Feeding Compact Objects: Accretion on All Scales
Proceedings IAU Symposium No. 290, 2012
C. M. Zhang, T. Belloni, M. Méndez & S. N. Zhang, eds.

doi:10.1017/S1743921312020078

How do red giants respond to mass loss?

Konstantin Pavlovskii and Natalia Ivanova

Dept. of Physics, University of Alberta,
11322-89 Ave, Edmonton, AB, T6G 2E7, Canada
email: pavlovsk@ualberta.ca

Abstract. Many interacting binaries start their mass exchange when a donor overfilling its Roche lobe has evolved to a giant branch. The response of the donor's radius to the mass loss as compared to the response of its Roche lobe determines the fate of the binary system – whether it will proceed with a stable mass transfer, or experience dramatic common envelope event. Recent studies of responses of realistic giant's stellar models to a fast mass loss showed that this response is not purely adiabatic as previously thought but depends on the behavior of giant's superadiabatic surface layer. In this contribution, we explore in further details how an interplay between superadiabatic layer's thermal timescale and the dynamic timescale of the donor affects the donor's mass loss. We also find that the initiation of the mass loss causes mass loss induced pulsations.

Keywords. binaries: general, convection, hydrodynamics, waves

In stars with outer convective envelopes, near the surface, convection's relative efficiency is decreasing and the actual temperature gradient is larger than it is predicted by adiabatic theory of convective energy transport: $\nabla > \nabla_{\rm ad}$. Mass of such superadiabatic layer depends on stellar's properties, and is significantly larger for more massive stars; for a 20 $M_\odot$ giant, mass of superadiabatic layer can become comparable to the mass of the whole envelope, while for low-mass giants its mass $< 10^{-4}$ $M_\odot$. This layer governs whether a giant will expand or contract upon the mass loss (Woods & Ivanova 2011, Passy, J.-C. *et al.* 2011).

Thermal timescale of this superadiabatic layer is much shorter than the thermal timescale of the whole star, which makes it comparable to the dynamical timescale $\tau_{\rm dyn}$ of the star. We find that thermal readjustment in these layers matters for the rate of mass loss below the thermal (10^{-4} to 10^{-2} $\rm M_\odot$/yr) mass loss for a 60 $R_\odot$ red giant (RG), for even higher mass loss rates the response becomes almost adiabatic (Fig. 1).

In simulations of 5$\rm M_\odot$ RG at various evolutionary stages we find that mass loss contributes to the energy of p-modes in convective envelope and excites them to substantial amplitudes. Removal of the outer layers triggers expansion of the underlying layers into vacuum and their subsequent oscillatory contractions and expansions. In addition, it produces a significantly non-adiabatic (with significant energy damping) rarefaction wave that propagates to the center of the star, reflects there and returns to the surface, contributing to the pulsations (Fig. 2). Initial drop in radius is due to continuous consumption of the outer layers as they are simultaneously expanding into vacuum (see the left panel of Fig. 2):

$$\dot r \approx \frac{2}{\gamma(r)-1} c_{\rm ad}(r) - \frac{\dot M}{4\pi\rho(r)r^2},$$

where r is current radius, γ is first adiabatic coefficient, c_{ad} is adiabatic sonic speed, $\dot M$ is mass loss rate, ρ is density. This equation is only valid for times much less than a $\tau_{\rm dyn}$

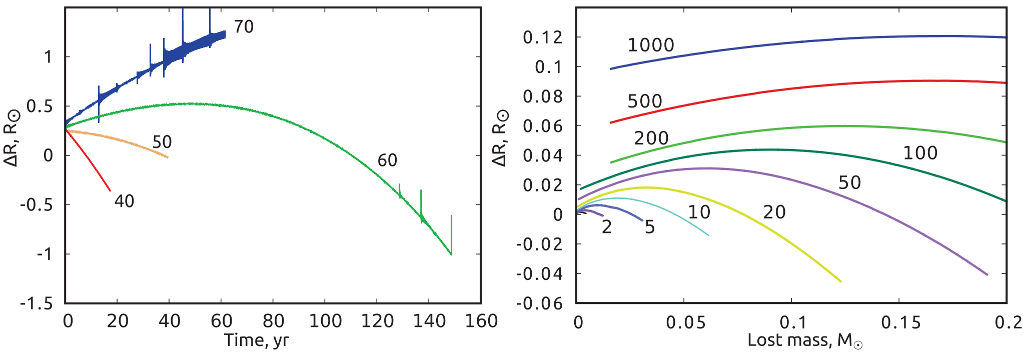

Figure 1. Left panel – post-dynamical response of a 5 $M_\odot$ RG at various evolutionary stages to continuous mass loss of 10^{-2} $M_\odot$/yr. Initial radii are indicated on the figure. Right panel – post-dynamical response of a 5 $M_\odot$ 60 $R_\odot$ RG to various rates of mass loss. Rates are indicated on the figure in units of 10^{-5} $M_\odot$/yr. Dynamical effects are not shown (for them, see the Fig. 2), initial values of ΔR should be regarded as order-of-magnitude estimates. Evolutionary trends are subtracted. Simulations conducted with `MESA` (Paxton *et al.* 2011),

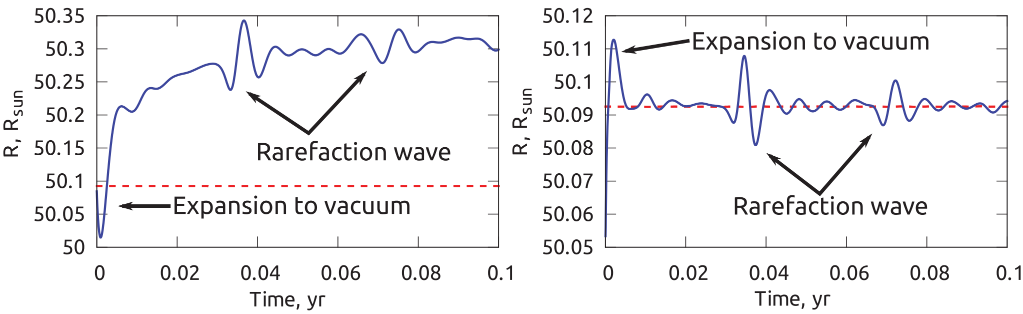

Figure 2. Dynamical timescale response of a 5 $M_\odot$ RG to continuous mass loss of 10^{-2} $M_\odot$/yr (left) and to instantaneous loss of $1.2 \cdot 10^{-5}$ $M_\odot$ (right). Dashed line shows the evolution of the same giant not subjected to mass loss. Only radial pulsations can be taken into account in this 1D consideration. Numerical artifacts that excite p-modes are excluded. Artificial viscosity coefficients are set to produce damping rates comparable to observations (Baudin *et al.* 2011, Belkacem *et al.* 2012).

after the start of mass loss and for zero gradient of gravitational potential at the surface. On a few $\tau_{\rm dyn}$ the mass loss response is almost entirely driven by pulsations (Fig. 2).

We conclude that at the start of the mass loss, the mass transfer rate in RGs is governed:

• during first few $\tau_{\rm dyn}$ – by pulsations driven by such dynamical effects as expansion to vacuum and rarefaction wave;

• after – by non-adiabatic response of the superadiabatic surface layer for mass loss rates lower than $\approx 10^{-2}$ $M_\odot$/yr for a 60 $R_\odot$ RG.

References

Paxton, B., Bildsten, L., Dotter, A., Herwig, F., Lesaffre, P., & Timmes, F. 2011, *ApJS*, 192, 3
Baudin, F., Barban, C., Belkacem, K., Hekker, S., *et al.* 2011, *A&A*, 529, A84
Belkacem, K., Dupret, M. A., Baudin, F., Appourchaux, T., *et al.* 2012, *A&A*, 540, L7
Passy, J.-C., Herwig, F., & Paxton, B. 2011, *ArXiv*, 1111.4202v3
Woods, T. E. & Ivanova, N. 2012, *ApJ*, 739, L48

https://doi.org/10.1017/S1743921312020078 Published online by Cambridge University Press