Wind accretion and formation of disk structures in symbiotic binary systems

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Abstract

We investigate gravitationally focused wind accretion in binary systems consisting of an evolved star with a gaseous envelope and a compact accreting companion. We study the mass accretion and formation of an accretion disk around the secondary caused by the strong wind from the primary late-type component using global 2D and 3D hydrodynamic numerical simulations. In particular, the dependence of the mass accretion rate on the mass loss rate, wind temperature and orbital parameters of the system is considered. For a typical slow and massive wind from an evolved star the mass transfer through a focused wind results in rapid infall onto the secondary. A stream flow is created between the stars with accretion rates of a 2–10% percent of the mass loss from the primary. This mechanism could be an important method for explaining periodic modulations in the accretion rates for a broad range of interacting binary systems and fueling of a large population of X-ray binary systems. We test the plausibility of these accretion flows indicated by the simulations by comparing with observations of the symbiotic variable system CH Cyg.

Symbiotic binaries

Symbiotic binaries are unique astrophysical laboratories for studies of wind accretion because of the wide separation of the components, and the ability to study the individual components and the accretion processes from multiwavelength studies from X-ray to radio (e.g., Karovska et al. 2010). A typical symbiotic consists of a mass-losing AGB or a red giant star and a hot accreting companion, often a white dwarf (WD). The components in these systems are assumed to be detached (at least during most of the orbital motion) and the compact companion accretes mass from the massive wind of the cool evolved star.

Numerical model

The numerical model is based on previous two-dimensional models described in de Val-Borro et al. (2009), hereafter referred to as Paper I. We solve the basic equations of hydrodynamics describing the evolution of the density and velocity field in three-dimensions:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0, \quad (3)$$

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v} = -\frac{1}{\rho}\nabla p - \nabla \Phi, \quad (4)$$

where ρ is the density in the orbital plane, $\mathbf{v}$ the velocity of the fluid, p the pressure and Φ the gravitational potential.

Our code is based on the FLASH code (Fryxell et al. 2000), which is a fully parallel block-structured Adaptive Mesh Refinement (AMR) implementation of the Piecewise Parabolic Method (PPM) in its original Eulerian form[a]. The code has been extensively tested in various compressible flow problems with astrophysical applications. A realistic 3D hydrodynamical simulations of the interaction of the wind from a giant star with a companion using the spherical coordinates version of the code is in progress. The computational domain spans about one radian around the orbital plane of the system centered on the primary to cover the whole region of interest close to the accretor. The spatial resolution per separation in the 3D simulations is about a factor of two smaller than in the 2D simulations.

[a]The source code is available at http://www.flash.uchicago.edu/

Results

We present numerical simulations of gravitationally focused wind accretion in the CH Cyg binary system. The wind parameters of our model are those of a slow spherically symmetric wind from an evolved star at the dust acceleration surface. A tidal stream is observed in our simulations for a wide range of binary separations using an isothermal equation of state. We have considered simulations with a locally isothermal equation of state. The results of this work and a comparison of the models with observations of the symbiotic binary CH Cyg are summarized below:

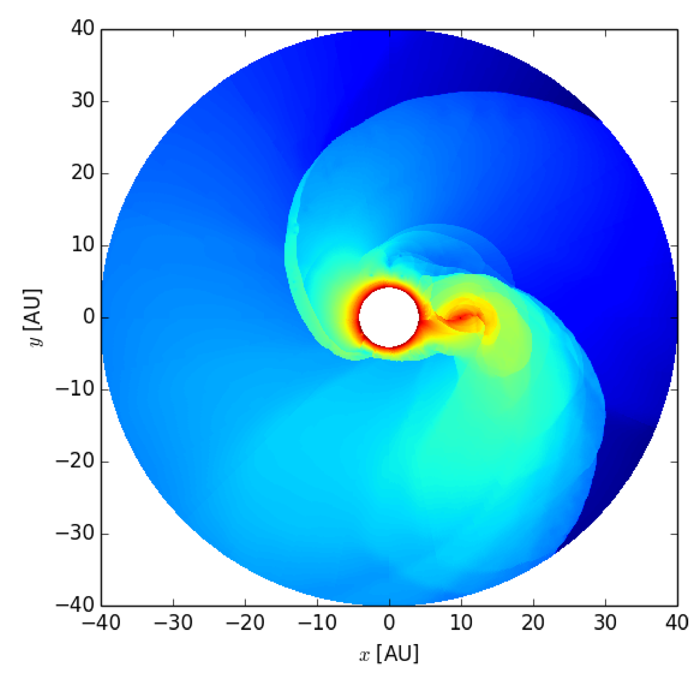
- The focused wind accretion in this system shows a complex dynamics, resulting in a powerful flow beyond the accreting companion.
- A bow shock and a spiral-like tail structure forms near the position of the secondary and on the farther side from the primary due to the supersonic orbital motion.
- Mass transfer through a focused wind leads to a stream flow onto the WD with variable accretion rates of 2–10% percent of the mass loss from the primary.
- This mechanism could explain the morphology of the outflows detected in the HST and Chandra images of CH Cyg at much larger scales (e.g., Karovska et al. 2010).

Wind accretion in CH Cygni

CH Cyg system

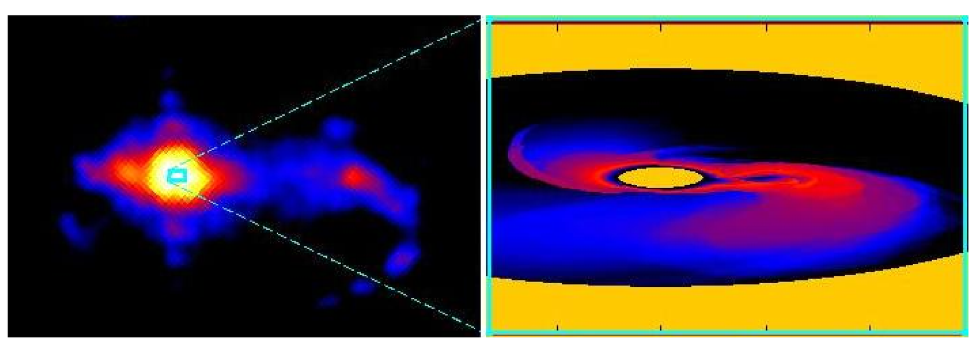
Parameter	Value
$M_{\rm RG}$	$2M_\odot$
$M_{\rm WD}$	$0.6M_\odot$
P	15.6 yr
a	8.5 AU
$\dot{M}$	$2\times10^{-6}\ M_\odot$/yr
v	20–40 km s^{-1}

We integrate the equations of hydrodynamics until the density distribution of the gravitationally focused wind reaches a quasi-stationary state. The adopted orbital and wind parameters correspond to the symbiotic binary CH Cyg (long-period orbit in Hinkle et al. 2009, shown in the table on the left). The stellar wind produced by the donor star is deflected towards the secondary within the orbital plane, and the relaxed density distributions present a Keplerian accretion disk.



Orbital plane density contours in logarithmic scale for a simulation of CH Cyg after an orbital period. The system has a separation of 8.5 AU and a mass ratio $q = 3.3$.

The formation of a stream flow is dependent on the wind velocity and temperature at the dust formation radius which determines the velocity at the secondary's position. Our simulations were run on a grid with uniform radial spacing in our base grid and 5 additional levels of refinement. The computational grid was centered on the giant star in the rotating reference frame of the binary system. The numerical method changes the accuracy of the solution by modifying the spacing of the grid points in certain regions as a function of time. The AMR algorithm places high resolution grid patches only at the regions where time-dependent shocks are formed.



HST image of CH Cyg acquired in 2008 (Karovska et al. 2010) with FOV of 1250 AU × 875 AU and the projected simulation taking into account the inclination ($\sim 84°$) with respect to the line of sight with a FOV of approximately 45 AU × 30 AU.

An HST image of CH Cyg is shown in the left panel of the figure on the left. The cyan box in the center of the observed CH Cyg image has approximately the same size of the inner region showed in the simulated image in the right panel. There is a strikingly similar morphology of the accretion outflow on the companion and beyond with that of the observed outflow structure at much larger scales.

Acknowledgments

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