From Interacting Binaries to Exoplanets: Essential Modeling Tools
Proceedings IAU Symposium No. 282, 2011
Mercedes T. Richards & Ivan Hubeny, eds.

doi:10.1017/S1743921311026858

Multi-Technique Study of the X-Ray Binary Cygnus X-1

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Abstract. Short review of our 36-year Cyg X-1 study using multi-technique methods and based on our optical photometric, high-resolution spectral and spectropolarimetrical observations.

Keywords. Stars: magnetic fields, stars: atmospheres, stars: abundances, accretion disks, techniques: polarimetric, techniques: spectroscopic, techniques: image processing, stars: early-type, stars: individual (Cyg X-1 = HDE 226868=V1357 Cyg), X-rays: binaries

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Cyg X-1/HDE226868/V1357 Cyg ($m_V = 9^m$) is an X-ray binary system (the orbital period $P = 5.6^d$) whose relativistic component is the first black hole (BH) candidate. The optical component, an O9.7 Iab supergiant, is responsible for about 95% of the system's optical luminosity. The remaining 5% is due to the accretion structure (disc and surrounding gas) near the BH. The intensive investigations of Cyg X-1 are being carried on for 40 years, but a lot of phenomena in the system remain unclear. Here there is a short review of our 36-year Cyg X-1 study using multi-technique methods and based on our optical photometric, high-resolution spectral and spectropolarimetrical observations.

The main optical photometric variation (the ellipsoidality effect) was studied in detail with the Roche model. Thirty-six years ago, Bochkarev, Karitskaya & Shakura (1975) used the amplitude $A = 0.035 - 0.050^m$, the difference in depth minima $\Delta A < 0.005^m$ to derive the admissible values of parameters for Cyg X-1: inclination $25 < i < 67$; mass ratios $0.2 < q < 0.55$; filling factor $0.9 < \mu < 1$; $M_o > 17M_{sun}$; $7M_{sun} < M_x < 27M_{sun}$. It is interesting that very new research (Orosz *et al.*, 2011) has obtained values within our ranges for the parameters.

In the frame of the 1994-1998 international campaign "Optical Monitoring of Unique Astrophysical Objects" 2258 UBVR observations of Cyg X-1 were made during 407 nights. The main results are reported by Karitskaya *et al.* (2000) and Karitskaya *et al.* (2001). Evidence of irregularities in matter flowing between the components was found. By comparing photoelectric (UBVR) and X-ray ASM/RXTE (3-12 keV) flux variations we found different kinds of variability (orbital variations, various flares, dips, so-called precession period 147/294 days) and a correspondence between optical and X-ray variations. Cross-correlation analysis revealed lags of X-ray (2-10 keV) long-term variations in respect to the optical ones (7^d in 1996 and 12^d in 1997-1998). It allowed determining accretion time which is much shorter than with the standard accretion model.

The results of Cyg X-1 spectral monitoring are presented in Karitskaya *et al.* (2003, 2005, 2006, 2007a), Karitskaya *et al.* (2008). The observations were carried out with the Echelle-spectrographs of the Peak Terskol observatory (altitude 3100 m, North Caucasus) 2 m telescope (spectral resolution R = 13000 or 45000) and BOAO (Korea) 1.8 m telescope (R = 30000) covering most of the optical range. Optical spectral line profile variations were found during the X-ray flare.

Non-LTE modeling of the observed spectra allowed us to put limits on the parameters of Cyg X-1 O-supergiant component: $T_{eff} = 30400 \pm\ 500$ K, log $g = 3.31 \pm\ 0.07$, and the element overabundances: from 0.4 dex to 1.0 dex for He, N, Ne, Mg, Si, that is, the elements affected by CNO- and α-processes (Karitskaya, *et al.* (2005, 2007b), Karitskaya *et al.* (2011a)). Tidal distortion of the Cyg X-1 optical component and its illumination by X-ray emission of the secondary are taken into account.

The photometric and spectral variations point to the supergiant parameters' changes on the time scale of tens of years. Line profile non-LTE simulations lead to the conclusion that the star radius has grown $\sim$ 1-4% from 1997 to 2003-2004 while the temperature decreased by $1300-2400$ K (Karitskaya, *et al.* 2006, Karitskaya *et al.* 2007a). This agrees with the X-ray activity growth in these years. An increase in the Roche lobe filling degree causes greater instability in the accretion process.

The spectral line profile sets permitted us to construct the binary 2D and 3D tomographic maps using HeIIλ4686Å profiles (Karitskaya *et al.* 2005, 2007a, Sharova *et al.* 2011). The comparison of the 2D tomographic map with the theoretical calculations allowed us to construct a more precise system model and receive better information on the gas flowing. The hard limits on Cyg X-1 component mass ratio were obtained by such manner: $1/4 < M_X/M_O < 1/3$.

Our VLT 8-m telescope spectropolarimetric observations permitted us to reveal the magnetic field of $\sim$ 100 G on the supergiant and to suspect the magnetic field of $\sim$ 600 G on the outer parts of the accretion structure (Karitskaya *et al.* 2010, Karitskaya *et al.* 2009, Karitskaya *et al.* 2011b, Bochkarev & Karitskaya 2011a, Bochkarev & Karitskaya 2011b). For the first time the existence of magnetic accretion on the black hole has been confirmed. Such magnetic field will be increased during disc accretion and can be responsible for the observed X-ray flickering.

Acknowledgements

The work is supported by RFBR grants 04-02-16924, 06-02-16234, 09-02-01136 and 09-02-00993.

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