A Massive Star Odyssey, from Main Sequence to Supernova
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Influence of radiation pressure and wind momentum on mass transfer in massive binaries

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Abstract. We perform radiation hydrodynamics simulations of mass transfer in close and massive binary systems, focusing especially on the impact of radiation pressure and wind momentum from the two luminous stars that compose the system. We find that for the large mass transfer rates important for the evolution of such binary systems (of the order of $10^{-3}\,\mathrm{M_\odot\,yr^{-1}}$), the light and wind momenta are too low to affect the behaviour of the dense gas stream ejected by the Roche Lobe filling component. In particular, the presence of a wind-wind collision between the two stars has no effect on the gas stream dynamics.

1. Introduction

A central element controling the evolution of binary star systems is the mass transfer associated with the envelope growth of either component (Roche Lobe OverFlow), occurring mostly during hydrogen or helium shell burning. Currently, even the most sophisticated binary star evolution models treat this mass transfer in a crude way via a single parameter β. Conservative mass transfer tends to follow inductive argumentation (choose β to reproduce the characteristics of observed binaries period, mass ratio) or heuristic argumentation that still lack detailed analysis (enhanced mass loss for a critically rotating star for example). In this modest attempt, our incentive is to study the modalities of mass transfer in *massive* binary systems. The two components are hot and luminous stars characterised by radiatively driven outflows associated with a high mass loss rate ($\dot{M} \approx 10^{-7}\,\mathrm{M_\odot\,yr^{-1}}$) and a high asymptotic velocity ($\sim 1000\,\mathrm{km\,s^{-1}}$). Here, we wish to assess the impact of the combined radiation and wind-ram pressures from two luminous stars on the gas stream ejected by the Roche Lobe filling component. How conservative is mass transfer in that situation?

2. Modalities of mass transfer

Mass transfer originates from the envelope growth associated with molecular weight changes in the stellar core, or most importantly during (envelope) shell burning. Due to the modified gravitational potential in a binary system, the envelope growth cannot occur as freely as for single (isolated) stars. When a binary component approaches its Roche radius, material within its envelope and located near the zero gravity point of the system (L1) can transfer into the potential well of the other star. If one assumes that such gas stream is isothermal,

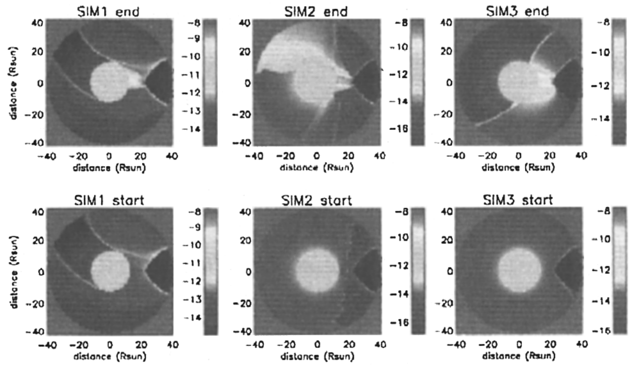

Figure 1. Equatorial density (log) grayscale with the secondary in the center, the primary to the right, before (*bottom*) and during (*top*) mass transfer. Sim 1, 2, and 3 cover the situations where the primary wind momentum wins over, balances or loses against the secondary's. *No inflow* is allowed into the secondary in Sim 1 and 2. In this close binary system, the stream directly impacts onto the secondary: if the secondary surface allows inflow (Sim 3), conservative mass transfer results.

it is the *density gradient* along the streamline that does the work against gravity and allows overflow: the material is *de-compressed and accelerated* from the photosphere to L1 (Lubow & Shu 1975; Ritter 1988)

3. Radiation hydrodynamics simulations

We perform radiation-hydrodynamics simulations, with ZEUS-2D (Stone & Norman 1992), of a massive close binary system (4 d period). We work in the orbital plane of the system, whose individual components have the following properties: $M_1 = 28\,\mathrm{M_\odot}$, $L_1 = 1.8\times10^5\,\mathrm{L_\odot}$, $R_1 = 15\,\mathrm{R_\odot}$, $\dot{M}_1 =$ variable, $v_{\infty 1} =$ variable and $M_2 = 26\,\mathrm{M_\odot}$, $L_2 = 1.5\times10^5\,\mathrm{L_\odot}$, $R_2 = 11.5\,\mathrm{R_\odot}$, $\dot{M}_2 = 10^{-8}\,\mathrm{M_\odot\,yr^{-1}}$, $v_{\infty 2} = 1700\,\mathrm{km\,s^{-1}}$. The orbital separation is $40\,\mathrm{R_\odot}$. The radiation force calculated follows the parametrisation of Castor *et al.* (1975). We assume a stellar surface outflow with the sound speed and select a density that allows the coverage of different wind momenta situations. Mass transfer takes the form of a stream of 3° (as seen from the primary), inflowing the simulated domain at the sound speed ($20\,\mathrm{km\,s^{-1}}$) and a density of $10^{-8}\,\mathrm{g\,cm^{-3}}$, *i.e.*, $\dot{M}_{\mathrm{transfer}} \approx 5\times10^{-6}\,\mathrm{M_\odot\,yr^{-1}}$ (Figure 1).

References

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