Consequences of Mass Loss on the Final Fates of Massive Stars

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Abstract

The mass loss rates of massive stars are lower at lower metallicity according to both, theory and observations. Stellar evolutionary calculations treat mass loss as a simple function of luminosity, temperature, stellar mass and surface composition. This approximation has the advantage that the evolution can be followed without the expensive calculations of stellar atmosphere models, but it also adds some additional uncertainity.

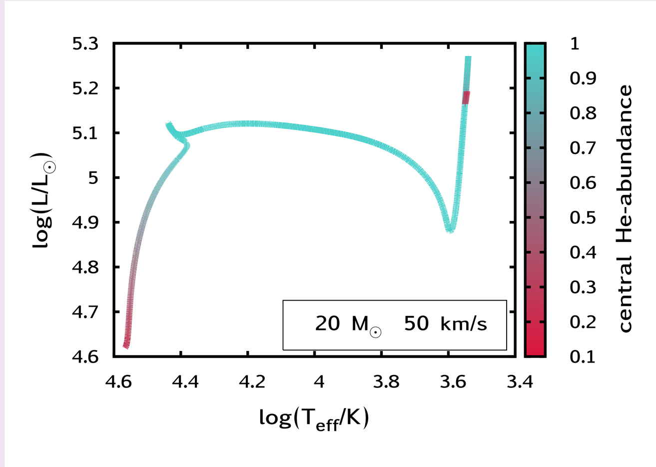
The mass that is lost on the Main Sequence can already influence the whole later evolution. However, the real adventure begins when stars finish core hydrogen burning and start to burn elements of higher atomic numbers. These late stages are not well understood due to observational constraints: stars spend only a small fraction of their lifetime in these stages which are therefore not likely to be observed. On the other hand, these stages are crucial to predict and model the final fates (different types of supernovae and gamma-ray bursts) and remnants (black holes, neutron stars) of the massive stars in question.

Yoon et al. 2006 computed low Z models beyond core hydrogen burning with the assumption of CNO enhanced mass loss. The fastest rotators show properties of the hot, compact, luminous Wolf–Rayet stars. They also identified them as candidates of supernovae and as possible progenitors of long gamma-ray bursts. In this work, the late evolution and final fates are revised, and the consequences of using different mass loss prescriptions are discussed.

Stellar evolution + mass loss recipes

Stellar evolutionary tracks

- hydrodynamic simulation of an isolated, rotating gas sphere (= star)
- nuclear burning, 1D
- Hertzsprung–Russell diagram: T_{eff} vs. Luminosity (log)



Mass loss on the top of it

- model atmospheres with different L_*, M_*, T_{eff}, v_∞/v_{esc} (*Vink et al. 2000*)
- OR spectral analyses → $\dot{M}$ as a function of L_* etc. fitted (= "mass loss recipe /prescription") e.g. *Hamann et al. 1995* (for $\log(L/L) > 4.5$):

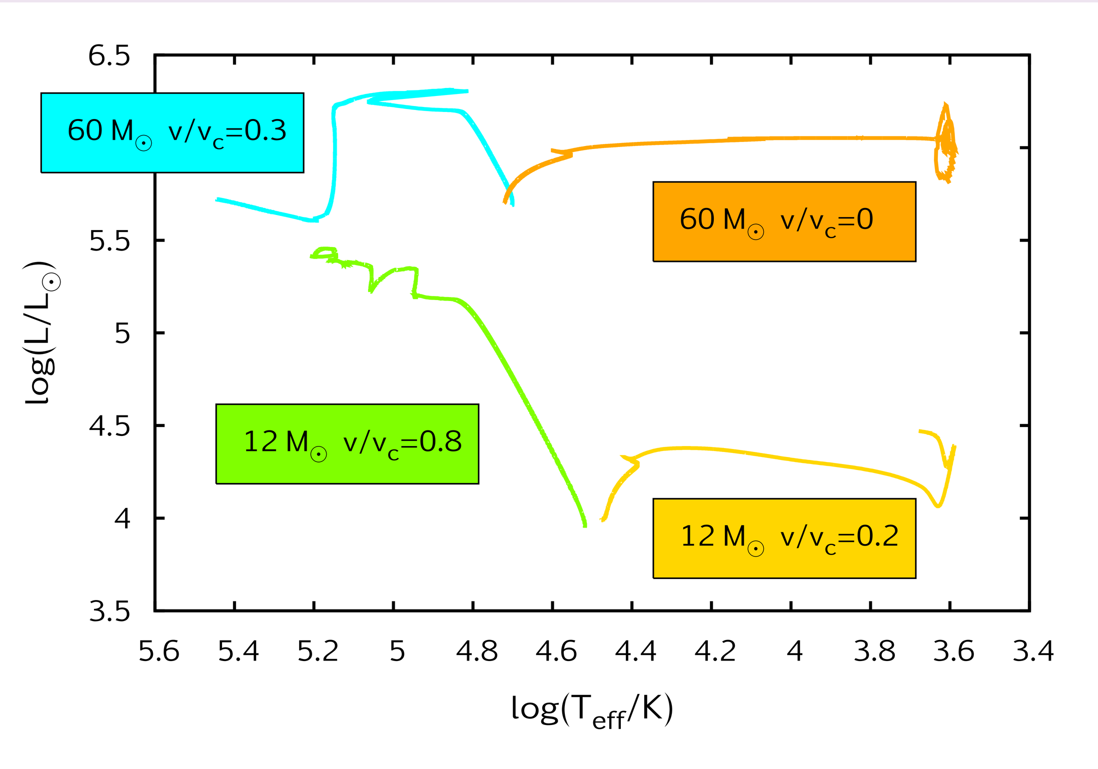
$$\log \dot{M} = -11.95 + 1.5 \log \frac{L_*}{L} + 2.85 X_s + 0.86 \log Z$$

- $\dot{M}$ is calculated in every step and the corresponding M is removed

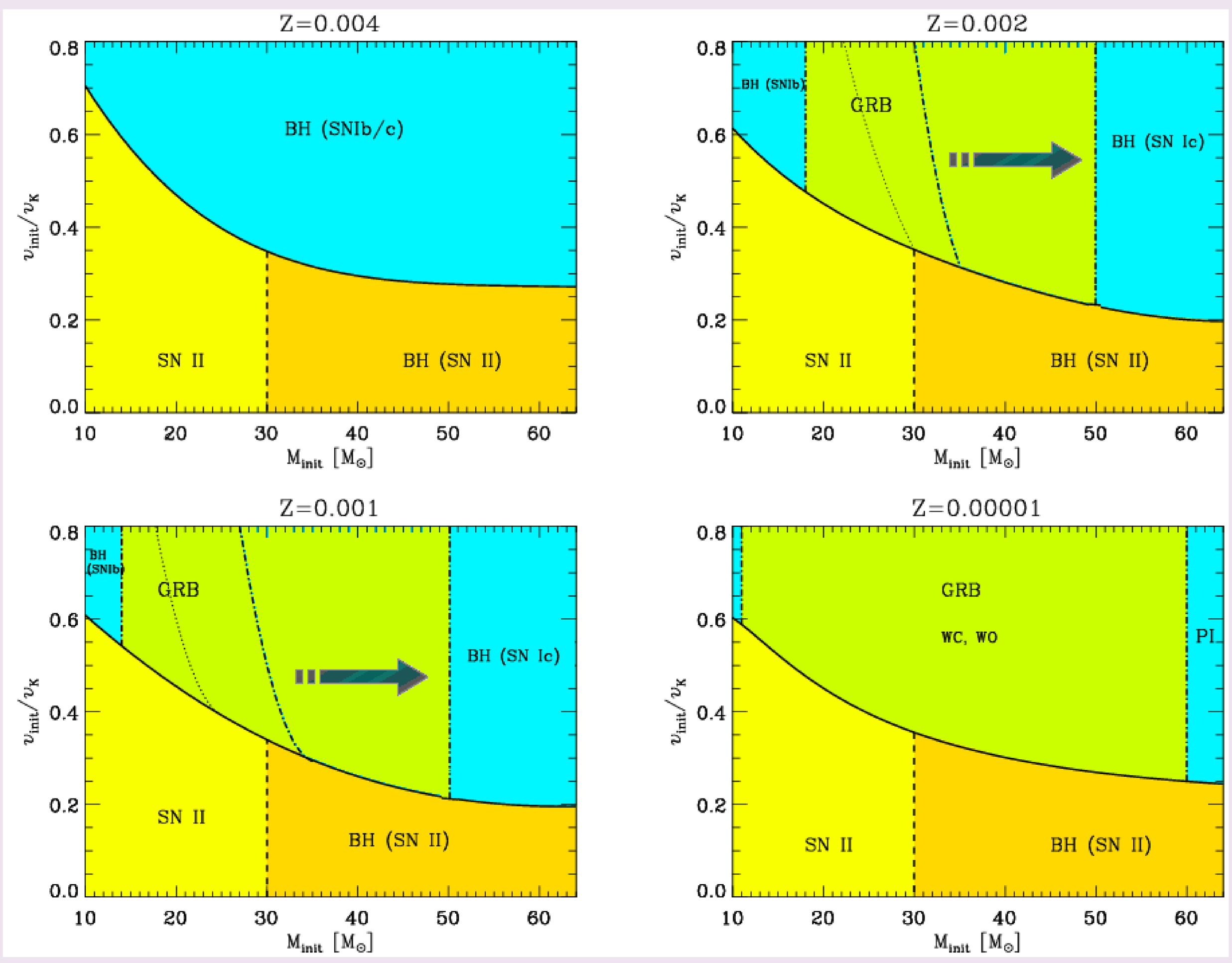
→ fast but approximate
→ mass loss rate has a feedback on the evolution!

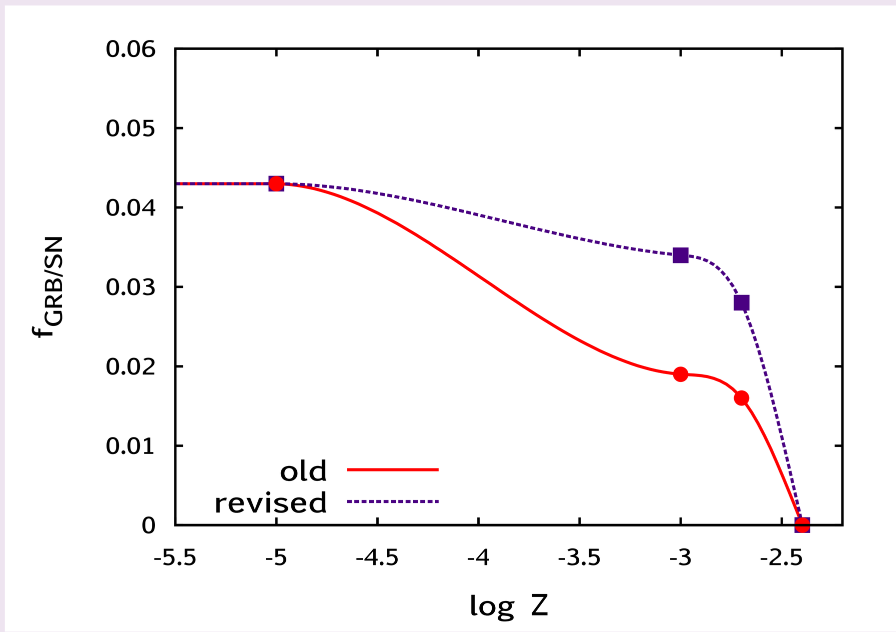
Low Z tracks

Yoon et al. 2006 calculated low Z tracks and predicted their final fates. The Hertzsprung–Russell diagram of these tracks is shown here, color coded according to the final fate prediction (right block).



Yoon'06 REVISED





If one recalculates the tracks without the CNO enhanced mass loss, the results change considerably, as shown in these figures (arrows mark the change). Overall, we have more fast rotating stars and, therefore, more lGRBs at immediate Z ranges.

The WR mass loss

Progenitors of lGRB and SN Ib/c are WR stars

- scarce observations and complicated physical conditions →
- mass loss rate determinations are highly uncertain

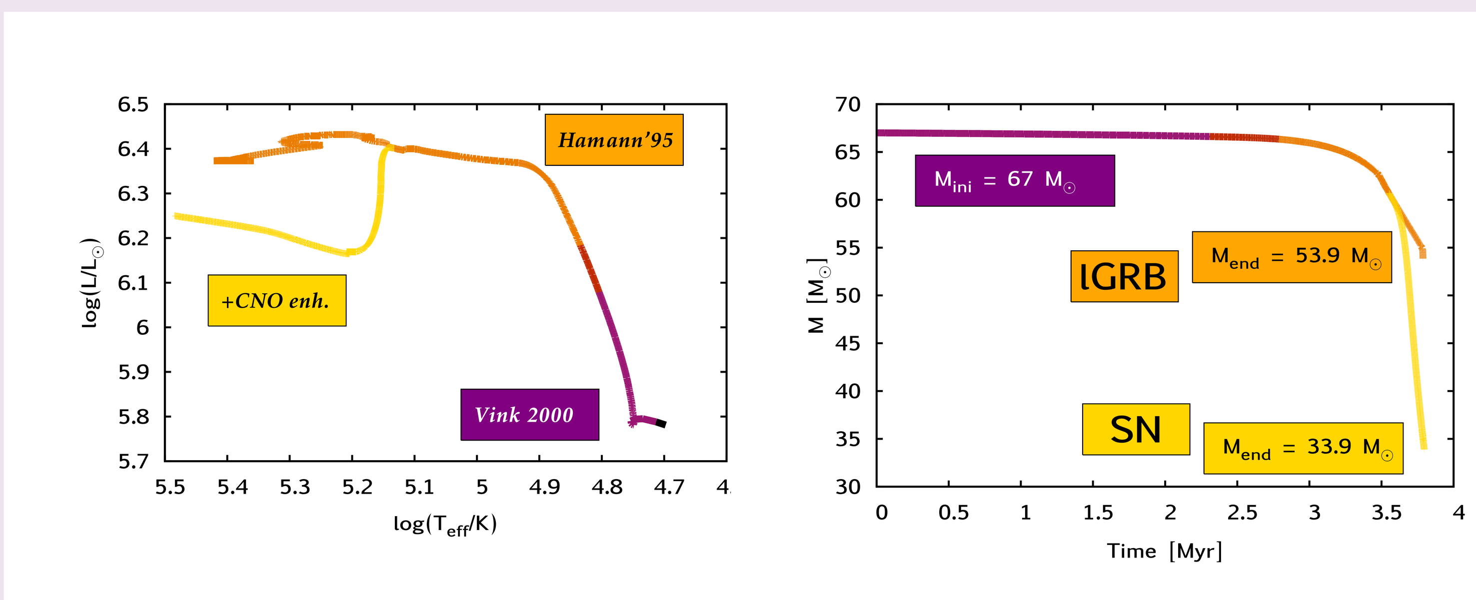
Mass loss rate has a feedback on the evolution
...and on the final fate too!

Mass loss recipes used in *Yoon'06* for WR stars

- *Hamann et al. 1995* reduced by a factor of 10 + Z (Fe) dependence of *Vink et al. 2001* ✓
- enhanced mass loss due to CNO in the surface: $\dot{M} = f \cdot \dot{M}_{H95}$, $f \sim 19 \cdot Z_{CNO}^{surf}$
  - ad-hoc approach
  - probably unphysical (CNO are ionized at $T_{eff} > 10^5 K$) ?↯
  - How much does it effect the final fate predictions?

CNO enhanced mass loss

67 M⊙ v/vc=0.3 tracks from *Szécsi et al. 2014*



- lGRB: fast rotating WR star (collapsar model)
- Mass loss → angular momentum loss → no collapsar
- If CNO enh. massloss is unreasonable: more lGRBs and less SNe →