Neglecting the porosity of hot-star winds can lead to underestimating mass-loss rates

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Context:
The mass-loss rate is a key parameter of massive stars. Adequate stellar atmosphere models are required for spectral analyses and mass-loss determinations. Present models can only account for the inhomogeneity of stellar winds in the approximation of small-scale structures that are optically thin. Compared to previous homogeneous models, this treatment of ``microclumping'' has led to reducing empirical mass-loss rates by factors of two to three. Further reductions are presently discussed in the literature, with far-reaching consequences e.g.for stellar evolution and stellar yields.
Aims:
Stellar wind clumps can be optically thick in spectral lines. We investigate how this ``macroclumping'' influences theradiative transfer and the emergent line spectra and discuss its impact on empirical mass-loss rates.
Methods:
The Potsdam Wolf-Rayet (PoWR) model atmosphere code is generalized in the ``formal integral'' to account for clumps that are not necessarily optically thin. The stellar wind is characterized by the filling factor of the dense clumps and by their average separation. An effective opacity is obtained by adopting a statistical distribution of clumps and applied in the radiative transfer.
Results:
Optically thick clumps reduce the effective opacity. This has a pronounced effect on the emergent spectrum. Our modeling for the O-type supergiant zeta Puppis reveals that the optically thin Halpha line is not affected by wind porosity, but that the PV resonance doublet becomes significantly weaker when macroclumping is taken into account. The reported discrepancies between resonance-line and recombination-line diagnostics can be resolved entirely with the macroclumping modeling without downward revision of the mass-loss rate. In the case of Wolf-Rayet stars, we demonstrate for two representative models that stronger lines are typically reduced by a factor of two in intensity, while weak lines remain unchanged by porosity effects.
Conclusions:
Mass-loss rates inferred from optically thin emission, such as the Halpha line in O stars, are not influenced by macroclumping. The strength of optically thick lines, however, is reduced because of the porosity effects. Therefore, neglecting the porosity in stellar wind modeling can lead to underestimating empirical mass-loss rates.

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