Clumped stellar winds in supergiant high-mass X-ray binaries

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Abstract. The clumping of massive star winds is an established paradigm, which is confirmed by multiple lines of evidence and is supported by stellar wind theory. We use the results from time-dependent hydrodynamical models of the instability in the line-driven wind of a massive supergiant star to derive the time-dependent accretion rate on to a compact object in the Bondi-Hoyle-Lyttleton approximation. The strong density and velocity fluctuations in the wind result in strong variability of the synthetic X-ray light curves. Photoionization of inhomogeneous winds is different from the photoinization of smooth winds. The degree of ionization is affected by the wind clumping. The wind clumping must also be taken into account when comparing the observed and model spectra of the photoionized stellar wind.

Keywords. accretion, instabilities, stars: mass loss, X-rays: binaries

1. Clumping of massive star winds

Massive luminous OB-type stars possess strong stellar winds. The winds are fast, with typical velocities up to $2500\,\mathrm{km\,s^{-1}}$, and dense, with mass-loss rates $\dot{M} \gtrsim 10^{-7}\,M_\odot\,\mathrm{yr^{-1}}$. The driving mechanism for the mass-loss from OB stars has been identified with radiation pressure on spectral lines (Castor *et al.* 1975). Early on Lucy & Solomon (1970) suggested that the stationary solution for a line-driven wind is unstable. Lucy & White (1980) proposed that the winds break up into a population of dense blobs. Feldmeier *et al.* (1997a,b) used hydrodynamic simulations to model the evolution of wind instabilities and found that the winds are non-stationary and inhomogeneous. The inhomogeneity affects stellar wind diagnostics. Stewart & Fabian (1981) used *Einstein* spectra of O-stars to study the transfer of X-rays through a uniform stellar wind. They found that the mass-loss rate derived from X-ray spectra is lower by factor of a few than the mass-loss rates obtained from fitting the Hα line. As most plausible explanation for this discrepancy they suggested the neglect of the clumping in O-star winds. A theory of X-ray transfer in clumped winds that accounts for clumps of any shapes and optical depths was developed by Feldmeier *et al.* (2003) and Oskinova *et al.* (2004). Indeed, accounting for wind clumping allows to consistently model the UV/optical and the X-ray spectra of single O-stars (Oskinova *et al.* 2006, 2007). These conclusions are confirmed by full 3-D radiative-transfer models of stellar winds (Šurlan *et al.* 2012).

The mass-loss rates of massive stars are in good agreement with observed X-ray fluxes from high-mass X-ray binaries (HMXBs). HMXBs are the products of binary star evolution. These systems consist of an early-type massive star and a compact companion, neutron star (NS) or black hole (BH), on a close orbit (Iben *et al.* 1995). Accretion of stellar wind onto the compact companion powers the high X-ray luminosity of $\sim 10^{33}$–$10^{39}\,\mathrm{erg\,s^{-1}}$. HMXBs can be divided in subclasses depending on the spectral type of the donor star – supergiant (SG) or Be-star.
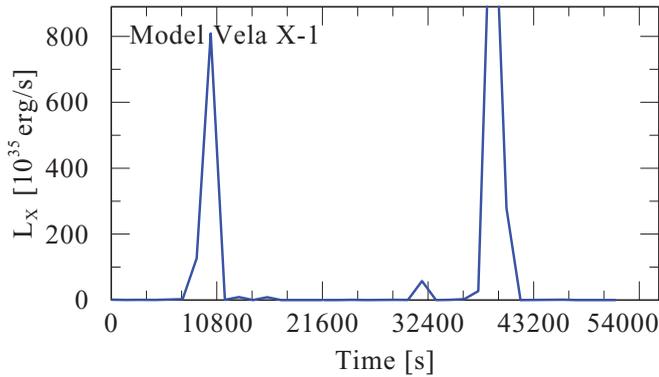
Figure 1. Synthetic X-ray light curves for the BondiHoyle accretion of a non-stationary stellar wind on to a NS with $m_X = 1.4\,M_\odot$. Parameters of Vela X-1 were used in the simulation.

2. Effect of wind-clumping for HMXBs

We employ the results of hydrodynamical simulations of the line driven stellar wind presented in Feldmeier *et al.* (1997a,b). These hydrodynamic simulations derive the dynamic and thermal structure of stellar winds from the basic underlying physical principle, namely the acceleration of stellar wind by the line scattering of stellar UV photons.

The time dependent hydrodynamic simulations provide absolute values for the wind density and velocity as functions of radius and time. We use the predicted density and velocity field to compute synthetic X-ray light curves. An example of a light-curve is shown in Fig. 1. The variability is very large because of the strong variations in the wind velocity (shocks). The highly non-uniform wind density also contributes to the variability of accretion rate. The variations in the model light-curve are much larger than even strongest variability observed in HMXBs. We are prompted to conclude that simple Bondi-Hoyle accretion with clumped winds is not a sufficient explanation of variations in wind-accreting X-ray binaries.

Oskinova *et al.* (2012) showed that the photoionization of the wind by the radiation from accreting object is strongly affected by the wind clumping. In the optically thin case, the photoionization parameter has to be reduced by a factor χ compared to the smooth wind model, where χ is the wind inhomogeneity parameter.

Thus, wind clumping affects the accretion regime, the photoionization, and the wind opacity for the X-rays.

References

Castor, J. I., Abbott, D. C., & Klein, R. I. 1975, *ApJ*, 195, 157
Feldmeier, A., *et al.* 1997a, *A&A*, 320, 899
Feldmeier, A., Puls, J., & Pauldrach, A. W. A. 1997b, *A&A*, 322, 878
Feldmeier, A., Oskinova, L., & Hamann, W.-R. 2003, *A&A*, 403, 217
Iben, I., Jr, Tutukov, A. V., & Yungelson, L. R. 1995, *ApJS*, 100, 217
Lucy, L. B. & Solomon, P. M. 1970, *ApJ*, 159, 879
Lucy, L. B. & White, R. L. 1980, *ApJ*, 241, 300
Oskinova, L. M., Feldmeier, A., & Hamann, W.-R. 2004, *A&A*, 422, 675
Oskinova L. M., Feldmeier A., Hamann W. 2006, MNRAS, 372, 313
Oskinova, L. M., Hamann, W., & Feldmeier, A. 2007, *A&A*, 476, 1331
Oskinova, L. M., Feldmeier, A., & Kretschmar, P. 2012, *MNRAS*, 421, 2820
Stewart, G. C. & Fabian, A. C. 1981, *MNRAS*, 197, 713
Šurlan, B. *et al.* 2012, *A&A*, 541, 37