

Modification of AGB wind in a binary system

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Abstract. We explore one of plausible causes of asymmetry in the wind of an AGB star – the presence of a binary companion. We have developed a simple method for estimating the intrinsic non-sphericity of the outflow in that case. Assuming the Roche model, local stellar parameters (T_{eff} , g) are calculated, and then a formula for the local mass loss rate is applied. As a by-product a relation between the ratio of stellar radius to the Roche lobe radius and the overall wind enhancement is obtained.

1. Introduction

Shapes of Planetary Nebulae, that deviate from spherical symmetry (in particular – axisymmetric ones) are often ascribed to binary interactions (e.g. Soker 1997). When an Asymptotic Giant Branch star loses its mass – which is to become a PN – the companion can affect the trajectories of the outflowing matter, concentrating it to the orbital plane. A density gradient between equatorial and polar regions is created, and when the star leaves AGB and the hot fast wind starts to break its way through the remnants of the expelled giant’s envelope, the elliptical or bipolar symmetry forms naturally.

In attempts to calculate such effects it is widely assumed, that the intrinsic AGB wind is spherically symmetric and the asymmetry is introduced only by the companion’s influence. But this need not to be the case for relatively close binaries, where the giant is noticeably distorted by tidal forces. Differences in local conditions through the stellar surface, mainly in temperature and gravity, may lead to different intensities of the outflow. Thus the wind would show an intrinsic directivity.

We investigate this possibility, using a simple model.

2. The model

We assume that:

- The orbit is circular and the giant corotates with orbital motion – hence the Roche model for the gravitational potential applies.
- Stellar surface is defined by the Roche equipotential surface.
- The local mass loss rate per unit area, \dot{m} , is a function of local stellar parameters such as effective temperature, T_{eff} , and gravity, g .

- The luminosity is spread uniformly over the solid angle and therefore the effective temperature depends only on radius and inclination of a given surface element.

We have calculated sequences of models, representing stars filling increasing fraction of their Roche lobes for various mass ratios. For each point of the stellar surface we have computed gravity and effective temperature (relative to the spherical case). This allowed us to evaluate local mass loss rates, using the prescription derived by Arndt, Fleischer, & Sedlmayr (1997). Integration over the whole surface leads then to obtaining total mass loss rates.

3. Results

Figures 1–2 present our results. Figs. 1a–d show the local mass loss rates (according to Arndt et al. prescription), represented by grayscale. For each figure black denotes maximum and white – minimum in the mass loss rate. The mass loss rate at the dotted line is equal to that of a single, undistorted (i.e. spherical) star. It marks the border between the "polar" regions where the mass loss rate is lower, and the "equatorial strip" where it is higher than for a single star.

In Figs. 1a–c configurations with the mass ratio $q = 0.5$ and the ratio of giant volume radius to critical Roche surface volume radius $R/R_{RL} = 1.0, 0.5, 0.1$ are shown. The stars are viewed from the orbital plane, with the hemisphere facing the companion closer to the observer. Fig. 1d presents for comparison the $q = 0.5, R/R_{RL} = 0.5$ case viewed from the opposite hemisphere.

Fig. 2 plots the enhancement of the total mass loss rate caused by the presence of the binary companion, $\Delta\dot{M}/\dot{M}_{single}$, against the R/R_{RL} ratio. Note logarithmic scale on both axes. Points represent numerical results, lines – the derived analytical relation, which is

$$\Delta\dot{M}/\dot{M}_{single} \sim (R/R_{RL})^3$$

(see Sect. 4).

4. Discussion

As one could expect, we find significant differences in the local mass loss rates across the surface of the giant distorted by the presence of a companion. The gradient between the equatorial and polar regions is evident, although the strongest enhancement occurs toward the companion. It would be interesting to use these results as an input for modelling shapes of the Planetary Nebulae formed in binary systems, replacing the assumption of intrinsic sphericity of the AGB wind.

For evolutionary calculations considering binary evolution it is important to know by how much the stellar mass loss rate is affected by the presence of the companion. Tout and Eggleton (1988) proposed a formula, according to which the tidal torque would enhance the mass loss by a factor of $1 + B \times (R/R_{RL})^6$, where B is a free parameter to be adjusted (ranging from 5×10^2 to 10^4).

In our model the mass loss rate enhancement depends mainly on the g value at the giant's point closest to the binary companion. Therefore one may

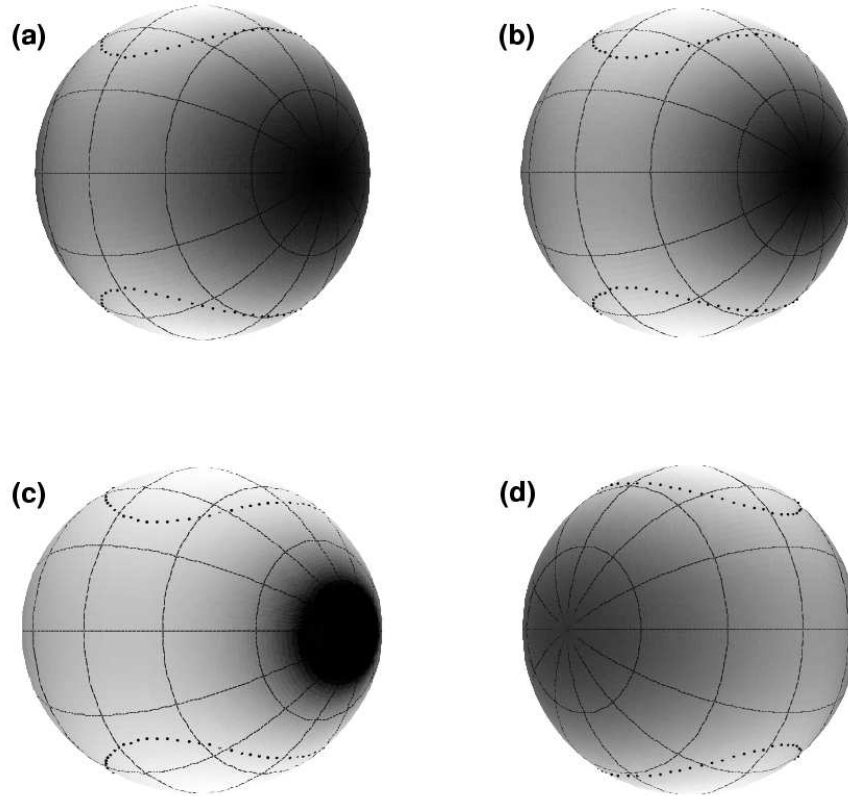


Figure 1. (a) The differences in the local mass loss rate per unit area across the surface of a giant. Dark and light regions have, respectively, high and low mass loss rate per unit area. At the dotted line the local mass loss rate is equal to that of a single star. The mass ratio is $q = 0.5$. The ratio of the radius of the star to the Roche lobe volume radius is $r = R/R_{RL} = 0.1$. (b) Same as Fig. 1a, but for $r = 0.5$. (c) Same as Fig. 1a, but for $r = 1.0$. (d) Same as Fig. 1b, but viewed from the opposite hemisphere.

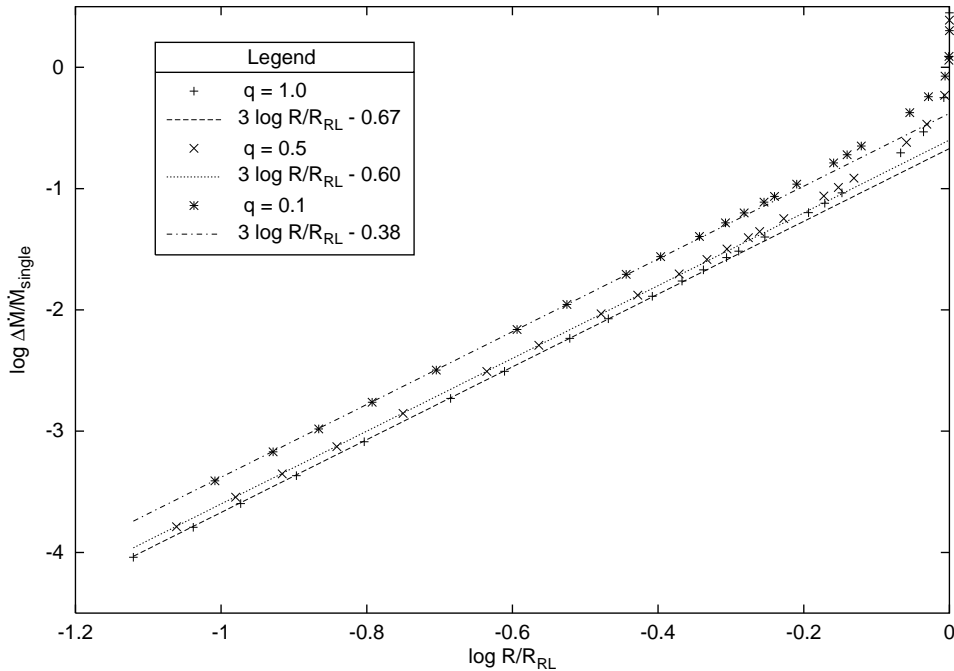


Figure 2. The dependence of the total mass loss rate enhancement, $\Delta\dot{M}/\dot{M}_{single}$, on the R/R_{RL} ratio. Results for $q = 1.0, 0.5$, and 0.1 are shown. Points denote numerical results, lines – fitted linear relations.

try a simple analytical approach to derive a similar relation for wind enhancement. Let us denote the gravity of a single star by g_{single} . Expanding the ratio g^{-1}/g_{single}^{-1} at the point closest to the companion into a series in small R/R_{RL} gives $const \times (R/R_{RL})^3$ as a first non-zero term following the unity. This leads to the following dependence for the mass loss rate:

$$\dot{M} = \dot{M}_{single} (1 + const \times (R/R_{RL})^3).$$

Our numerical results confirm the above relation up to $\log R/R_{RL} \sim -0.2$ (i.e. $R/R_{RL} \sim 2/3$), which is shown on Fig. 2.

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