

Envelope Inflation or Stellar Wind?

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We an optically-thick, transonic, steady wind model for a H-free Wolf-Rayet star. A bifurcation is found across a critical mass loss rate \dot{M}_b . Slower winds $\dot{M} < \dot{M}_b$ extend by several hydrostatic stellar radii, reproduce features of envelope inflation from Petrovic et al. (2006) and Gräfenner et al. (2012), and are energetically unbound. This work is of particular interest for extended envelopes and winds, radiative hydrodynamic instabilities (eg. wind stagnation, clumping, etc.), and NLTE atmospheric models.

1 Introduction

Understanding the structure of Wolf-Rayet (WR) stars are critical for two reasons. Observationally, WRs have optically-thick winds that extend the photosphere to larger radii (Hamann et al. 2006, Crowther et al. 2006) and obscure basic stellar parameters (e.g. hydrostatic radius, rotation, etc.). This has implications for single and binary evolution, and predict type Ic supernova progenitors, shock breakout and early SN lightcurves, GRB hosts. Stellar models predict significantly inflated stellar envelopes that approach or exceed the Eddington limit (Petrovic et al. 2006; Gräfenner et al. 2012). The models are capped by a density (and gas-pressure) inversion to maintain hydrostatic equilibrium.

We find the envelopes must have supersonic velocity fields, if they are to be consistent with a steady WR outflow. Furthermore, they would decelerate and contain multiple sonic points due to the density inversion. It is critical to understand the influence of dynamics as NLTE atmospheric models (e.g. CMFGEN; Hillier & Miller 1998 and PoWR; Hamann & Gräfenner 2004) presume the velocity field is monotonic.

2 Results

We replicate a $23M_{\odot}$ helium star with solar metallicity from Gräfenner et al. (2012). We continue the integration including dynamical terms at the iron opacity bump in a separate calculation, with the sonic point criteria solved exactly within the Rosseland approximation. The radiative diffusion approximation becomes invalid where line-force amplification (LFA) enhances, and dominates, the wind acceleration. Castor et al. (1975) expresses this condition as an optical depth parameter $t = \sigma_e v_{th} \rho / (dv/dr) < 1$ for line-driven winds, with thermal velocity v_{th} and electron scattering opacity σ_e .

For $\dot{M} > \dot{M}_b$, the wind accelerates monotonically until LFA dominates the acceleration. These winds are expected to successfully escape the star. Weaker winds $\dot{M} < \dot{M}_b$ exhibit structure similar to envelope inflation. For $\dot{M} < 6 \times 10^{-6} M_{\odot}/\text{yr}$, the wind does not accelerate significantly such that $t < 1$, and are

thus described adequately by the diffusion approximation. These models decelerate to become subsonic again, and fail to escape.

The minimum mass loss rate to which the extended structure is erased is $\dot{M}_b = 10^{-4.8} M_{\odot} \text{ yr}^{-1}$. This \dot{M}_b does not coincide with the dynamical estimate from Petrovic et al. (2006) nor Gräfenner et al. (2012). Instead, we find models $\dot{M} < \dot{M}_b$ become energetically unbound. Such a condition is drawn onto Fig. 1, which clearly bifurcates the set solutions.

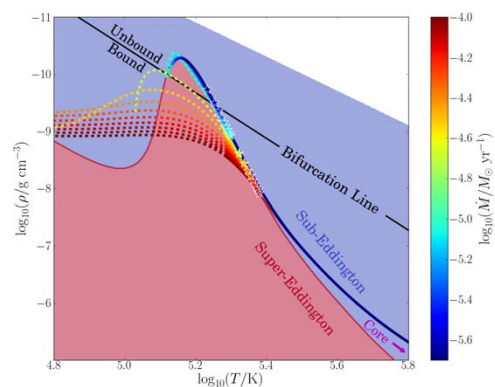


Fig. 1: Figure 3: $(\rho - T)$ map partitioned into sub- and super-Eddington regions (blue and red, respectively). The iron opacity bump is at $\log(T/K) = 5.2$. A Bifurcation Line $e \simeq 4aT^4/3\rho - GM_*/R_* = 0$ is where the energy density exceeds the gravitational potential. R_* is the hydrostatic radius where dynamics are negligible (i.e. $v \ll c_i \simeq 30 \text{ km s}^{-1}$). Dashed lines are where $t < 1$, which roughly corresponds to $v \gtrsim 125 \text{ km s}^{-1}$.

References

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