Evolution through helium burning: massive stars

Evolution of "massive" stars, M > (8…10)M$_\odot$ through central H- and He-burning phase are affected crucially by the treatment of convection (overshooting, semiconvection).

Very massive stars have very intensive mass loss (stellar winds), which can uncover the stellar cores such that layers modified by ε_n can become visible (Wolf-Rayet stars).

Also rapid rotation (~100 km/s) cause additional mixing.

Modelling of massive stars is therefore very complicated.

Evolution through helium burning: massive stars

Semiconvection

Important for M > 10M$_\odot$

because of decreasing (shrinking) convective core mass with time, brought about by the increasing concentration of ε_{CNO}.

Leaves behind a chemical composition of varying concentration around convective core.

Both ∇_μ and ∇_{rad} are rapidly varying (oscillating) functions of position, located in/near where

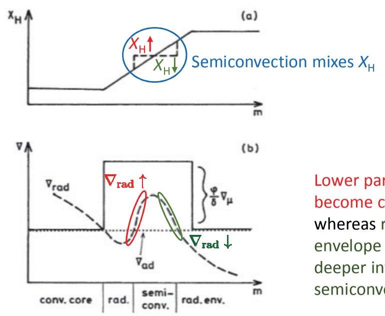
$$\nabla_{ad} < \nabla_{rad} < \nabla_{ad} + \frac{\varphi}{\delta}\nabla_\mu \ .$$

Evolution on the main sequence

Convection: "semiconvection"

Semiconvection (slow mixing) occurs if

$$\nabla_{ad} < \nabla_{rad} < \nabla_{ad} + \frac{\varphi}{\delta}\nabla_\mu \ .$$



Since $\kappa \sim (1 + X_H)$
and $\nabla_{rad} \sim \kappa$.

Lower part will eventually become convective, whereas radiative envelope will grow deeper into the formerly semiconvective layer.

Evolution through helium burning: massive stars

Semiconvection

Important for M > 10M$_\odot$

because of decreasing (shrinking) convective core mass with time, brought about by the increasing concentration of ε_{CNO}.

Leaves behind a chemical composition of varying concentration around convective core.

Both ∇_μ and ∇_{rad} are rapidly varying (oscillating) functions of position, located in/near where

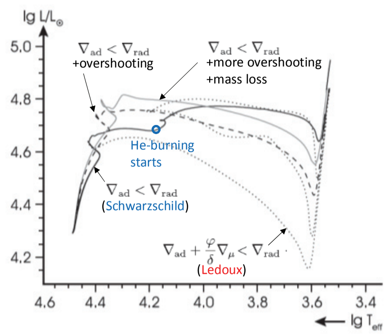
$$\nabla_{ad} < \nabla_{rad} < \nabla_{ad} + \frac{\varphi}{\delta}\nabla_\mu \ .$$

This makes a clear definition of the size of the convective core difficult, with a region just outside the core with fluctuating radiative and convective layers, the size of which is rather difficult (uncertain) to compute.

Evolution through helium burning: massive stars

Semiconvection

$M = 15M_\odot$

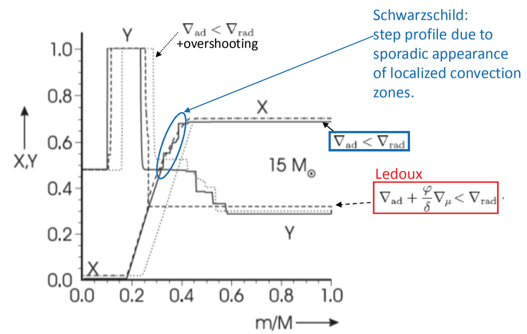


Evolution through helium burning: massive stars

$M = 15M_\odot$

Semiconvection

Chemical profiles at the end of H-MS

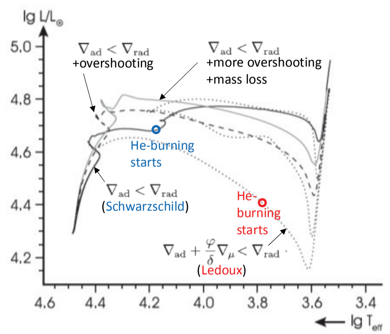


For Ledoux criteria: H-MS lasts longer by 1.4My and He start burning later by 40 ky.

Evolution through helium burning: massive stars

Semiconvection

$M = 15M_\odot$

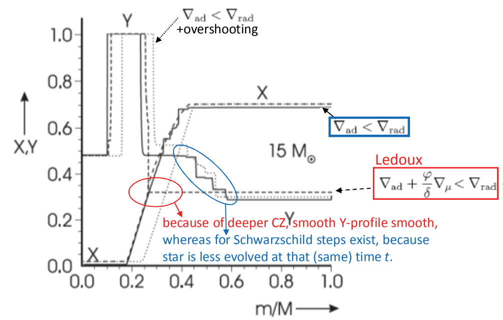


Evolution through helium burning: massive stars

$M = 15M_\odot$

Semiconvection

Chemical profiles at the end of H-MS

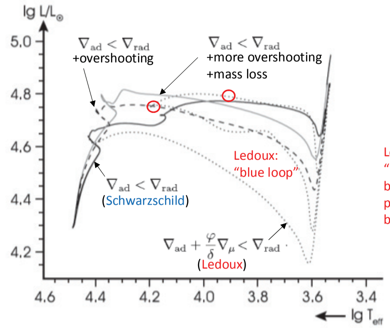


For Ledoux criteria: H-MS lasts longer by 1.4My and He start burning later by 40 ky.

Evolution through helium burning: massive stars

Semiconvection

M = 15M$_\odot$



Ledoux:
"blue loop" during central He-burning; Y_c ~ 19% at hottest point & Y_c~0 when halfway back to Hayashi line.

Evolution through helium burning: massive stars

Overshooting (OV) / mass loss: particularly important for very massive stars