THE OPTICAL HIGH-RESOLUTION SPECTROSCOPY AS A METHOD OF X-RAY BINARY CYG X-1 INVESTIGATION

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ABSTRACT. Recently a lot of photometric effects were revealed during the investigation of the first candidate to black hole Cyg X-1. Besides of orbital variations different kinds of flares, so-called precession period 147/294 days and a significant correlation between the long-time optical and 2-10 keV X-ray variations with the lagging of the last one there are among them. The detail spectral analysis is recognized as necessary for understanding physical nature of these phenomena. We discuss the high-resolution spectroscopy potential to recognize the manner of gas flow between the components, the physical characteristics of gas outflowing from supergiant and in the regions of accretion structure, the origin of 147 day period and so on.

The some first results of test observations been conducted by using of the echelle-spectrometer on Peak Terscol Observatory 2-m telescope are given. They demonstrate that spectra contain important information about flowing gas physical condition even with relatively low N/S.

Key words: Spectroscopy; stars: X-ray binary: black hole; stars: individual: Cyg X-1, V1357 Cyg, HDE 226868.

1. Introduction

Cyg X-1 is the unique X-ray binary system whose relativistic component is the first candidate in black hole. The mean orbital light curve with period of 5.6^d is accounted for the tidal distortion of the optical star (supergiant O9.7Iab) in relativistic object gravity field. Supergiant has T_{eff}=32000K, log g=3.2 (Herrero et al., 1995). It almost fills its Roche lobe. The flowing out matter from the supergiant creates the accretion structure near the relativistic component - the relatively small accretion disc, outer part of which have T_{eff} ~12000K, and some gas structure around it. In V band the accretion structure produce ~4% of total system radiation and this input can depend e.g. on the phase of "precessional" period $147/294^d$. The nature of this period is not clear until now. The same statement concerns to Cyg X-1 sudden transitions from ordinary "hard low" to "soft high" states with different X-ray spectra hardness.

The modern model hydrodynamic calculations of the flowing gas in close binary systems conducted for example by group of Boyarchuk, Bisikalo, Kuznetsov, Chechotkin (1998) are capable of getting the detail picture of gas distribution, the velocity field and other gas physical characteristics. It is necessary to know the system parameters for this calculations. But in spite of long time intensive investigations of Cyg X-1 the system parameters are known very poor until now because of the absence of X-ray eclipse. Especially it is concerned to the system inclination angle. Cherepashchuk (1996) estimates its value in limits 28° - 63° by using the mean orbital light curve investigations. Herrero et al. (1995) have received somewhat another parameter values by using their spectral data for Cyg X-1. So there is some (not large) contradiction between the results obtained by spectral and photometrical methods. Also there is some contradiction between the limits on distance to Cyg X-1 based on interstellar extinction measurements and the star luminosity obtained by Herrero et al. (1995) using their unified models. Apparently more precise spectroscopy and line profiles decision are needed. Also some spectral lines consist from several components accordingly to different regions of origin and it is necessary to divide this components accurately. Besides of this the distortion of supergiant shape (the ellipsoidality effect, including gravitational darkening) should be taken into account.

Recently the observational evidences of non-stationarity of matter flowing from one component to another have been appeared (Karitskaya, 1998). The irregularity of matter overflowing can produce shock waves in the region of interaction this matter with the accretion disc and in the surrounding gas. It can also produce a redistribution of scattering and absorbing matter near the relativistic component. Karitskaya et al. (2000) revealed as flares which can be result of appearing temporal hot regions ("hot spots") as simultaneous X-ray dips which indicate the appearance of absorbing gas on the line of sight. Each mentioned factor influences on spectral line characteristics. It is means that spectral researches are required.

Recently Karitskaya et al. (2000, 2001) discovered 7^d and 12^d delay of X-ray flux (2-12 keV) variations relatively to long time optical variability as well as between the optical and X-ray flares. The physical interpretation has been offered as the typical time of matter passing through the accretion structure. So the investigation of the line profile variations relative to described earlier flux variations may help us to observe the consequence of the matter passing through this structure.

Although the accretion discs are known already for a long time until now the dynamics of gas flow interaction with outer rim of disc and the process of matter outflowing from the optical component are not very clear. Especially this is concerned to Cyg X-1 where the supergiant underfills its Roche lobe on several percent. So it is desirable that from one hand the matter transportation occurs with the aid of the focused stellar wind (Gies, Bolton, 1986) and from another hand – with the aid of the stream of matter forming because of upper atmosphere layers filling supergiant Roche lobe. The comparison of observed spectrum line profiles with profiles calculated on the base of advanced supergiant model atmosphere, which includes the influence of stellar wind and outer X-ray illumination, can permit to search the process of matter outflow formation.

2. Urgent tasks of Cyg X-1 investigation for which detailed spectral analysis be demanded

The precise high resolution spectroscopy (especially combined with photometric, X-ray and radio observations) opens the wide possibility for the investigation of processes of matter outflowing from the supergiant, sporadic and quasi-periodic instability of flowing , gas flow interaction with the outer parts of accretion structure (see Introduction).

However for adequate analysis of observations of such high quality it is necessary to use new methods which include the comparison of observed and theoretical line profiles calculated in NLTE - approximation, in outflowing stellar atmospheres, irradiated by second component X-rays from the outside. The machineries developed by N.A.Sakhibullin's research group from Kazan University may be a basis of corresponding methods.

The precise high resolution spectroscopy observations with the help of the 2m-RCC telescope of Peak Terskol Observatory with echelle-spectrometer would allow to solve the following actual tasks:

1. Spectral line profiles for different orbital phases using for:

a) to obtain a tomographic map of gas distribution in the system and to compare it with gasdynamic calculations carried out e.g. in Institute of Astronomy of RAS;

b) to determine more exact the Cyg X-1 mass function and other parameters.

2. From the analysis of the spectral lines of ions with essentially different ionization potentials (HI, HeI, HeII) to obtain:

a) the velocity gradients in gas outflow from supergiant;

b) the distribution of the atmosphere parameters along the optical component surface;

c) the limitations on the possible variations of gas motion in the atmosphere with the phase of "precessional" period $147/294^d$, which may to throw light on the nature of this period.

3. From comparison the sporadic spectral variations with flare phenomena to specify nature:

a) of a few-day-long optical flares (Karitskaya et al., 2000, Bochkarev, Karitskaya, Lyuty, 1998);

b) of the "hard/soft" state transitions.

3. Test observations. Preliminary results

Test observations were fulfilled 24 August, 2002 and 28 November, 2002 in relatively fortunate moments (see Table 1). In the first time Cyg X-1 was in so-called high soft state, at the same time, already to November, 2002 it has returned to its ordinary low hard state.

The both moments fall on the nearly the same orbital phase 0.5 (Table 1), when the X-ray component was in front of supergiant. The phase coincidence (the difference 0.1) means the similar component situation relatively to observer. So it is especially very important to compere these spectra.

The observations have been conducted with echelle-spectrometer in Coude focus of the 2-m telescope of Peak Terscol Observatory. The detector was CCD-camera Wright Instruments (1252x1242 pixels) with pixel size 22.5x22.5 mkm. This echelle-spectrometer covers the spectral range from 0.36 mkm to 1.03 mkm with spectral resolution 45000. One hour and two hour expositions were done. The obtained spectra expanded over 86 and 85 echelle-orders of 60Å width . The weather conditions were far from ideal. In the region of H_α the signal to noise rate S/N was reached 150, but in blue parts it was worse significantly.

For continuum determination we used quality method of model stellar atmosphere. For this purposes the LTE-model atmosphere for supergiant with T=33000 K, log g=3.5 was calculated. For continuum determination we used spectral intervals without significant lines in the model spectrum. It permits to reach precision of about 0.5/(S/N). Fig.1 and fig.2 show some of the obtained line profiles, which permit us to make comparison.

The spectra have the absorption lines of supergiant - HI, HeI, HeII, CNO 4640Å blend, lines of heavy elements, but there are also strong emission components in lines such as H_α and HeIIλ4686Å, which profiles are very complicated (fig.1). They consist of the components, originated in different regions of the system and have strong variations. In November, when soft X-ray radiation dropped to 4 times, the line H_α became significantly stronger and HeIIλ4686Å became weaker.

The total width of emission line HeIIλ4686Å is ~600km/s which is near to this component virial velocity. At the time of strong soft X-ray radiation (August 2002) the He ionization equilibrium shifts to the more high ionization stage and this line became significantly stronger.

The line H_α in November (Cyg X-1 hard state) has weak absorption and strong red emission, the red wing being prolonged until several hundreds km/s. This means, that this line is created in expanded outflowing layer of supergiant. The fluorescence of moving to the X-ray component HI is weaker than in the back side (red wing). This may be connected with the X-ray component influence - the hydrogen ionization by X-ray radiation in the side of X-ray source. This process not occur on the back side of supergiant because of its shadow. May be another reason - supergiant stellar wind is not allowed to the second component neighbourhood by the matter flowing from X-ray component. In August (during strong soft X-ray radiation) H_α has the classical PCyg profile and became weaker. The layer width became smaller relative to the star radius because of hydrogen ionization by soft X-ray radiation occur significantly stronger - HI in stellar wind rests only near the stellar surface. The spectral lines of HeI are numerous and strong (up to 30% of continuum level, see fig.2), and show some variability. In November strong HeI lines have PCyg profiles: red wings are stronger then in August and emissions are clearly seen for the most strong lines. There is the same situation for H_β line. In August the increased soft X-ray ionized outflow envelope around the supergiant and we cannot to see its indication in this sample of lines particulary around orbital phase 0.5.

Table 1: Spectral observations.

date of 2002	JD - 2452000	orbital phase	147^dperiod phase	X-ray state
24 Aug.	511.340	0.438	0.40	"high"
28 Nov.	607.174	0.552	0.05	"low"

So already from two test spectra of high resolution received by us we may see by what manner the increased soft X-ray flux vary the ionization structure of matter in the system Cyg X-1.

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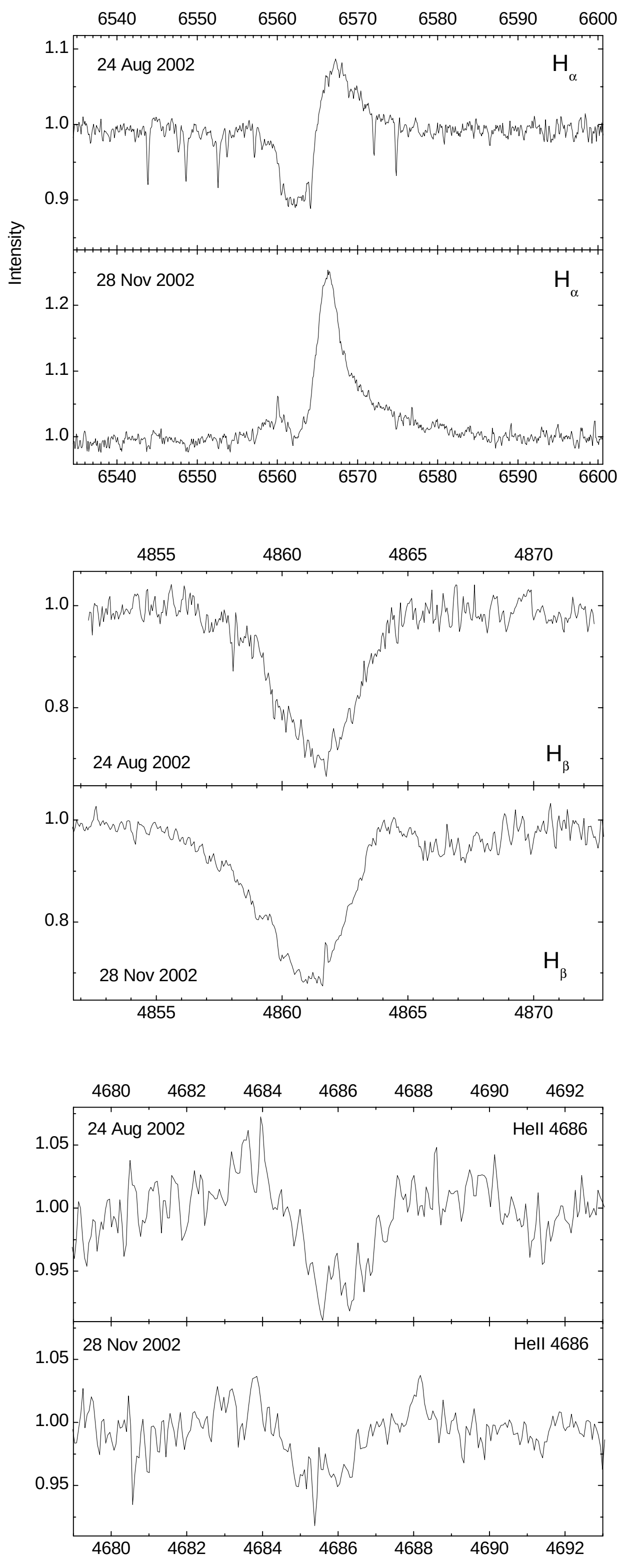

Figure 1: The line profile variations for H_α, H_β and HeIIλ4686 Å.

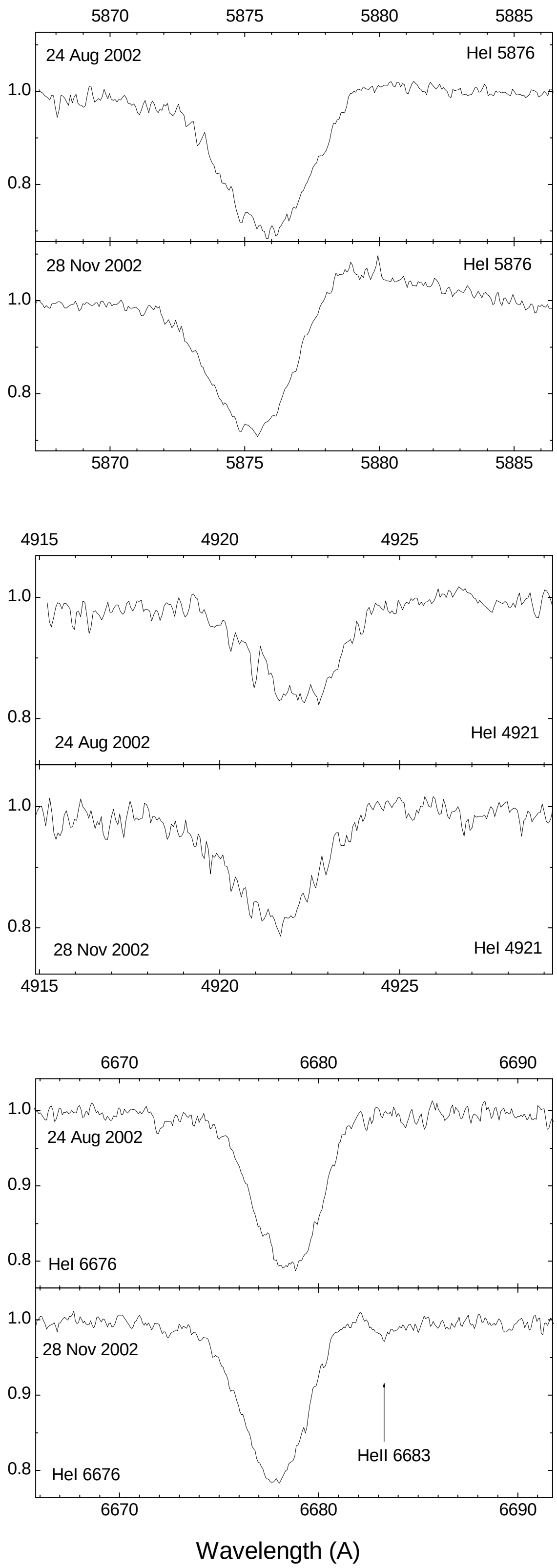

Figure 2: The profiles for some lines of HeI.