2D wind clumping in hot, massive stars from hydrodynamical line-driven instability simulations using a pseudo-planar approach

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Context: Clumping in the radiation-driven winds of hot, massive stars arises naturally due to the strong, intrinsic instability of line-driving (the `LDI'). But LDI wind models have so far mostly been limited to 1D, mainly because of severe computational challenges regarding calculation of the multi-dimensional radiation force. Aims: To simulate and examine the dynamics and multi-dimensional nature of wind structure resulting from the LDI. Methods: We introduce a `pseudo-planar', `box-in-a-wind' method that allows us to efficiently compute the line-force in the radial and lateral directions, and then use this approach to carry out 2D radiation-hydrodynamical simulations of the time-dependent wind. Results: Our 2D simulations show that the LDI first manifests itself by mimicking the typical shell-structure seen in 1D models, but how these shells then quickly break up into complex 2D density and velocity structures, characterized by small-scale density `clumps' embedded in larger regions of fast and rarefied gas. Key results of the simulations are that density variations in the well-developed wind statistically are quite isotropic and that characteristic length-scales are small; a typical clump size is ~0.01R at 2R, thus resulting also in rather low typical clump-masses ~10^17 g. Overall, our results agree well with the theoretical expectation that the characteristic scale for LDI-generated wind-structure is of order the Sobolev length. We further confirm some earlier results that lateral `filling-in' of radially compressed gas leads to somewhat lower clumping factors in 2D simulations than in comparable 1D models. We conclude by discussing an extension of our method toward rotating LDI wind models that exhibit an intriguing combination of large- and small-scale structure extending down to the wind base.

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