Rotating first stars: A theoretician perspective

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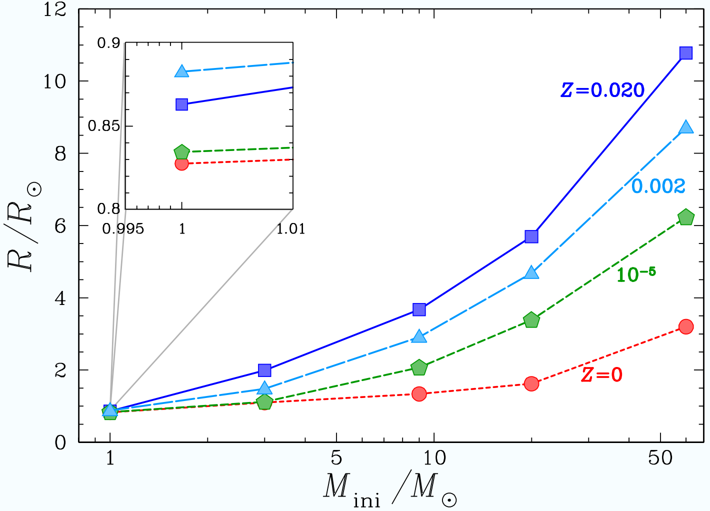
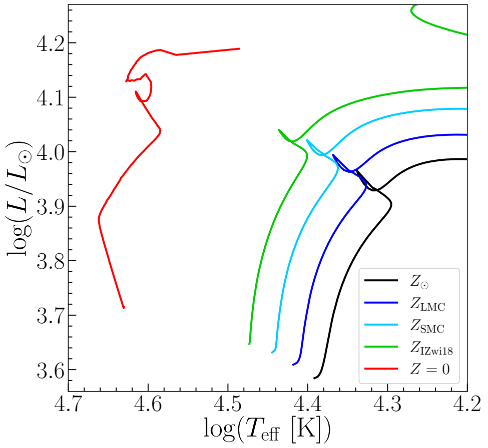
Metallicity effects on stellar evolution

Ekström+ 2008



Metallicity effects on stellar evolution

models from Ekström+ 2012; Georgy+ 2013; Groh+ 2019; Murphy+ 2021



More compact stars
→ bluer
→ more luminous

$Z \neq 0$: CNO-cycle from start
$Z = 0$: *pp*-chains first

$Z \neq 0$: strong contraction after MS
$Z = 0$: almost no structural changes

Winds of massive stars

precise mechanism not at reach in 1D codes

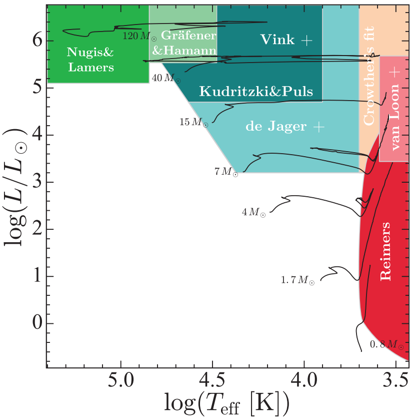
implemented through pre-scriptions of rates

de Jager+ 1988; Nieuwenhuijzen & de Jager 1990; Kudritzki+ 1987; Kudritzki & Puls 2000; Vink+ 2000 2001 2011; Bestenlehner 2020; Björklund+ 2021; Reimers 1975; van Loon+ 2005; Beasor+ 2020; Kee+ 2021; Nugis & Lamers 2000; Gräfener & Hamann 2007

often narrow validity domain:
→ switch from one to another

wind clumping? How much?

steady state vs outbursts:
in models, always averaged rates



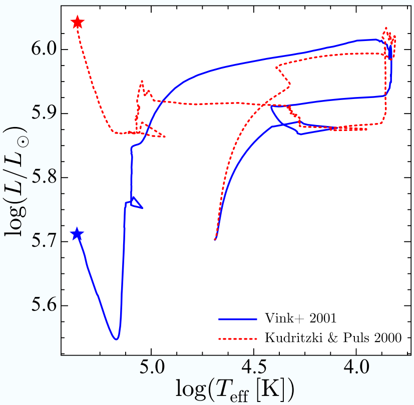
Winds of massive stars

key ingredient for massive stars evolution

even a slight change during a limited time modifies the outcome and the endpoint

comparisons between obs and models for massive star is rather a check for $\dot{M}$ than anything else!

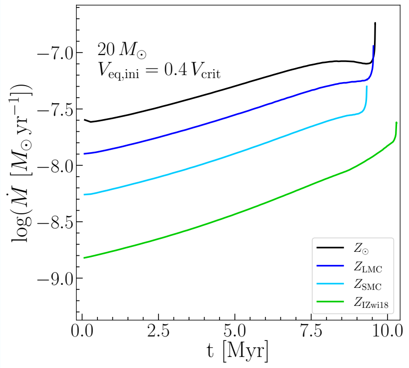
60 $M_\odot$ *models at* $Z = 0.014$



Low-Z mass loss

- lower radiative winds scaling ~ $Z^{0.85}$ (uncertain at low Z or advanced stages)
- different position in HRD
- difficult to form WR stars with single star scenario

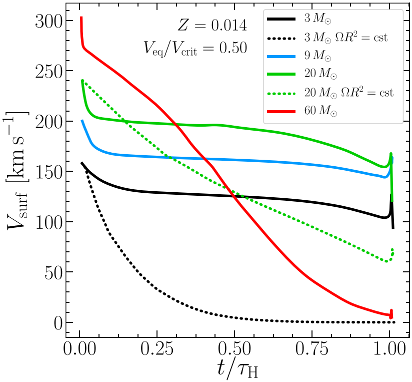
models from Ekström+ 2012; Georgy+ 2013; Groh+ 2019



Rotating massive stars

Two competing processes for the surface velocity evolution:

- MASS LOSS
  → deceleration of the surface
- TRANSPORT
  → core-envelope coupling



The net result is a complex combination of the two

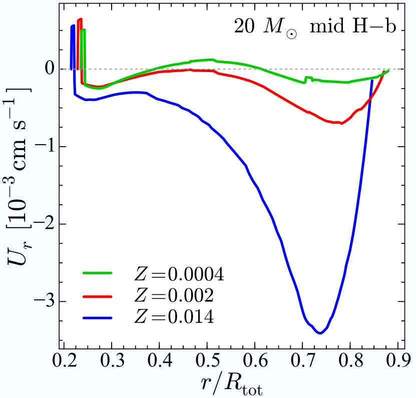
Metallicity effects on internal transport

weaker meridional circulation

steeper Ω-gradient
→ stronger shear

shorter diffusion time:
$t_{\mathrm{diff}} \propto \frac{R^2}{D}$

models from Ekström+ 2012; Georgy+ 2013; Groh+ 2019



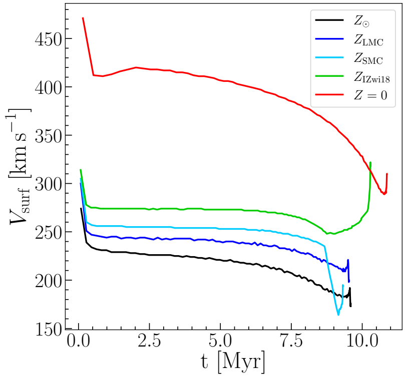
Metallicity effect on internal transport

less winds

less transport

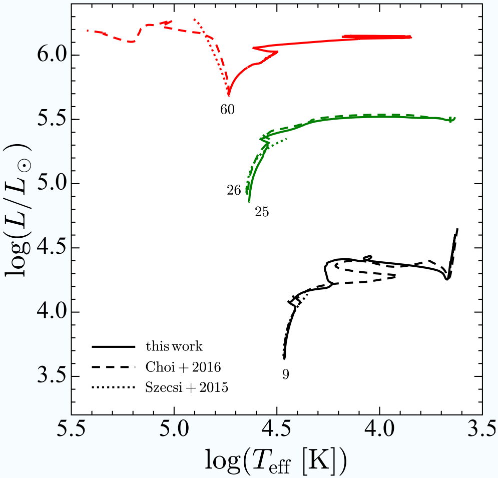
compact star:
→ same angular momentum content leads to more rapid surface rotation

models from Ekström+ 2012; Georgy+ 2013; Groh+ 2019; Murphy+ 2021



Metallicity effect on internal transport

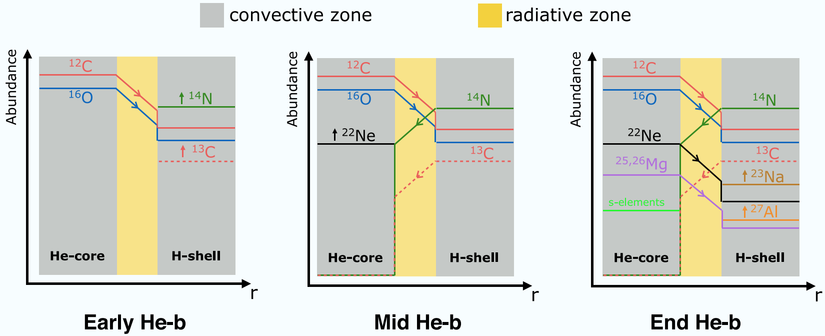
$Z = Z_{IZwicki18}$ comparison Szécsi+ 2015; Choi+ 2016; Groh+ 2019



homogeneous evolution: solution to produce WR stars?

Metallicity effect on nucleosynthesis

Choplin+ 2016 (see also Limongi & Chieffi 2012; Clarkson & Herwig 2021)

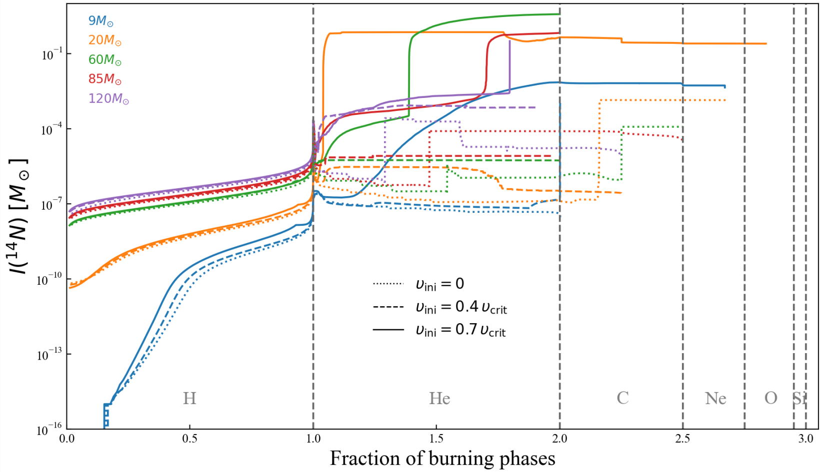


Diffusion of C from core to shell
CNO flash in the shell → N production

N back in the He-b core → ^{22}Ne → *s*-process *(Frischknecht+ 2012)*

^{14}N production in Pop III

Tsiatsiou+ in prep.



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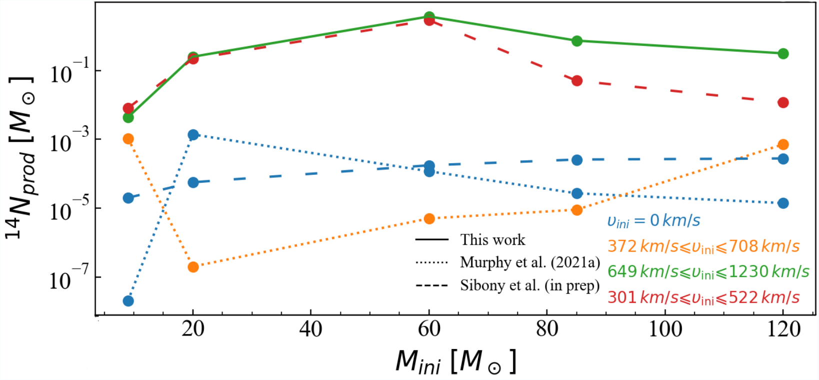
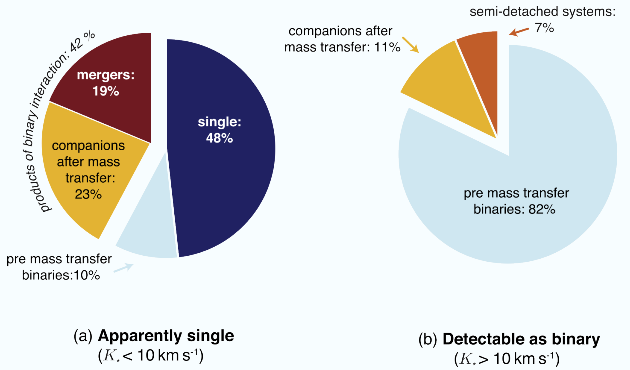


Massive binary stars

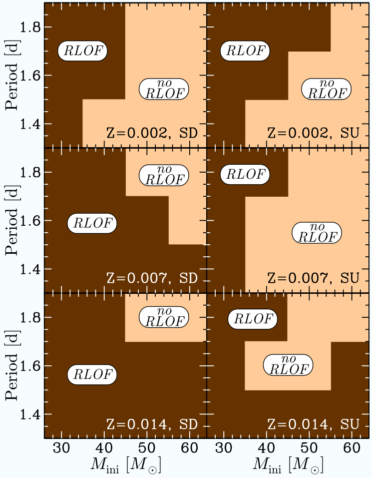
70% of O-stars could be binaries *Sana+ 2012*

de Mink+ 2014



Metallicity effects on binarity

Song+ 2016



compactness, rotation

RLOF less probable

less efficient RLOF mass transfer at low Z *Götberg+ 2018*

Binarity contribution to reionisation

stripped stars emit ionising photons

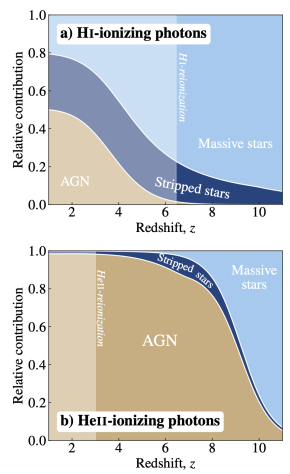
non negligible contribution at later times than massive stars

beware: the effect of rotation not taken into account

rotation: homogeneous evolution during MS
→ long duration for ionising emission

real Pop III: stay blue from ZAMS to end of core He-b

Götberg+ 2020



Wrap-up

- big gap between low-Z and Pop III
- rotation effects very strong
- binary effects only for extremely close systems
- is low-Z ($< Z_{\mathrm{IZwi18\ analogs}}$) possible?

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