A Massive Star Odyssey, from Main Sequence to Supernova
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Clumps and shocks in the outer winds of hot stars

Mark C. Runacres[1] and Stanley P. Owocki[2]

[1]*Koninklijke Sterrenwacht, Ringlaan 3, B-1180 Brussel, België*
[2]*Bartol Research Institute, University of Delaware,*
Newark, DE 19716, USA

Abstract. We present a moving periodic box technique to study the outer-wind evolution of instability-generated structure in hot-star winds. This has considerable computational and conceptual advantages

1. Introduction

Hot stars (spectral types O, B and Wolf-Rayet) lose mass through their strong, radiatively driven stellar winds. It is well known that these stellar winds show a great deal of structure (such as clumps and shocks). One plausible explanation for the existence of structure is the instability of radiative driving. This gives a small-scale, stochastic structure, distributed throughout the wind. This kind of structure could explain the black troughs seen in saturated ultraviolet lines. It has also been used to explain soft X-ray emission from hot stars.

Another plausible explanation for structure are co-rotating interaction regions. These are large-scale structures, rooted to the surface of the star and are believed to explain the rotational modulation of discrete absorption components seen in unsaturated ultraviolet spectral lines.

In this contribution we concentrate on the small-scale stochastic structure caused by the instability of the radiative driving mechanism. In particular, we investigate how this structure evolves as it moves out to large distances ($> 100\,R_*$). This is relevant for thermal radio emission (and the determination of mass-loss rates), for non-thermal radio emission, for soft X-rays from some stars (such as ζ Pup) and possibly for the structure seen in nebulae around Wolf-Rayet stars.

2. A new technique

In a previous paper (Runacres & Owocki 2002) we studied the evolution of wind structure up to a distance of $100R_*$, using time-dependent hydrodynamical models that take into account the instability of line-driving. We found that the radiative force plays little role in maintaining the structure in the outer wind (beyond $30R_*$).

As the evaluation of the radiative force dominates the computing time of these simulations, its negligible role for the evolution of outer wind structure allows us to construct cheaper models. This in turn allows us to run them for

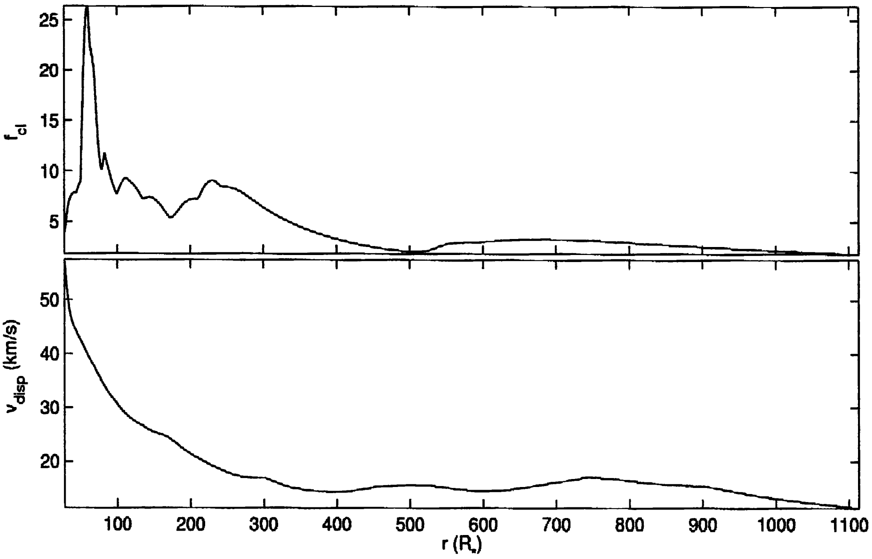

Figure 1. Clumping factor and velocity dispersion as a function of distance, for a periodic box simulation of wind structure

longer and study the structure at very large distances, say a thousand stellar radii. The technique we propose is a pseudo-planar, moving periodic box model. Despite its rather grand name, the technique is simple. Instead of keeping track of the whole stellar wind, we select a representative region at a given time, and put it in a box that moves outward at a convenient speed, generally close to the terminal velocity. Unlike their planar counterparts, the spherical equations of hydrodynamics are not invariant under a Galilean transformation. We therefore rephrase them, using variables that are scaled to take into account the secular expansion of the gas. This gives us equations that describe a spherically symmetric stellar wind, but have a form that is the same (*well ... almost*) as the planar equations and can therefore be used in a moving box. Finally, we impose periodic boundary conditions on the box. Details of this technique will be given in a subsequent paper.

3. Results

The figure shows the clumping factor (top panel) and velocity dispersion (lower panel) for a periodic-box simulation. The clumping factor drops under the influence of pressure expansion and rises when shell collisions occur. As these collisions can occur far from the star, the wind remains clumped up to very large distances: the clumping factor is 9 at 230 R_*. Just as for the radiatively driven calculations, the velocity dispersion decreases gradually.

References

Runacres, M.C., Owocki, S.P. 2002, A&A 381, 1015