Thermohaline mixing: an agent for chemical transport in stars

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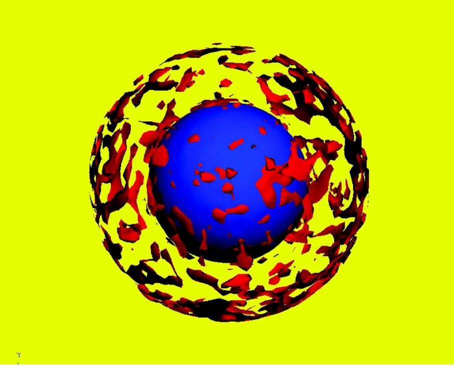
Introduction

- History – why does stellar evolution care about thermohaline mixing?
- What thermohaline mixing can potentially do
- What problems are there?

^{3}He burning

$$^3\mathrm{He} + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He} + 2p$$

- ^{3}He burning is an unusual burning reaction.
- It lowers the mean molecular weight of material.
- Eggleton et al. (2006) found it drove mixing in 3D hydro simulations of a red giant.



Eggleton, Dearborn & Lattanzio (2008)

Thermohaline mixing

- Charbonnel & Zahn (2007) identified the mechanism for this extra mixing process: thermohaline mixing
- Heat diffuses more rapidly than salt (chemical elements).
- A displaced element loses heat to its surroundings.
- It has a higher mean molecular weight that its surroundings, so is more dense than its surroundings
- It continues to sink.

Courtesy of E. Glebbeek

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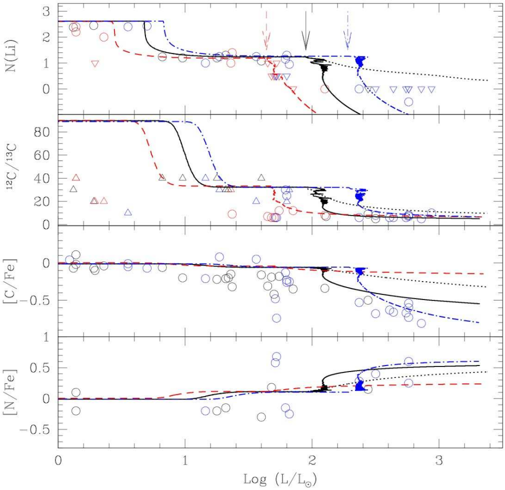
Relevance to stellar evolution

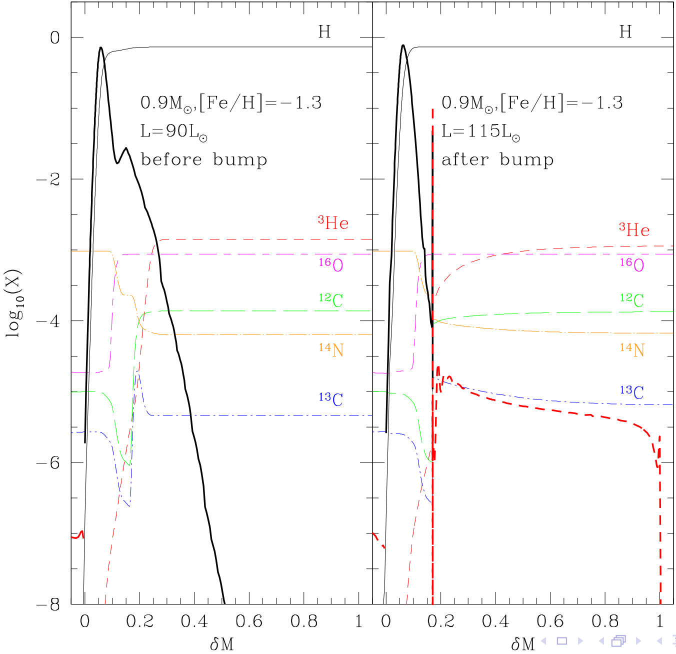
- On ascent of the giant branch, deep convective envelope develops.
- CN-cycled material dredged-up into the envelope – first dredge-up.
- H-burning shell then catches up with the homogenised region – luminosity bump.
- $^{3}\mathrm{He}$ burning lowers the mean molecular weight, driving thermohaline mixing.

Abundance changes on the giant branch

- Above the luminosity bump, stellar abundances change
- C, Li fall, while N rises
- The $^{12}C/^{13}C$ ratio also falls
- CN-cycled material is being brought to the surface
- Thermohaline mixing neatly accounts for this!

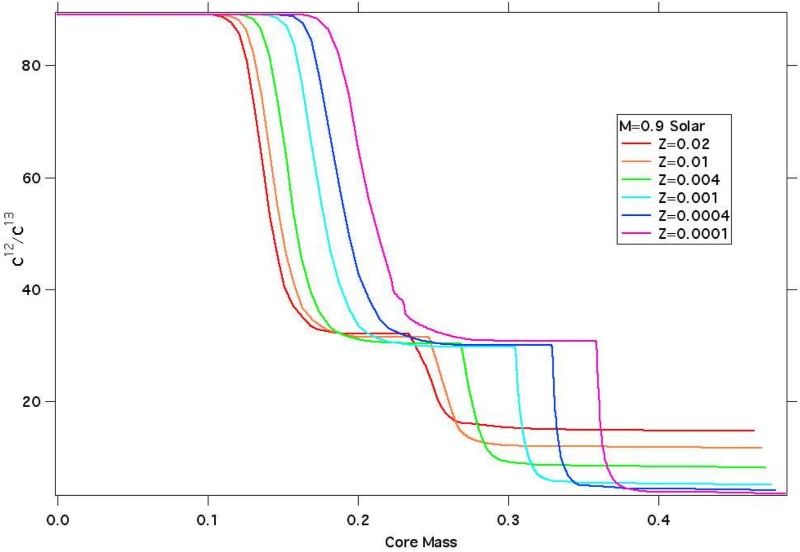
Charbonnel & Zahn (2007)




H
0.9M⊙,[Fe/H]=−1.3
L=90L⊙
before bump
L=115L⊙
after bump
3He
16O
12C
14N
13C
log10(X)
δM
0
−2
−4
−6
−8
0.2
0.4
0.6
0.8
1

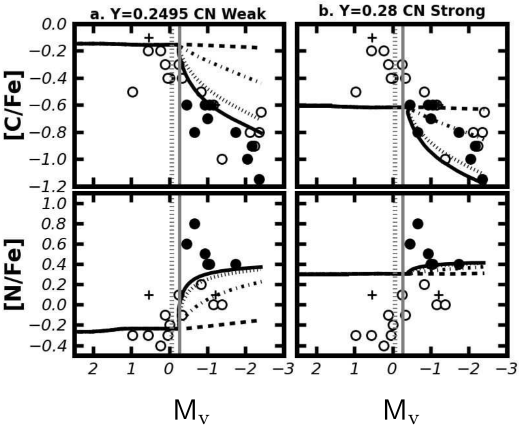
Metallicity dependence

Eggleton, Dearborn & Lattanzio (2008)



Mixing in M3

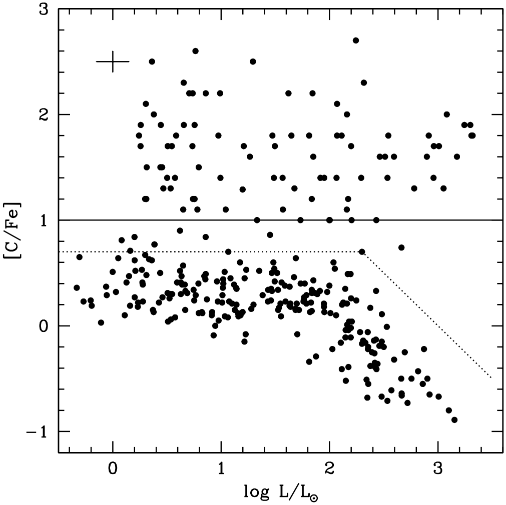
- Thermohaline mixing ought to be at work in globular clusters
- The picture is complicated by multiple populations
- Allowing for the CN-weak and CN-strong stars being from different populations, thermohaline mixing also explains the abundance trends in M3.



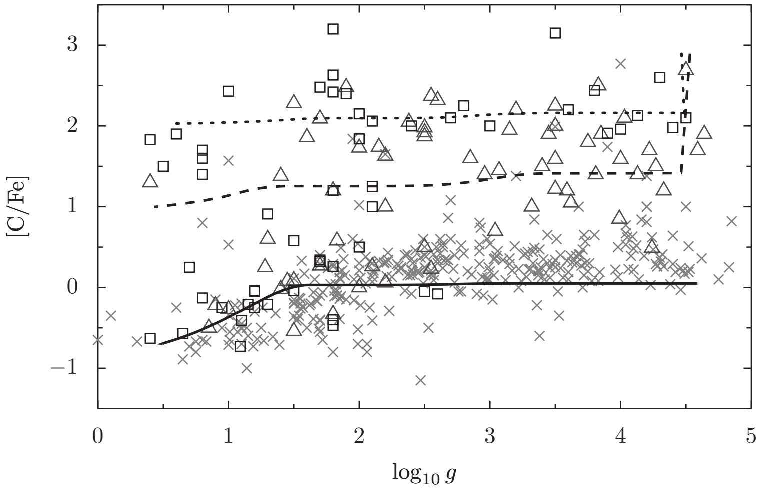
Carbon-enhanced metal-poor stars

- 20% of metal-poor stars are carbon-rich.
- Most are binaries, with a long dead AGB star having produced their carbon.
- They don't show evidence for mixing on the giant branch.
- Thermohaline mixing also fits this evidence – mixing is less efficient in C-rich stars.

Lucatello et al. (2006)



Carbon-enhanced metal-poor stars



Stancliffe et al. (2009)

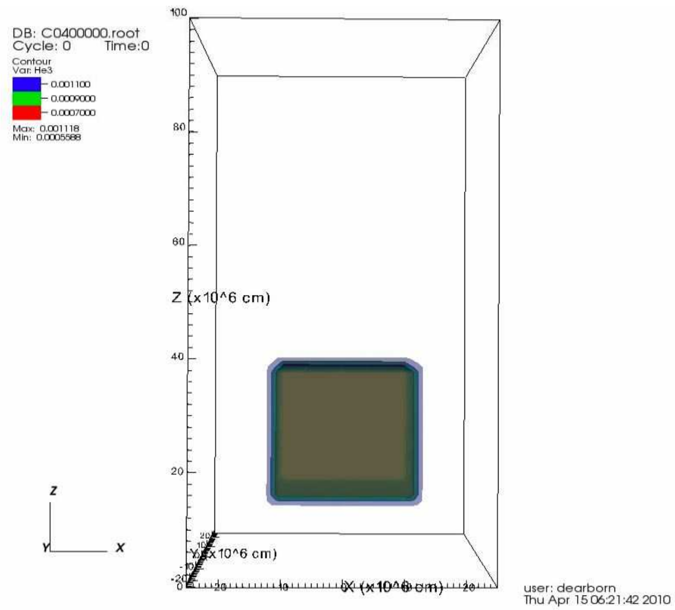
Mixing after the giant branch

- Thermohaline mixing doesn't destroy all the $^3\mathrm{He}$ on the giant branch!
- Mixing can continue into later stages, core helium burning and beyond (Cantiello & Langer, 2010; Charbonnel & Lagarde, 2010)
- In low metallicity stars, it can lead to significant lithium production on the asymptotic giant branch (Stancliffe, 2010)

Problems

- Thermohaline mixing is still fit with a parameter – we have little justification for that parameter
- Other processes can inhibit thermohaline mixing...
- Magnetic fields (Charbonnel & Zahn, 2007b)
- Rotation (horizontal turbulence) may disrupt thermohaline mixing (Denissenkov & Pinsonneault, 2008)
- We need detailed modelling of interactions.

3D hydrodynamical modelling



Conclusions

- Thermohaline mixing seems to neatly fit many observations
- It would be nice to have an a priori justification for the mixing rate, rather than fit a parameter.
- Thermohaline mixing will interact with other processes – we need to determine how.