Impact of mass loss on the formation, structure and evolution of Wolf-Rayet stars

The Wolf-Rayet phenomenon in the Universe
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Context

- Massive stars are subject to intense mass loss.

  45-65% of their initial mass is removed during their lifetimes

- Mass loss is a **major source of uncertainty** in stellar models, but has a large **impact on stellar evolution**.

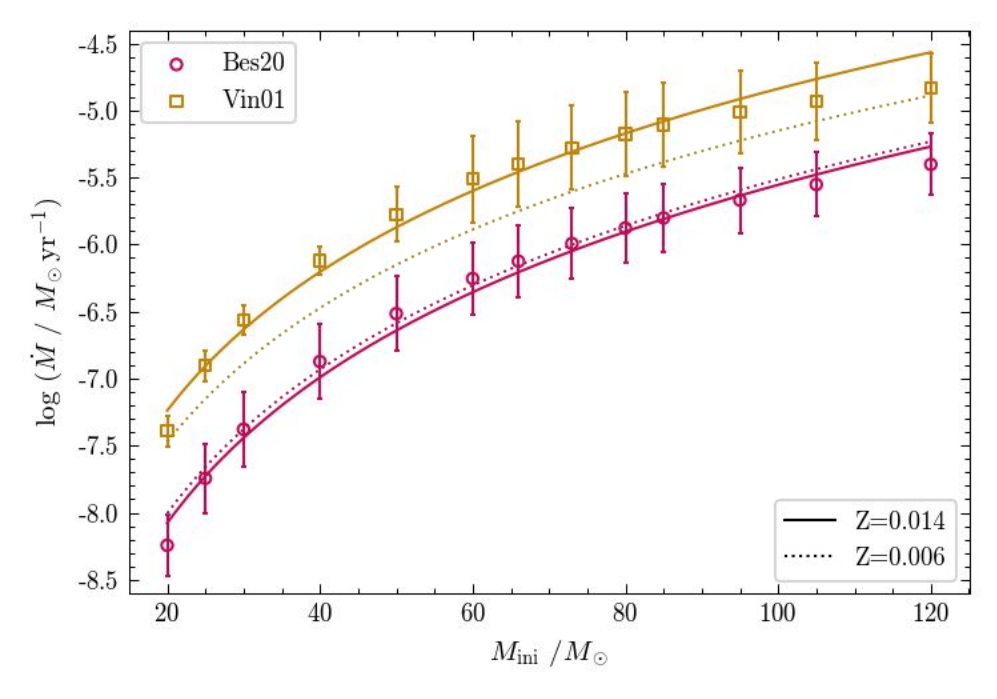
  A wide range of mass loss scenarios must be considered.

Focus of this work:
Investigating the effect of main sequence mass loss on the evolution of massive stars. ***Josiek et al. (in prep.)***
→ *Stellar evolution models*

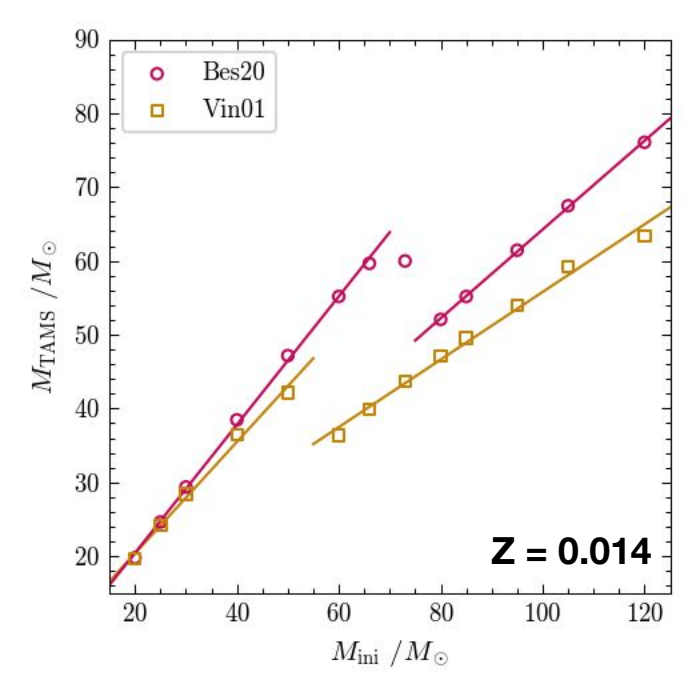
Models

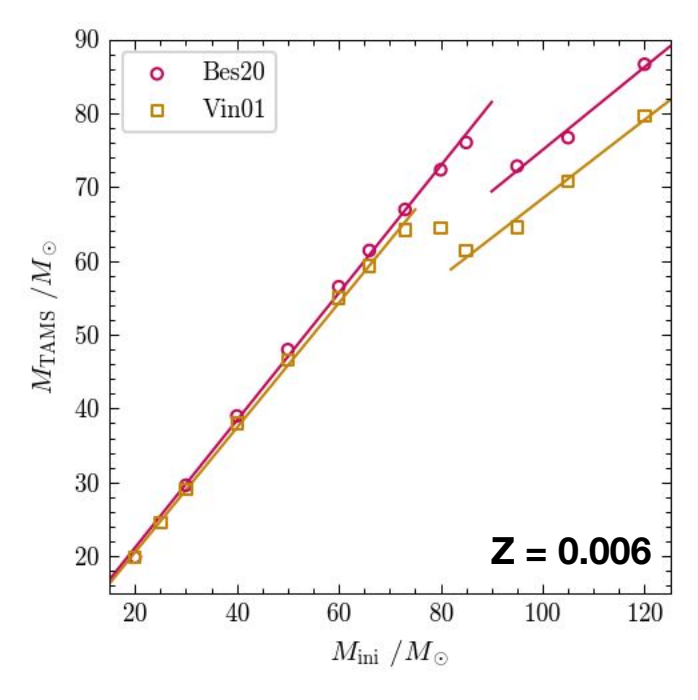
- Geneva Stellar Evolution Code (**GENEC**)
- Initial masses: **20–120 $M_\odot$**
- Metallicity: Solar (**0.014**), LMC (**0.006**)
- **Rotation-free**
- 2 **O/B mass loss** prescriptions:
  - Vink et al. (2001) [standard] **Vin01**
  - Bestenlehner (2020), calibrated on LMC by Brands et al. 2022 **Bes20**
- Run from **ZAMS** to the end of central **carbon burning**

Mass loss rates (Main sequence)



Mass lost during the main sequence





Regime Transition

Vin01:
Bistability jump

Bes20:
Optically thin/thick winds ($\Gamma_{\rm Edd}$)

The theoretical Wolf-Rayet star

In evolution models:

T_{eff} > 10 000 K

X_{surf} < 0.3

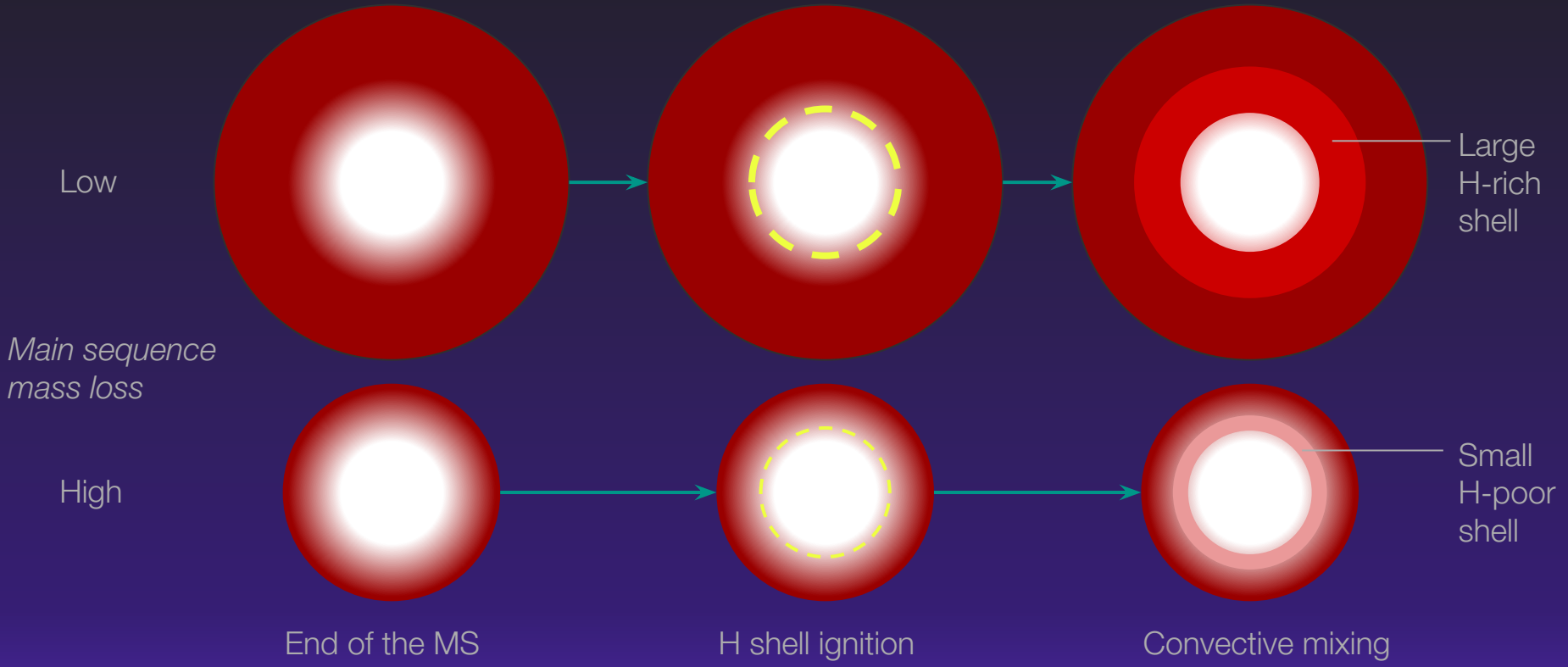
Subtypes:

WNL	N/C > 1, $X_{surf}>10^{-5}$,
WNE	N/C > 1, $X_{surf}<10^{-5}$,
WC	N/C < 1, $T_{eff} < 10^{5.25}$ K,
WO	N/C < 1, $T_{eff} > 10^{5.25}$ K

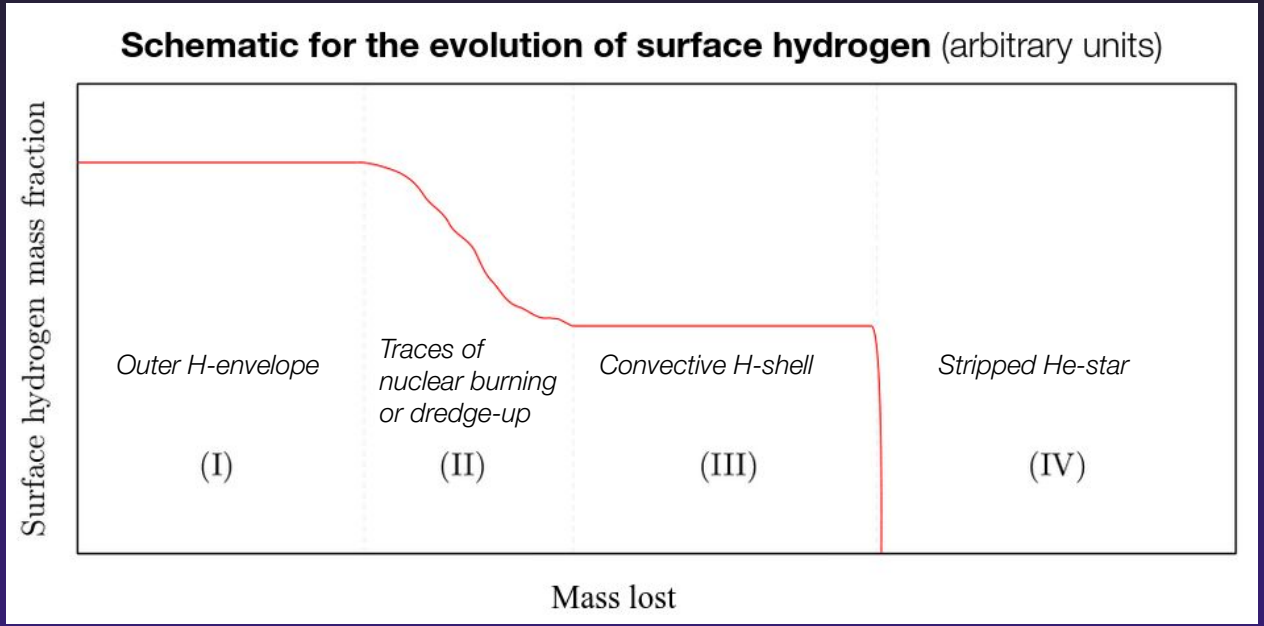
- Mass loss is closely linked to these criteria ($T_{eff}\uparrow$ & $X_{surf}\downarrow$ by removing surface material)
- Not applicable to non-WR stripped stars (e.g. through binary mass transfer) (e.g. Shenar et al. 2020)
- **Spectroscopic classification ≠ Theoretical classification**

How is hydrogen (re)distributed inside the star?

H He



Evolution of surface hydrogen



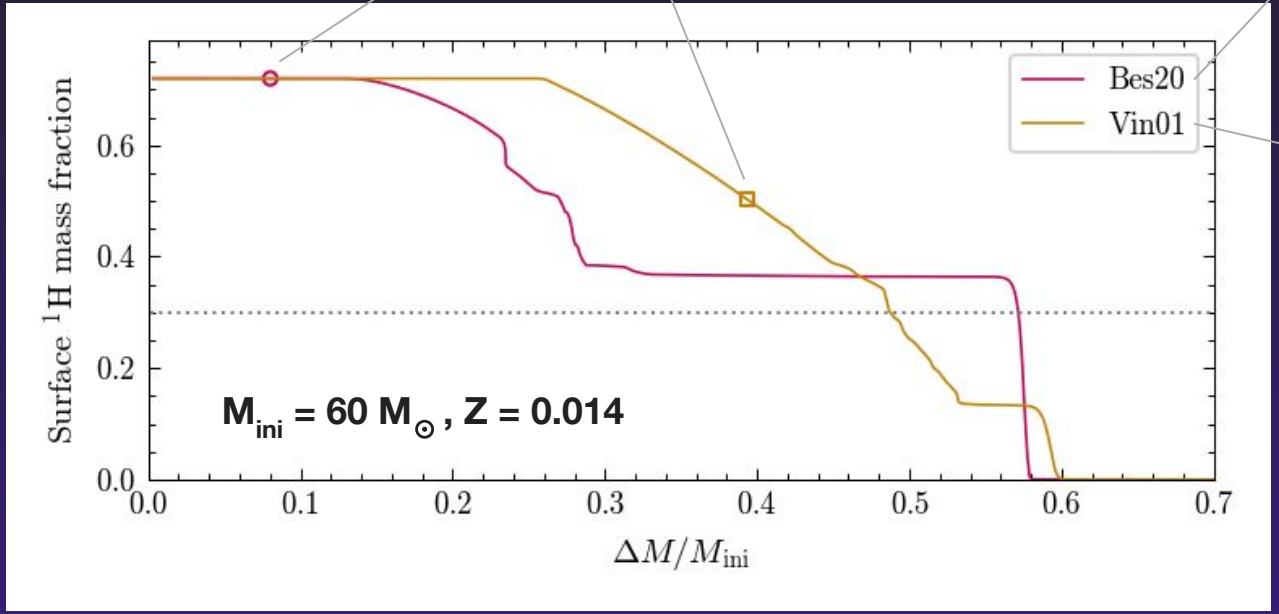
Typical “hydrogen depletion curve”

Evolution of surface hydrogen

End of the MS

Low MS mass loss regime

High MS mass loss regime

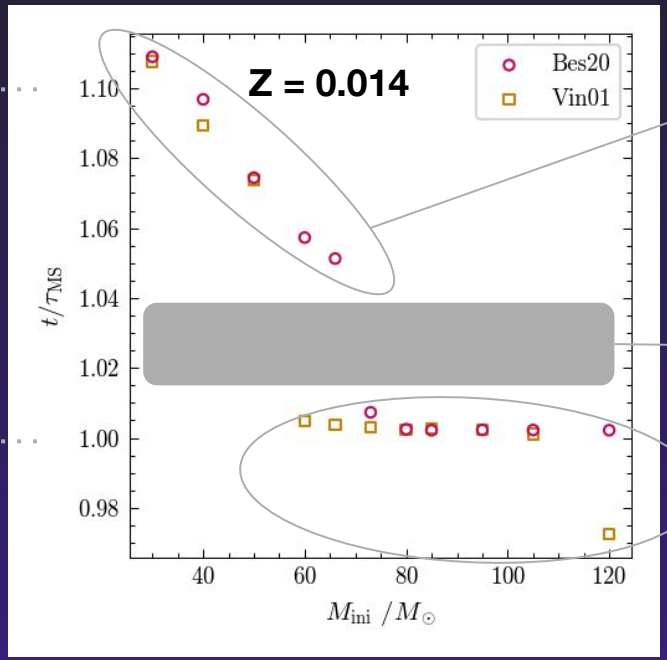


“Hydrogen depletion curve” with model data

Time of WR formation

He burning

H burning



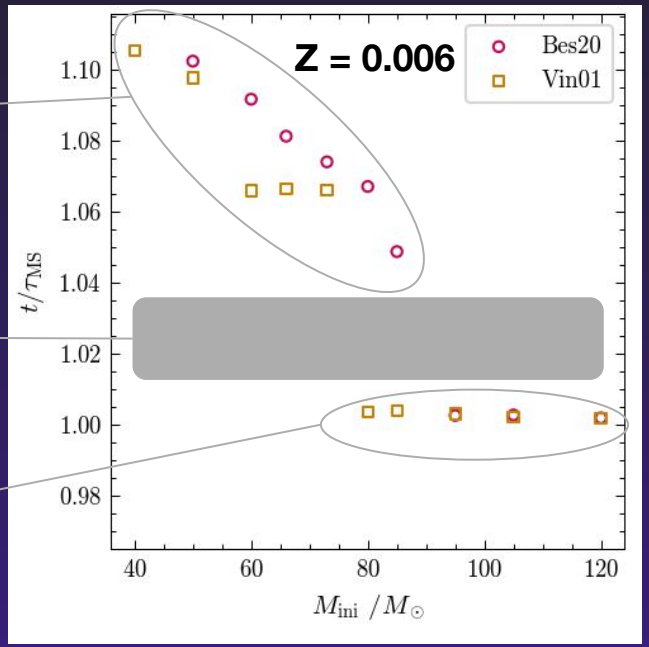
Late-formed

Low MS mass loss

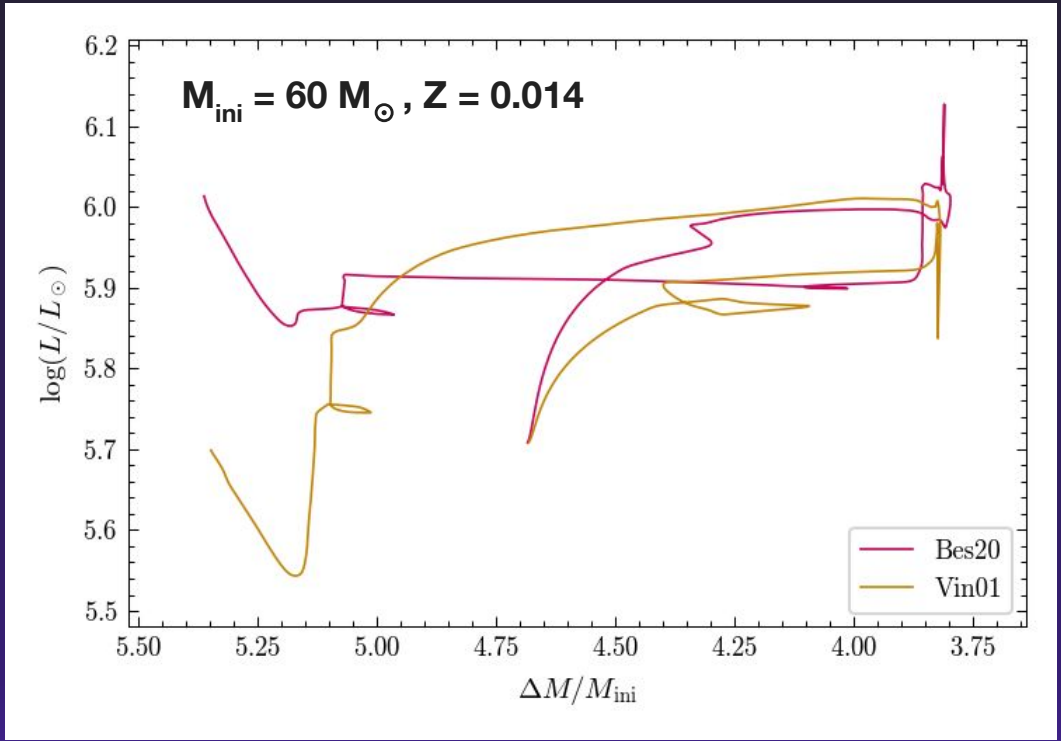
Gap

Early-formed

High MS mass loss

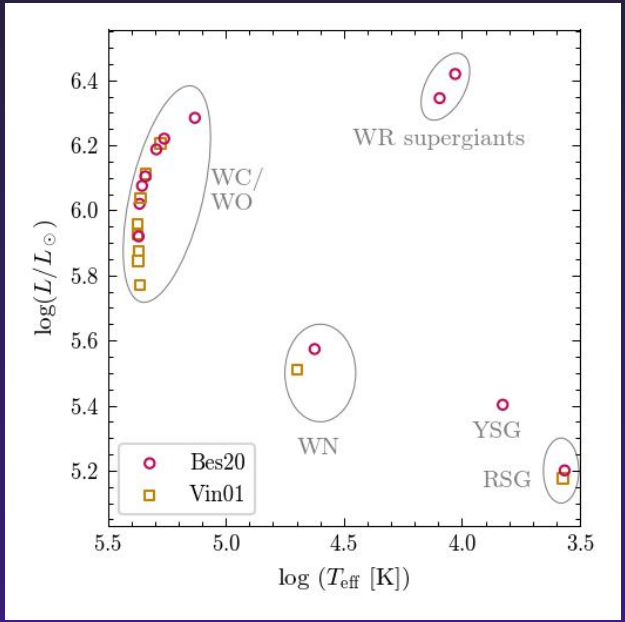


Evolution in the HRD

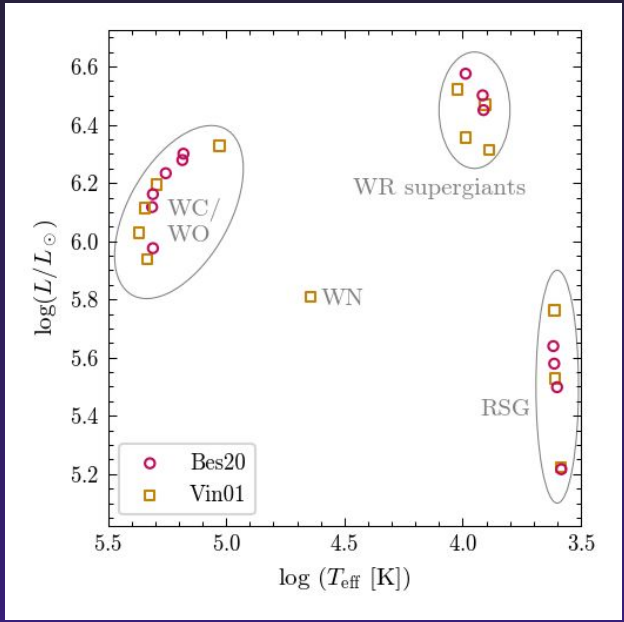


Evolution endpoint

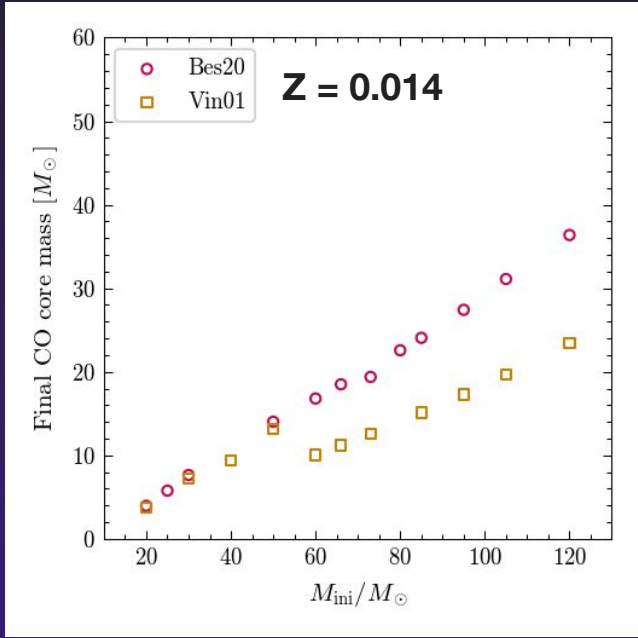
Z = 0.014

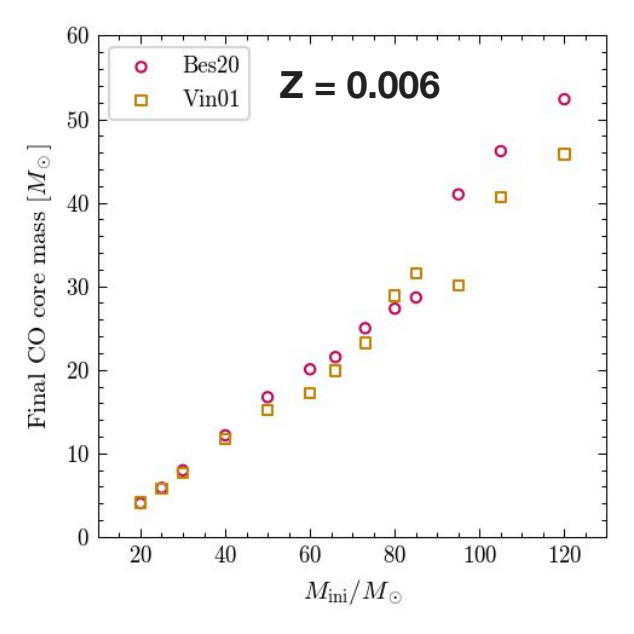


Z = 0.006



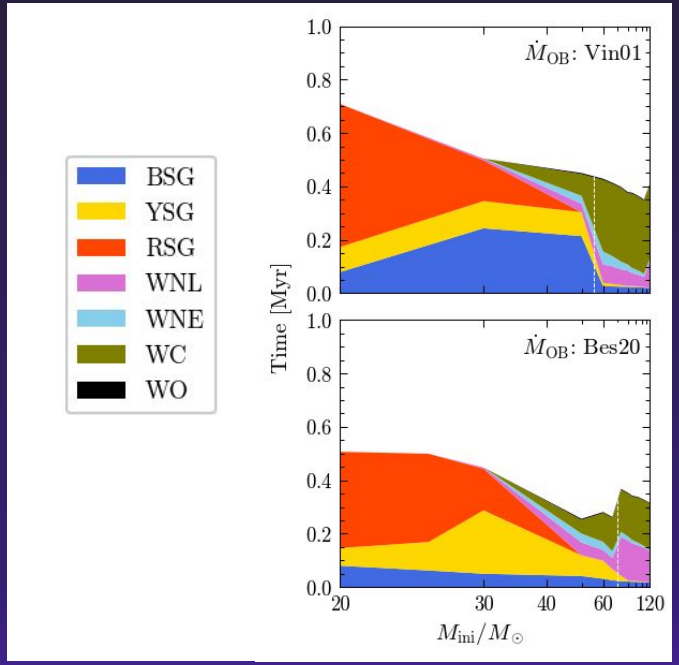
Final core mass



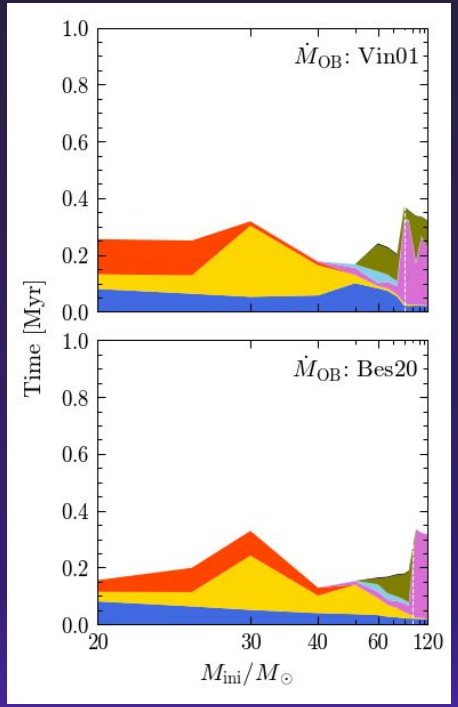


Timescales/Populations

Z = 0.014



Z = 0.006



Conclusions

❶ There are two distinct regimes for main-sequence mass loss. (According to the two mass loss prescriptions)

❷ Main sequence mass loss impacts the stellar structure deeply. Structure of **convective zones** (hydrogen shell, MS core)

❸ There are two formation channels for single Wolf-Rayet* stars.

Late-formed: **O/B → RSG/YSG → BSG → WNE (→ WC/WO)**
Early-formed: **O/B → WNL → WNE → WC/WO**

** For theoretical Wolf-Rayet stars!*