Feeding Compact Objects: Accretion on All Scales
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Accretion of stellar winds in high-mass X-ray binaries

Petr Hadrava[1] **and Jan Čechura**[1,2]

[1]Astronomical Institute, Academy of Sciences, Prague, Czech Republic
email: had@sunstel.asu.cas.cz
[2]Faculty of Mathematics and Physics, Charles University, Prague
email: j.cechura@gmail.com

Abstract. Our analysis of optical spectroscopy of high-mass X-ray binaries like Cyg X-1 confirms that most of the Balmer-lines emission anticorrelated with the X-ray flux originates from the circumstellar matter between the donor star and the accreting compact component. In order to study its structure and variability and the consequent accretion rate we have developed a 3-D numerical model based on radiation hydrodynamics of the supergiant stellar wind. The results show a non-stationary BHL-accretion on the compact component.

Keywords. Stars: winds, outflows, X-rays: binaries, Accretion, Hydrodynamics

1. Introduction

Observational and theoretical study of mass-exchange in binary stars with compact components enables us to improve our understanding of the accretion process as well as the stellar structure and evolution. In high-mass X-ray binaries the mass-loss from the donor star takes place in the form of radiatively-driven stellar wind modulated by the tidal forces which determines the outer boundary conditions for the accretion on the compact companion.

In order to investigate the mass-exchange in such binaries, we observed and analyzed optical spectra of the first galactic black-hole candidate Cyg X-1/HDE 226868 and we modelled numerically the mass-loss and the radiation hydrodynamics of the circumstellar matter.

2. Disentangling of optical spectra of Cyg X-1

Our spectra were obtained in Hα region using Coudé spectrograph at Ondřejov 2-m telescope starting from 2003. For their analysis, we used our method of Fourier disentangling that enables us to separate the spectra of binary components and simultaneously to determine their orbital parameters. Unlike the Doppler tomography which enables to map a smooth distribution in the velocity space of the emitting matter assuming its intrinsic line-profile to be given by a δ-function, the disentangling enables to fit the observed spectra as a superposition of several discrete sources with arbitrary spectra varying in strength. In the case of Cyg X-1, the Hα line can be decomposed into a nearly constant P-Cygni line-profile of the supergiant donor star and an emission of the circumstellar matter which does not move with the black-hole companion but is shifted in phase and amplitude of radial velocity and anticorrelates with the soft X-ray emission. Simillar conclusions have been found from spectra obtained at Purple Mountain Observatory (Yan *et al.* 2008) which, however, indicate a slight change of the P-Cyg profile between the X-ray states.

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3. Stellar wind

Models of Parker's evaporative or radiatively driven stellar wind in binares showed that the tidal force can modulate the distribution of the mass-loss rate across the surface of a component star in directions towards the L_1 and L_2. These radial models, however, did not self-consistently include the Coriolis force and the tangential gradients of the pressure. We thus re-investigated the problem in the framework of the 3-D numerical radiation hydrodynamics taking into account the CAK model of line-driven radiative force and Roche potential (Hadrava & Čechura 2012). The non-radial forces modify the distribution of the outflow rate by skewing the stream-lines and changing their divergence which influences the position of critical point. This, consequently, influences the flux of matter that can hit the vicinity of the compact companion and feed the accretion.

The radiative drag is dominant for the stellar wind in high mass (early-type) supergiants. A gravity darkening may thus decrease the radiative flux in the same directions as the tidal force enhances the outflow. These two effects nearly cancel each other for the von Zeipel's value of the gravity darkening ($T_{\rm eff} \sim g^{0.25}$).

The line-driven stellar wind is also influenced by an X-ray feedback; the heating and photoionization by the X-ray flux depopulate the electron levels available to absorb the momentum of radiation from the primary and decrease the radiative drag on the wind. We thus treat in the new version of our code the standard k-parameter of the CAK-model dependent on the ionization parameter $\xi = \frac{L_{\rm x}}{n_{\rm p} r^2}$, decreasing to 0 for $\xi > 10^2$ erg $\cdot$ cm $\cdot$ s^{-1}. The preliminary results of our model support the hypothesis that the X-ray ionization tends to slow down the wind material in the immediate vicinity of the compact companion and thus increase the overall accretion rate. However, if the photoionization radius penetrates close enough to the surface of the donor, the CAK line-driven mechanism is blocked right at the base of the wind that, therefore, does not reach the escape velocity and effectively stop supplying the accretion process with the material.

4. Bondi-Hoyle-Lyttleton accretion on compact companion

Our numerical radiation-hydrodynamic model of the evolution of circumstellar mater solved the equations of continuity and motion of the mass while the temperature was hold constant for simplicity. This model which roughly corresponds to energy balance dominated by radiation of the supergiant, converged quickly to a stationary solution determined by the boundary conditions on the surface of the donor star. A remarkable feature of this solution is a gaseous tail formed behind the compact companion. This structure is formed by a kind of Bondi-Hoyle-Lyttleton accretion, i.e. a focusing of the wind passing close to the compact companion by its gravitation. The sampling of the grid was not sufficient to resolve a possible inner accretion disk which must be small regarding the small angular momentum of the nearly homogeneous inciding wind. The result is quantitatively different when the equation of energy conservation is included into the solution, i.e. when the assumption of radiative energy balance is abandoned. The hydrodynamic heating then increases the pressure in the tail and opposes its compression. An extended shock front is formed and the inflowing material is accumulated temporarily on it before it is either accreted onto the compact companion or it is blown away inside the tail. The solution is thus no longer stationary and is subjected to quasiperiodic oscillations.

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