Stellar mass-loss near the Eddington limit. Tracing the sub-photospheric layers of classical Wolf-Rayet stars

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Towards the end of their evolution hot massive stars develop strong stellar winds and appear as emission line stars, such as WR stars or LBVs. The quantitative description of the mass loss in these important pre-SN phases is hampered by unknowns such as clumping and porosity due to an in-homogeneous wind structure, and by an incomplete theoretical understanding of optically thick stellar winds. In this work we investigate the conditions in deep atmospheric layers of WR stars to find out whether these comply with the theory of optically thick winds, and whether we find indications of clumping in these layers. We use a new semi-empirical method to determine sonic-point optical depths, densities, and temperatures for a large sample of WR stars of the carbon (WC) and oxygen (WO) sequence. Based on an artificial model sequence we investigate the reliability of our method and its sensitivity to uncertainties in stellar parameters. We find that the WR stars in our sample obey an approximate relation with P_rad/P_gas~80 at the sonic point. This 'wind condition' is ubiquitous for radiatively driven, optically thick winds, and sets constraints on possible wind/envelope solutions affecting radii, mass-loss rates, and clumping properties. Our results suggest that the presence of an optically thick wind may force many stars near the Eddington limit to develop clumped, radially extended sub-surface zones. The clumping in these zones is most likely sustained by the non-linear strange-mode instability, and may be the origin of the observed wind clumping. The properties of typical late-type WC stars comply with this model. Solutions without sub-surface clumping and inflation are also possible but demand for compact stars with comparatively low mass-loss rates. These objects may resemble the small group of WO stars with their exceptionally hot stellar temperatures and highly ionized winds.

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