the stars in V band.

3 RESULTS

Figures 1–3 show the typical Hα line profiles observed in the spectra of the stars investigated and also the spectral region near He I and Na I resonance lines. The equivalent widths of Hα and HeI lines are given in Table 2. Note that for estimations of the equivalent width of the Hα line we subtracted the photospheric profile of a

Table 2. Log of spectroscopic observations and equivalent widths of emission Hα and absorption He I 5876 lines

Object	*Date*	*Spectral Range*	*V [m]*	*W(Hα) [Å]*	*W(He I) [Å]*
UX Ori	Jan. 31, 1992	Hα	10.98	6.71	–
	Oct. 03, 1992	Hα, He I 5876	10.97	11.22	0.77
	Feb. 12, 1993	Hα	10.05	5.40	–
BF Ori	Jan. 31, 1992	Hα	9.86	6.07	–
	Apr. 02, 1992	Hα	10.70	9.27	–
	Apr. 04, 1992	Hα	10.70	6.70	–
	Feb. 12, 1993	Hα, He I 5876	11.10	17.00	1.15
CQ Tau	Aug. 21, 1992	Hα, He I 5676	10.50	9.22	No
SV Cep	Sep. 21, 1992	Hα, He I 5876	–	13.06	0.42
WW Vul	June 04, 1992	Hα, He I 5876	–	14.11	0.84
	Aug. 18, 1992	Hα	10.50	15.77	–
	Aug. 19, 1992	Hα, He I 5876	10.57	14.60	0.49
	Aug. 21, 1992	Hα, He I 5876	10.59	15.46	0.89
	Aug. 22, 1992	Hα, He I 5876	10.48	15.14	0.56
	Oct. 01, 1992	Hα, He I 5876	–	14.28	0.46
	Oct. 02, 1992	Hα, He I 5876	10.41	14.04	0.24
	Oct. 03, 1992	Hα, He I 5876	10.38	14.90	0.30
VX Cas	Aug. 22, 1992	Hα, He I 5876	11.14	13.14	0.51
	Oct. 01, 1992	Hα, He I 5876	–	12.73	0.57
	Oct. 02, 1992	Hα, He I 5876	11.26	14.16	0.77
	Oct. 03, 1992	Hα, He I 5876	11.27	14.89	0.64
	Sep. 21, 1993	Hα, He I 5876	11.33	15.58	0.68

normal star of similar spectral type from the line profile observed. For this purpose we used the spectra of some normal stars (β Eri, ϵ Mon, 12 Cas, σ Per), obtained simultaneously with the spectra of the stars investigated. We show the example of extracting "pure" emission for the Hα line in the spectrum of WW Vul in Figure 4.

3.1 Hα line profiles

Figure 1 presents Hα line profiles. All of them have asymmetric two-component structure. About 50 % of the Herbig Ae/Be stars have the profile of such a type (Finkenzeller and Mundt, 1984). Since these stars have rapid axial rotation, an origin of such profiles is believed to be caused by rotation of the CS gas envelope. If the envelope with axially-symmetric velocity field does not contain large-scale inhomogeneities, the profile indicates the presence of the radial velocity component. If the red component of the line profile is more intense than the blue one ($V < R$), outflow takes place. In the opposite case ($V > R$), gas rotates and falls onto the stars.

Let us consider from this point of view the line profiles observed.

UX Ori. Figure 1 shows three spectra of this star obtained when it was in its bright state. The ratio V/R is systematically greater than unity and variable.

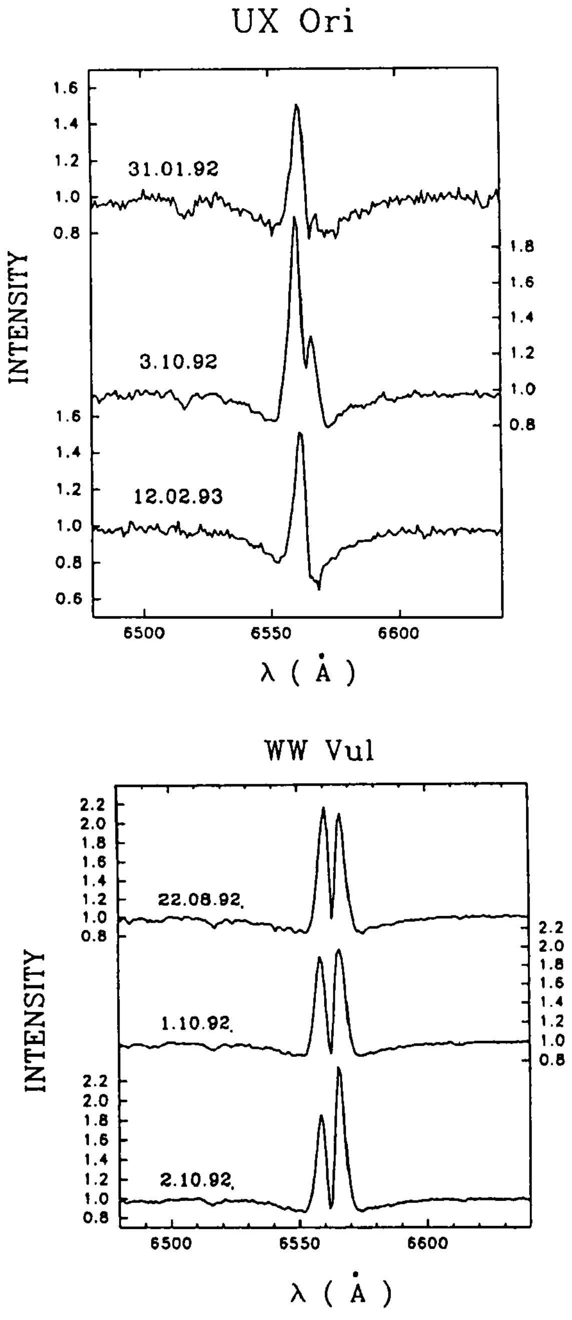


Figure 1 The examples of typical Hα line profiles in the spectra of UX Ori, WW Vul, and VX Cas.

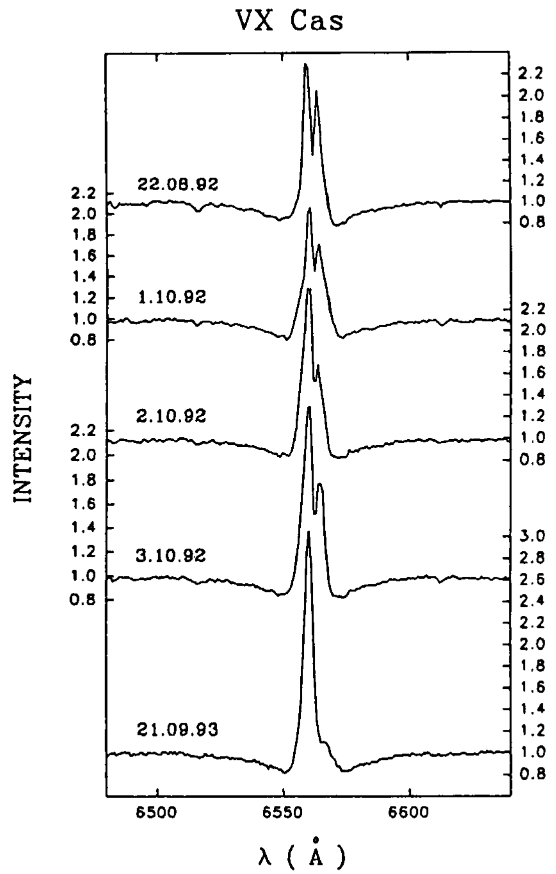


Figure 1 Continued.

The former argues that the gas rotates and falls towards the star, the latter shows that accretion is irregular. In the spectrum obtained on Feb. 12, 1993, asymmetric two-component profile transformed into classical inverse P Cygni profile.

Similar Hα line profiles in the spectrum of UX Ori were observed many years ago by Zajtseva and Kolotilov (1973) and Kolotilov (1977) and just recently by Grinin *et al.* (1994) in ESO at high spectral resolution. This means that accretion of matter onto UX Ori is occurring for a long time and is a normal state of this star.

WW Vul. We carried out a more lengthy series of observations for this star (Table 2). During these observations the star was bright and its magnitude practically did not change. It is seen from Figure 1b that Hα line profiles have the ratio V/R close to unity and changed within a narrow range from night to night. A similar Hα line profile was also observed for this star by Kolotilov (1977).

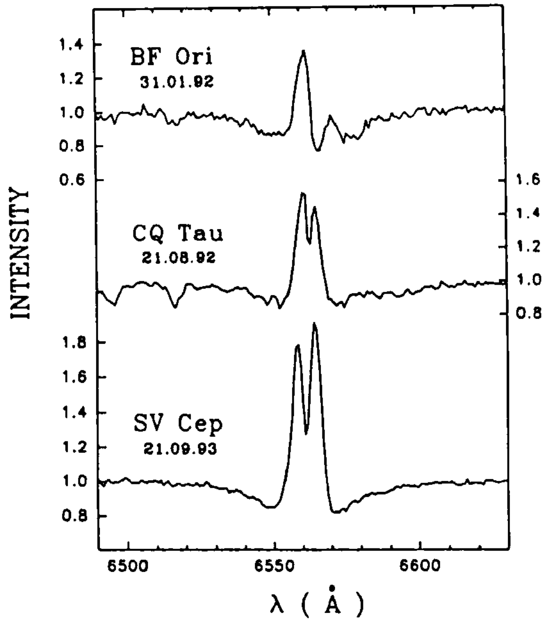


Figure 2 The profile of Hα line in the spectra of BF Ori, CQ Tau, and SV Cep.

The Hα equivalent widths differ from those of Kolotilov (1977) and Zajtseva *et al.* (1985) who observed the star at the same brightness state. Compared to Kolotilov's data, our values of $W(H\alpha)$ are lower approximately by the factor 3 and they are twice greater then from the data by Zajtseva *et al.* This means that parameters of the WW Vul gas envelope change not only from night to night but also have variations on a large time scale without significant changes of the star's magnitude.

VX Cas. During the observations the star was in the bright state. As in the case of UX Ori, all four Hα line profile have a two-component structure with $V/R > 1$ (Figure 1) indicating accretion of matter. A similar type of Hα line profile in the spectrum of this star was observed by Kolotilov (1977). Comparison of equivalent widths shows that the values obtained by Kolotilov at the same brightness are systematically higher (approximately by the factor 1.5).

BF Ori. Three of four Hα line profiles, obtained for this star in the bright state, have the ratio $V/R > 1$. One example is given in Figure 2. The line profile (12.02.93), observed when the star was faint ($V = 11^{m}.1$), has $V/R < 1$. The Hα spectrum of BF Ori is given also by Finkenzeller and Mundt (1984) and by Welty *et al.* (1992). In both cases the two-component line profile had V/R close to unity. Welty *et al.* noted that the spectrum asymmetric profiles of absorption lines indicating infall of matter towards the star.

CQ Tau and SV Cep. We obtained only one spectrum in the Hα region for each of the stars. Figure 2 shows that in the both cases, this line has two-component

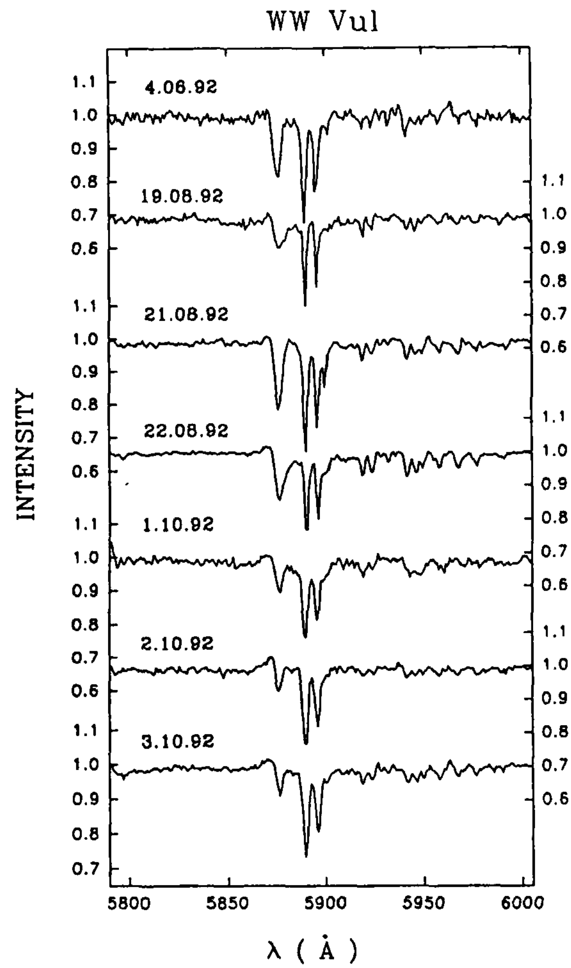
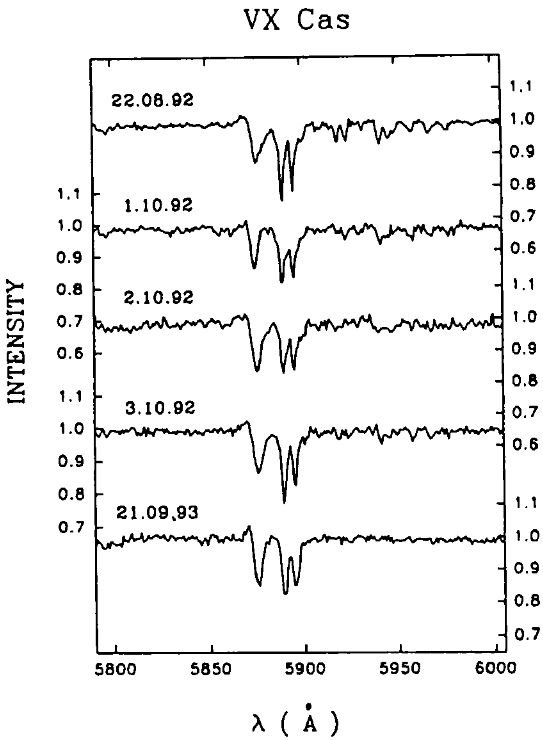


Figure 3 The examples of studied spectra of WW Vul, VX Cas, BF Ori, UX Ori, and SV Cep around the He I 5876 Å line.

and almost symmetric profile, which is typical for the Keplerian disks. Zajtseva and Kolotilov (1973) observed the two-component Hα line profile with $V/R > 1$ in the spectrum of SV Cep. Berdyugin *et al.* (1990) observed a similar Hα line profile for CQ Tau.

Thus, Hα line profiles, obtained when the stars were in a normal (bright) state, indicate infall of CS matter onto these stars. It is important to underline that spectroscopic evidence of the non-stationary gas accretion – inverse P Cygni line profiles – were observed episodically in spectra of many young stars (mainly, in T Tauri type stars) but, as a rule, in weak lines, for example, in high members of the Balmer series and metallic lines (see, e.g., Bukach *et al.*, 1982; Appenzeller and Mundt, 1989; Graham, 1992). Inverse P Cygni profiles in Hα line are observed very



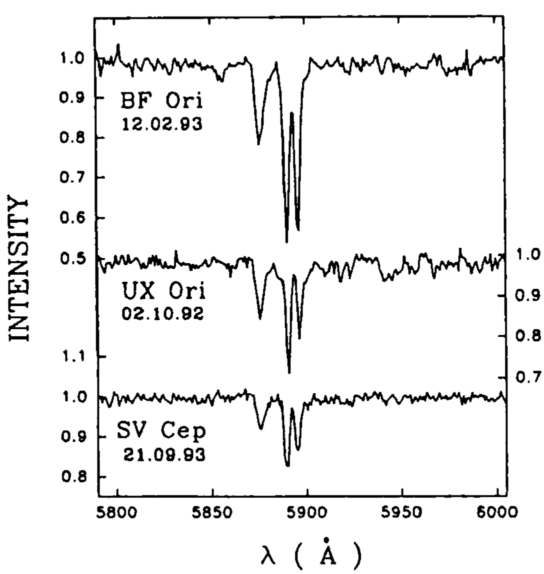


Figure 3 Continued.

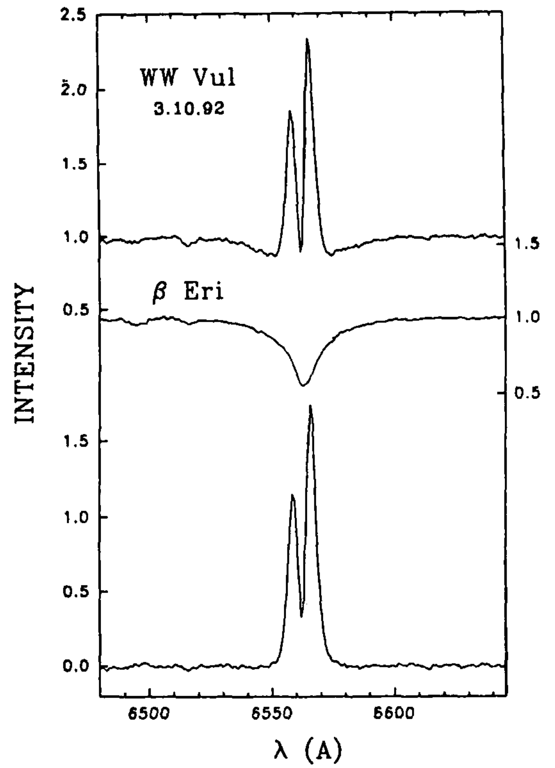


Figure 4 The example of account of photospheric profile of Hα line in the spectrum of WW Vul to derive the equivalent width of issuing components. As a "standard" of the photospheric profile, we use that of the Hα line in the spectrum of β Eri, a normal star of the same spectral type.

rarely. Usually this line indicates an alternative process: outflow of matter from young stars. In our case, the spectroscopic evidence of gas accretion onto young stars is observed in the main line of the Balmer series.

3.2 He I 5876 line

The spectra of the program stars in the region of He I 5876 Å are shown in Figure 3. We could not find in the literature any spectra in this region for these stars. According to Finkenzeller and Mundt (1984), this line appeared in absorption in the spectra of the hottest Herbig Ae/Be stars (early B stars). Therefore, the appearance of the strong absorption He I 5876 Å line in the spectra of five stars of interest was unexpected. Remember that all of them have spectral type A0-A5.

The equivalent width in this line reaches the value of 1.15 Å (Table 2). The observations of WW Vul and VX Cas reveal its significant variation (Figure 3). The conclusion about the variability of this line for UX Ori has been made from comparison of the spectrum in Figure 3 and the spectra obtained in ESO (Grinin *et al.*, 1994). It is difficult to discuss other stars because of lack of sufficient observational data.

In two cases (WW Vul and VX Cas) we observed a weak variable emission component to the blue side of the absorption line (Figure 3). The similar feature for several Herbig Ae/Be stars was recently pointed out by Bohm (1993).

4 DISCUSSION

The data presented above support the earlier suggestion (Grinin, 1992) that two-component Hα line is typical for the Herbig Ae/Be stars with non-periodic Algol-type minima. Such a profile is formed in the circumstellar disk-like rotating envelope. The preferencial asymmetry: $V > R$ indicates definitely that these envelopes are the accretion disks. In such a case, the presence of strong He I 5876 Å absorption line in the spectra of A-stars seems quite natural: high temperatures can be realized in the shock fronts at the collisions of the gas flows.

The hypothesis of the gas accretion was also considered by Guenther and Hessman (1993) at the interpretation of He I 5876 Å absorption line in the spectrum of the T Tauri type star BM And, which has also Algol-type variability. Similar approach can be applied also to the Herbig Ae/Be stars VV Ser (Chavarria-K *et al.*, 1988) and RR Tau (Grinin *et al.*, 1995), whose spectra have strong absorptions in this line. Both stars are known also as the photometrically active young stars with the amplitudes of about 2^m and 4^m in V band correspondingly (Herbig and Bell, 1988). In both cases the Hα emission line has two-component profiles.

It is necessary to note also the recent papers in which the spectroscopic evidences of the gas accretion onto some HAEBE stars were found both in optical (Graham, 1992; Hamann and Person, 1992; Welty *et al.*, 1992; Grinin *et al.*, 1994) and ultraviolet (Blondel *et al.*, 1993; Pérez *et al.*, 1993; and Grady *et al.*, 1993; 1995) regions of spectrum. All these stars are also known as irregular variable stars.

The question arises: what is the connection between the variability of these stars and the gas accretion onto them? Welty *et al.* (1992) supposed that the photometric activity of BF Ori is a result of non-stationary accretion and the additional radiation is formed in the hot spots on the stellar surface or in the boundary layer. However, this point of view cannot be applied to this star: the anti-correlation between changes of brightness and linear polarization of BF Ori (Grinin *et al.*, 1989) indicates clearly that its variability is caused by circumstellar obscuration. The latter means that the internal luminosity of the star corresponds to the upper value of its stellar brightness but not the low one. The same is true also for the other young stars with the Algol-type variability.

It seems more attractive the other interpretation of the mentioned above observational fact (Grinin, 1992): two-component Hα line profile in the spectra of photometrically active young stars is a result of their CS disks orientation: edge-on or under small inclination to the line-of-sight. The last conclusion is based on the high linear polarization which is systematically observed in the deep minima of these stars. Further investigations are necessary in order to understand are the spectral signatures of accretion the result of only preferencial orientation of CS surrounding or some additional conditions (for example the dublicity of the young stars) are needed.

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