Missing Optically Observed Type II Core Collapse Supernova from 18M⊙ stars.

“Enhanced mass-loss rate evolution with > 18M⊙ and missing optically-observed type II core collapse supernovae”

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Abstract

We use the MESA stellar evolution code to explore the lives and explosive deaths of stars within the range of 15-30 solar masses. These stars are expected to end their lives in a bright core collapse supernova, but observations detect much less core collapse supernovae in the mass range of M>18M⊙ than expected, a problem known as the ‘red supergiant problem’. Questions about the explosion mechanism also remain. We simulate the evolution of stars in the mass range range of 15-30 solar masses to study mass loss rates and the resulting amount of circumstellar material (dust) that might obscure an explosion. Our results indicate that these stars might explode as core collapse supernovae, but we found that statistical uncertainties do not allow us to address additional questions about the explosion mechanism. We assume that when a star has a luminosity and surface temperature in a specific range, it strongly pulsates, as observations suggest for lower mass stars. We further assume that these pulsations increase the mass loss rate by a factor of about 10. We then examine whether this enhanced mass loss rate can obscure the explosion if the star does explode.

Initial Data

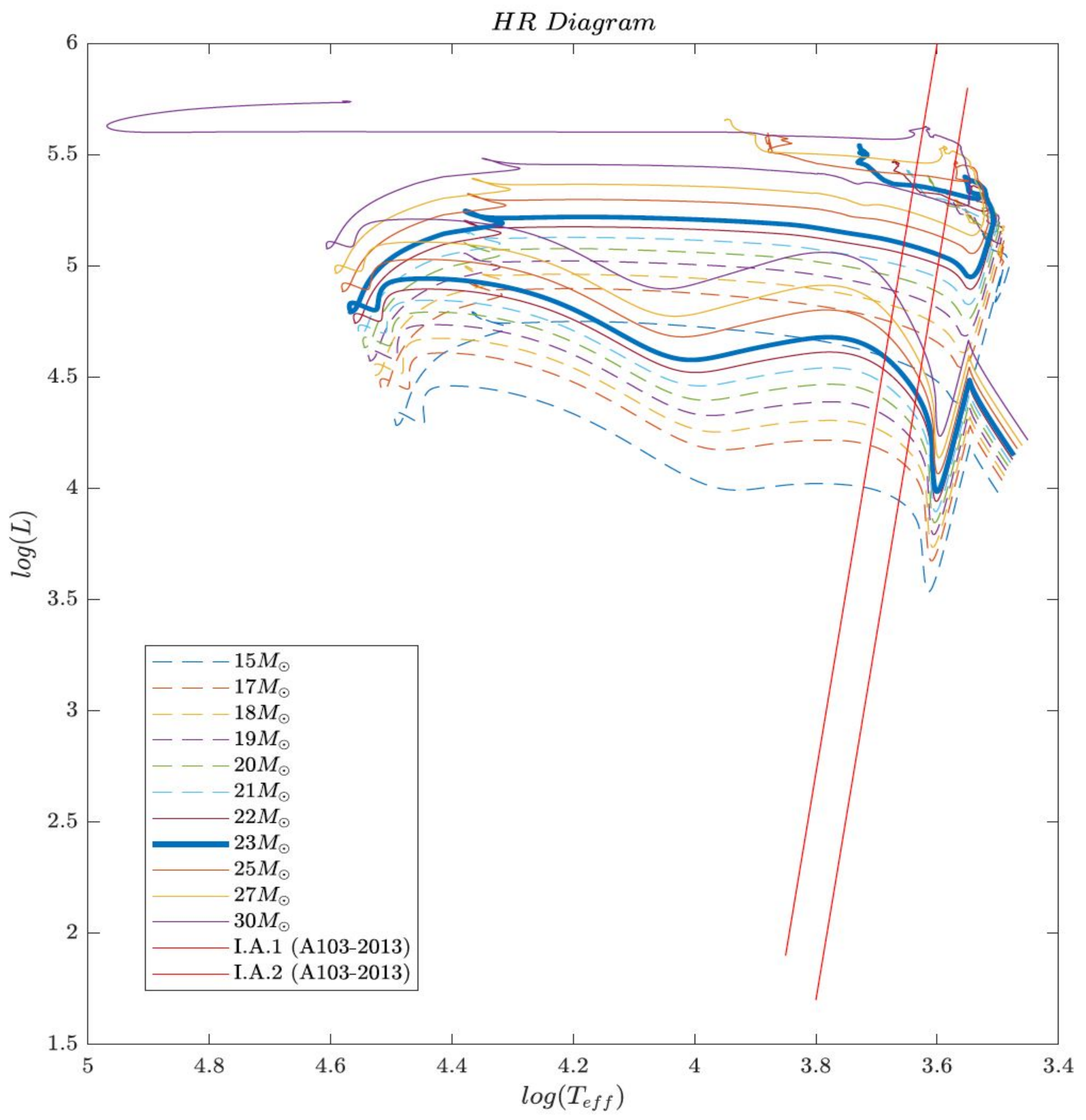


Figure 1: The HR Diagram, showing the evolution paths of stars ranging from 15-30 solar masses, and the Instability Strip, which shows where the mass loss rate was increased to ten times the original value of no increased mass-loss rate.

Equations

$$64 \lesssim \log\left(\frac{L}{L_\odot}\right) + 16.4\log\left(\frac{T_{\rm eff}}{[\rm K]}\right) \lesssim 65. \qquad (1)$$

$$\begin{aligned}\tau_{\rm V} &= \int_{R_{\rm in}}^{R_{\rm out}} \kappa_{\rm V}\rho\, {\rm d}r \\ &\simeq 5\left(\frac{\dot M}{10^{-4} M_\odot\ {\rm yr}^{-1}}\right)\left(\frac{R_{\rm in}}{10^{16}\ {\rm cm}}\right)^{-1} \qquad (2) \\ &\times \left(\frac{\kappa_{\rm V}}{100\ {\rm cm}^2\ {\rm g}^{-1}}\right)\left(\frac{v_{\rm w}}{10\ {\rm km\ s}^{-1}}\right)^{-1},\end{aligned}$$

Introduction

A bright stellar explosion known as a core collapse supernova (CCSN) was first a star of at least 8 solar masses with an upper limit of 120 M⊙ with uncertainties. At the end of the star's life, the core collapses, initiating the explosion. As the collapsing core density approaches that of a nucleus, strong nuclear interactions halt the collapse process and the infalling matter rebounds, producing an outwardly propagating shockwave. Only neutrinos are able to escape this dense and energetic shockwave, and a neutron-rich core is formed. Eventually the shock propagates through the star, completely disrupting the outer layers of the core and the entire envelope with the core becoming a neutron star or black hole. Questions about this explosion mechanism remain. The traditional mechanism is the delayed neutrino mechanism (Bethe & Wilson 1985) and an alternative is the jittering jets mechanism (Soker 2010, 2016).We simulated 48 stellar Models with the open-source code MESA to the point of their core collapse. Variables concentrated within the MESA software were the stellar hydrogen mass, and the optical depth of the dusty wind.

Additional Puzzle Pieces

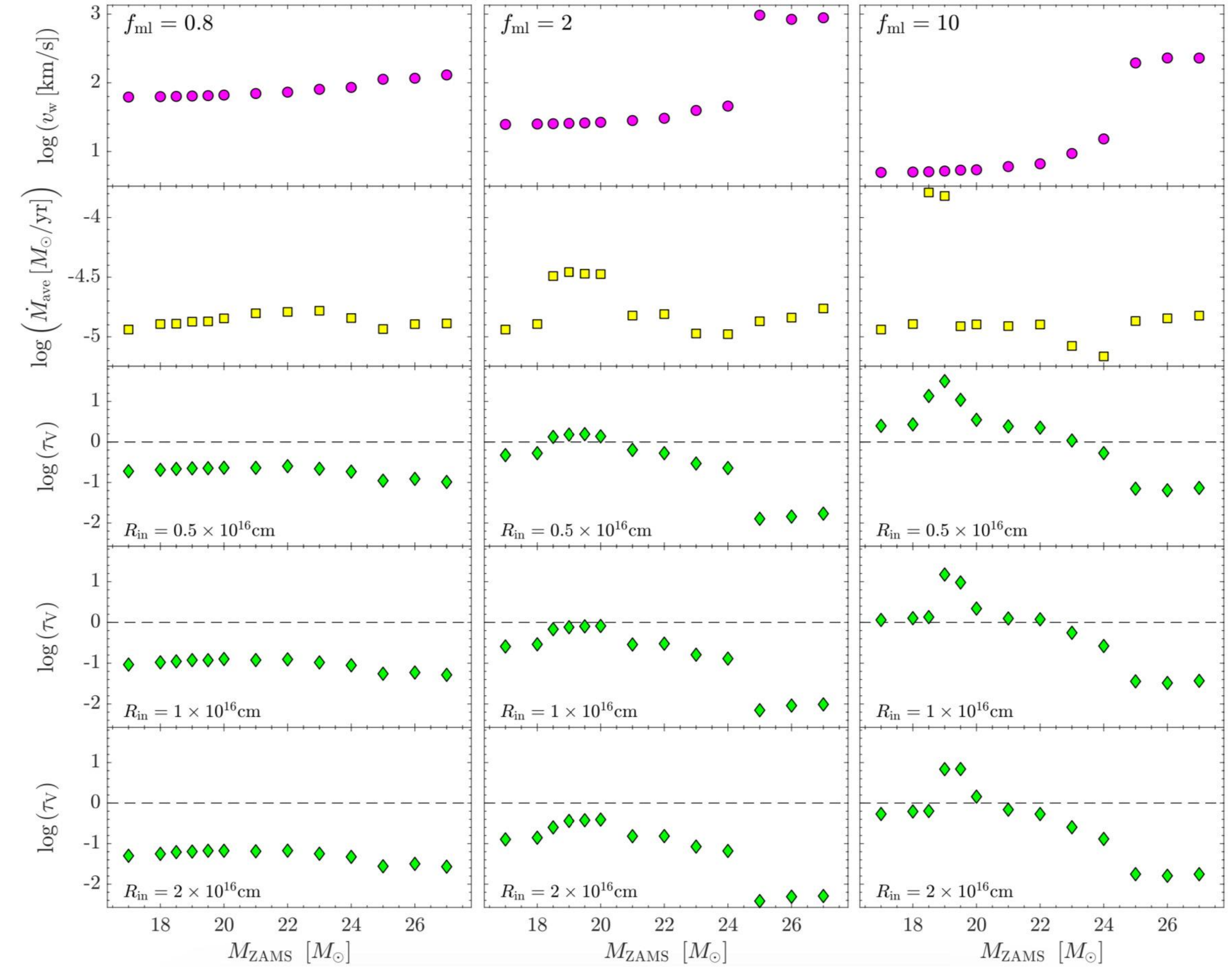


Figure 2: From the top row to bottom and in logarithmic scales: The wind velocity according to equation (1), the average mass loss rate in the last 100 years before core collapse, and the optical depth as given by equation (2) with opacity of $\kappa_V = 100 {\rm cm}^2 {\rm g}^{-1}$ and for three values of the inner radius, R_{in}=0.5, 1, 2e16 cm; the dashed black line marks: τ_V=1. We calculate each quantity for the 3 instability strop mass-loss scaling factors f_{ml}= 0.3 (left), f_{ml}= 2 (middle), and f_{ml}= 10 (right).

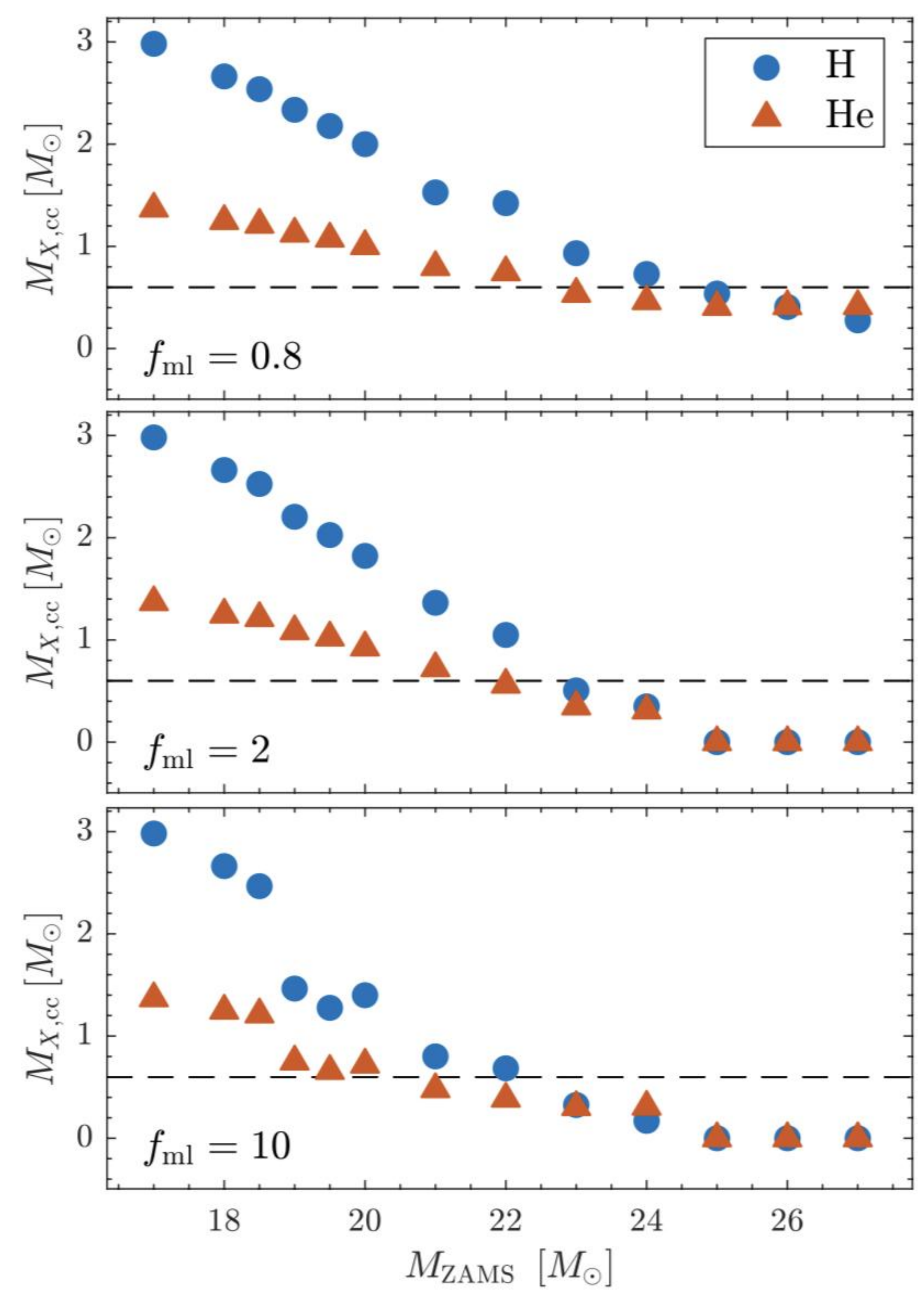
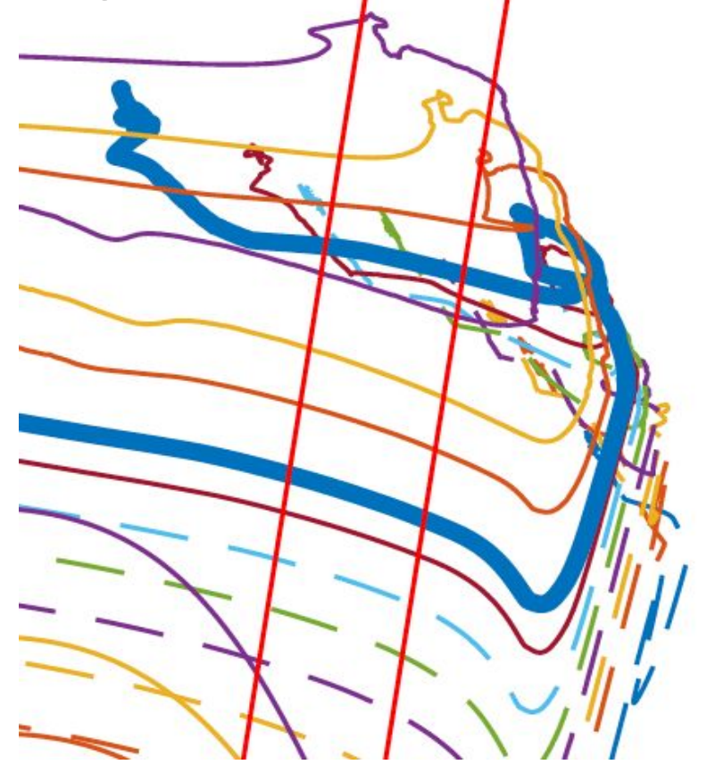


Figure 3: The final envelope mass of hydrogen (blue circles) and helium (orange triangles) as a function of the initial mass. The three panels are for the different mass-loss rate scaling factor f_{ml} , inside the instability strip as the star crosses from left to right in the HR diagram. These will explode as SNE IIb.

Results and Conclusions

It was found that having an enhanced mass-loss rate is necessary to explain the Red Supergiant Problem, and therefore raised a theoretical question regarding by what mass-loss rate was needed to solve this problem. Our results show four groups of stars depending on their property at explosion. Stars that start their life in the mass range 18.5-20M⊙ explode while still pulsating (i.e., inside the instability strip) and are therefore covered by dust. These will be obscured type II CCSN that observations are likely to miss. (2) Stars that start their life in the mass range 20-21 M⊙ leave the instability strip before they explode. These will form observable type II SN. (3) Stars that start their life in the mass range 21-24 M⊙ leave the instability strip and have a hydrogen mass of only <0.5-1 M⊙ when they explode. They will form Type IIb SN. (4) Stars that start their life with a mass of >24M⊙ explode after losing all their hydrogen in a wind, and will explode as type Ib or Ic SN, and will not be counted as type II SN.” If our assumption of enhanced mass loss rate holds, we might ease the red supergiant problem.

Figure 4.



References & Acknowledgements

References:

[1] Modules for Experiments in Stellar Astrophysics (MESA, version 10398 Paxton et al. 2011,2013, 2015, 2018)

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