Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies
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Heat conduction and colliding winds in Wolf-Rayet binaries

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Abstract. We numerically investigate the impact of heat conduction by thermal electrons on the physics of colliding winds by means of a 1D model problem. Compared to ideal flows, the hot plasma has significantly lower temperatures and has both a high- and low-density component. Consequently, the shocks in WR binaries become generally more radiative and the emitted X-ray spectrum is softer, shows more emission lines, and is a composite of the emission from high- and low density regions.

1. 1D model and results

To estimate the impact of heat conduction by thermal electrons on the dynamics of colliding winds, we consider a 1D non-magnetic model problem of colliding winds and apply parameters similar to those encountered in massive star binaries. We assume densities of $n = 6.5 \times 10^{10}\,\mathrm{cm}^{-3}$, velocities of $v = 2000\,\mathrm{km\,s}^{-1}$ and temperatures of $T = 3.1 \times 10^4\,\mathrm{K}$ for both flows. We then solve the Euler equations with a modified energy equation to account for heat conduction and radiative cooling. To solve the non-linear heat conduction ($E_t \propto -T^{5/2}\nabla T$, see *e.g.*, Spitzer 1965) we use the algorithm of Dai & Woodward (1998).

Compared to ideal flows (Euler equations), heat conducting flows show significantly lower temperatures of the shocked gas (some 10^6 K instead of some 10^8 K). Meanwhile, parts of the stellar winds are considerably heated. The shocks are isothermal and, consequently, a highly compressed hot zone is formed (Figure 1, left). If radiative cooling is applied, the situation becomes non-stationary due to the unstable character of the cooling (*e.g.*, Walder & Folini 1996). Where it cools, the gas is compressed further. But even with cooling, due to conduction, there is still a high density component of the hot plasma.

2. Conclusions for WR binaries

Our results of the model problem strongly suggest: heat conduction plays a significant role for binaries wide enough to allow the winds to reach their terminal velocities. One can estimate that typically the time-scale on which the gas is driven away from the central region of the binary is considerably larger than the heat conduction time scale. Consequently, the shocks become isothermal,

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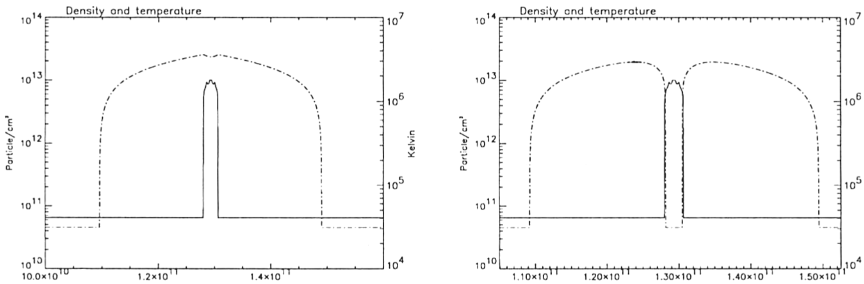

Figure 1. Density (solid line) and temperature (dashed line) structure of heat conducting colliding flows. The stellar winds ($2000\,\mathrm{km\,s^{-1}}$ from the left and the right) are heated which leads to isothermal shocks with higher post shock densities. *Left:* cooling not included. *Right:* cooling included.

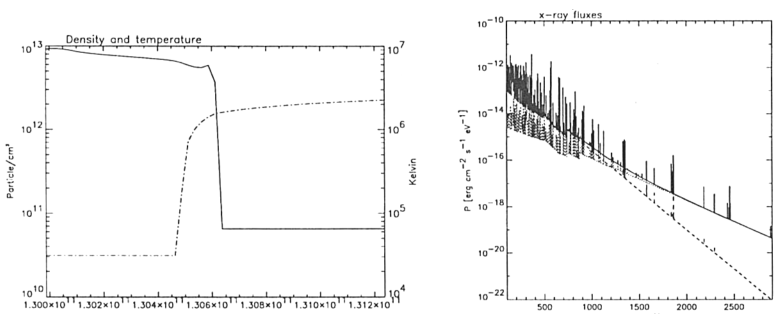

Figure 2. *Left*: Blow-up of the region of the right shock of the radiative case. Clearly, this situation is not stationary. *Right*: X-ray emission of the entire hot region (solid line), from the high density part (dashed line) and from the low density part (dotted line).

the peak temperature of the gas lower, and the peak density higher (see also Myasnikov & Zhekov 1998). Radiative cooling will likely lead to an unstable situation and further studies will be necessary to finally obtain a more comprehensive picture in this case. The presence of magnetic fields may still modify these results since heat conduction is strongly suppressed normal to the field.

Heat conduction considerably softens the X-ray emission which consequently contains more emission lines. Because the shocks are isothermal, the spectrum must, however, be a composite of the emission from high- and low density regions. Next generation satellites like *XMM* will allow to test these predictions.

References

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