The fate of super-AGB stars at low metallicity

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Ph-D thesis at Geneva Observatory with
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Gdansk 2005

Introduction

Astrophysical interest of sAGB stars:

- peculiar nucleosynthesis.
- can be important contributors to enrich the ISM.
- can be progenitors of ONe WD and neutrons stars.

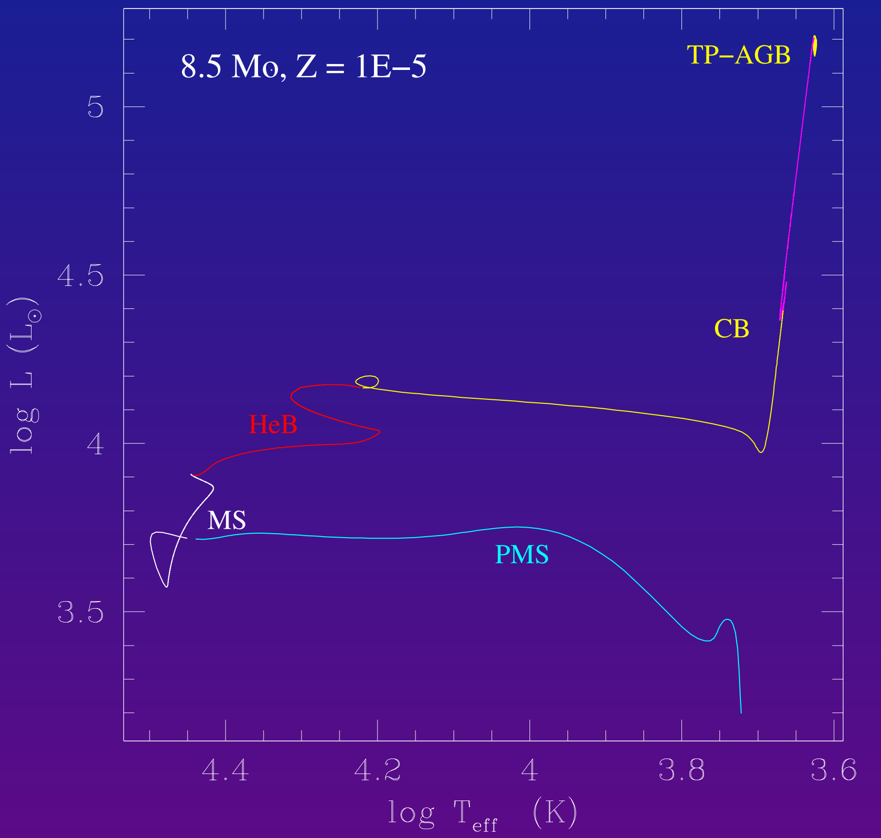
From observational point of view:

- Find a peak at $1.2\ M_\odot$ in the WD distribution;
- But no PN is find with such high mass central object.
- Some hints that sAGB can be precursors of SNIIp/n.

At $Z = 10^{-4}$, sAGB mass range is $7 - 9\ M_\odot$.
$\Rightarrow$ We investigate a $8.5\ M_\odot$ star at $Z = 10^{-4}$ with the stellar evolution code STAREVOL in order to determine its fate.

- Collaboration with: L.Siess, G. Leclair and C. Charbonnel.

H and He burning phases



End of H burning:

- $M_{\text{core}}^{\text{He}} = 1.18\ M_\odot$.
- Lifetime of MS: 2.57×10^7 yr

End of He burning:

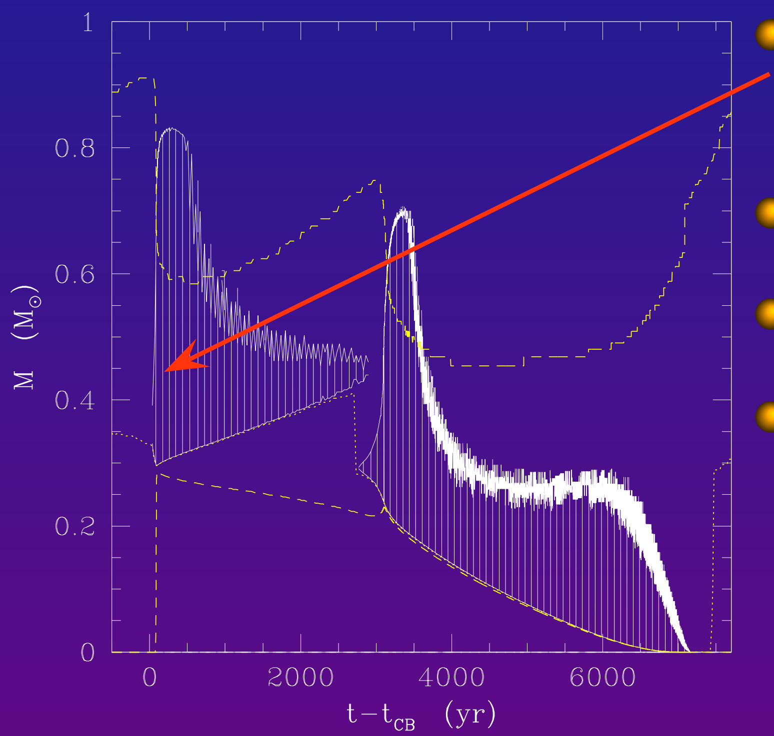
- $M_{\text{core}}^{\text{He}} = 2.34\ M_\odot$
- $M_{\text{core}}^{\text{CO}} = 1.07\ M_\odot$
- Lifetime: 4.57×10^6 yr

- Composition of the CO core: $^{16}\text{O} = 0.881$, $^{12}\text{C} = 0.118$.

Convective envelope sinks until it reaches the HBS which burns out.

Off-center Carbon burning

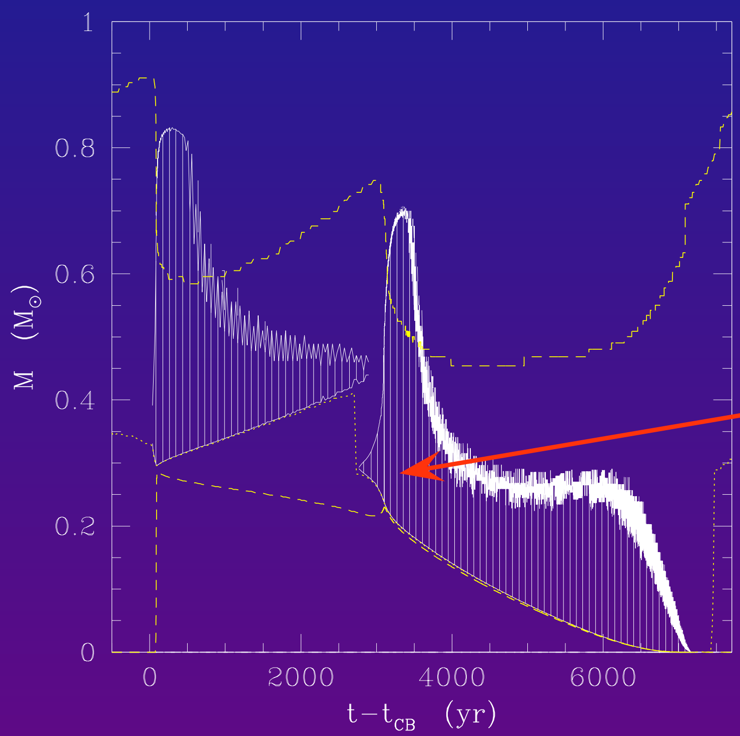
CO core is degenerate after He-burning.
HeBS increases T and ρ in the core until C ignites off center.



- C flash ($L_C = 1.4 \times 10^6\ L_\odot$) generates a first convective zone;
- 1.6×10^6 yr after central He-burning.
- $M^{CO}_{core} = 1.18\ M_\odot$
- $M^{C}_{igni} = 0.34\ M_\odot$

Off-center Carbon burning

CO core is degenerate after He-burning.
HeBS increases T and ρ in the core until C ignites off center.

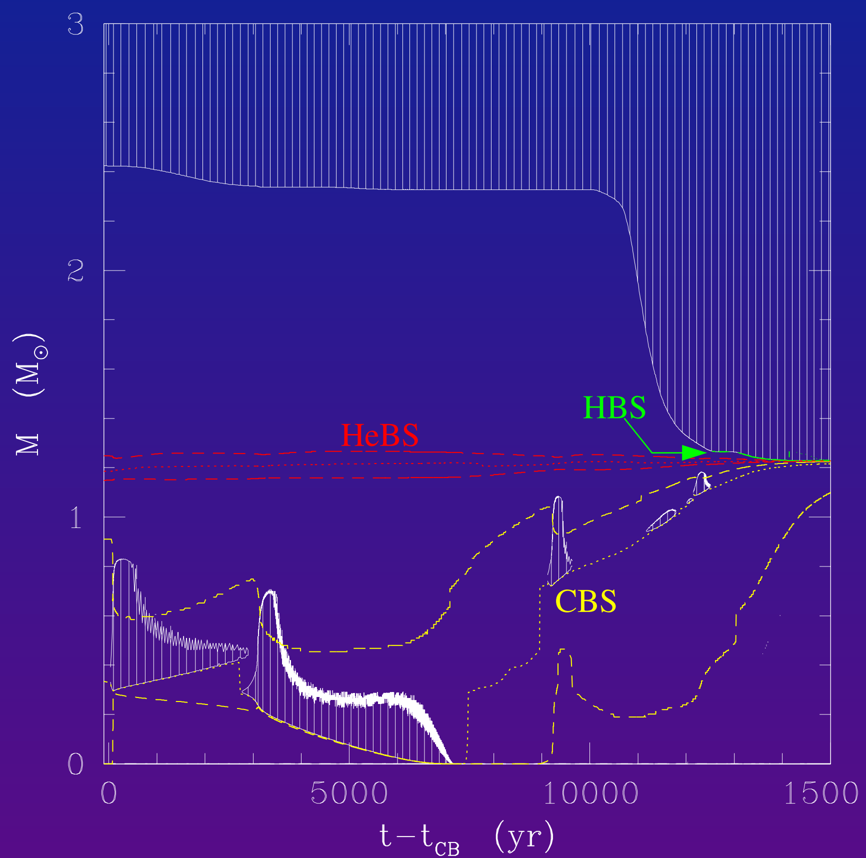


- C flash ($L_C = 1.4 \times 10^6\ L_\odot$) generates a first convective zone;
- After contraction a second convective zone appears.
- It propagates as a flame toward the center.

End of C burning, composition of the center:

- $^{16}O = 0.65$, $^{20}Ne = 0.26$;
- traces of: ^{23}Na, ^{24}Mg, ^{25}Mg, ^{21}Ne, ^{12}C, ^{26}Mg, ^{27}Al, ^{28}Si.

2DUP



$\Rightarrow$ AGB phase begins with a ONe core of $1.22\ M_\odot$.

Surface abundances:

- He raises to 0.36.
- Z increases to 6×10^{-4} (mostly ^{12}C, partly ^{16}O and ^{14}N).

After 2DUP the star has lost $3 \times 10^{-3}\ M_\odot$.

End of s-AGB

$\Rightarrow$ Fate of sAGB depends on the competition between mass loss and the growth of the core during the AGB phase.

$M_{\text{core}} = 1.37\ M_\odot$

- Electrons captures occur:
  - first on ^{27}Al:

    $$^{27}\text{Al} + e^- \rightarrow {}^{27}\text{Mg}$$

  - then on ^{25}Mg, ^{23}Na, ^{20}Ne...
- O deflagration which goes outward in the star.

$\Rightarrow$ SN with a neutrons star remnant.

$M_{\text{core}} < 1.37\ M_\odot$

- Mass loss is efficient to expel the envelope.
- Electrons captures are prevented.

$\Rightarrow$ planetary nebulae and a ONe white dwarf.

AGB phase

AGB phase with several assumptions on mass loss rate and mixing:

High mass loss	Low mass loss

• Blöcker (1995).
• Case $\mathcal{A}$:
  • no overshoot.
• Case $\mathcal{B}$:
  • with diffusive overshoot.
	• de Jager et al. (1988).
	• Case $\mathcal{C}$:
	  • no overshoot.

In all cases mass loss rates are scaled with $\sqrt{Z/Z_\odot}$.

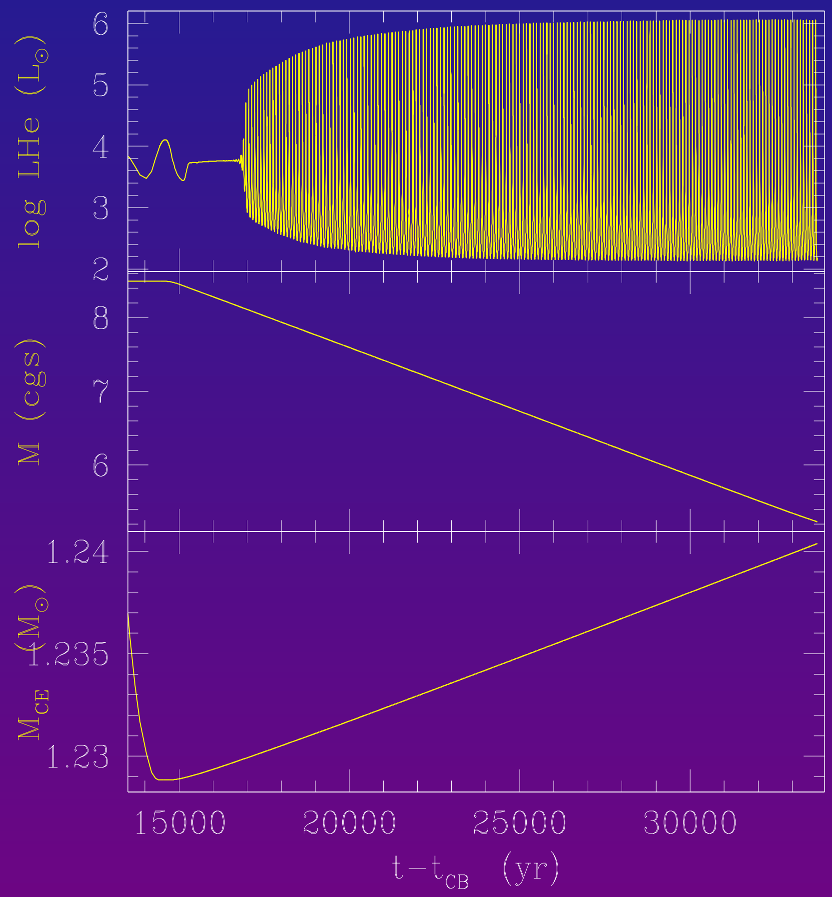
Diffusive overshoot follows Herwig (2000) below the envelope:

$$D_{\text{ov}} = D_0 \exp\left(\frac{-2z}{f.H_p}\right), \quad z = r_{\text{BCE}} - r \quad \text{and} \quad f = 0.004.$$

AGB: Blöcker, no OV

This model has been evolved through 176 thermal pulses.
$\tau(\mathrm{TPAGB}) \simeq 1.8 \times 10^4$ yr.

- Characteristics of the pulses:
  - Weak;
  - Short;
  - Frequent;
  - No 3DUP.
  - Very efficient HBB.



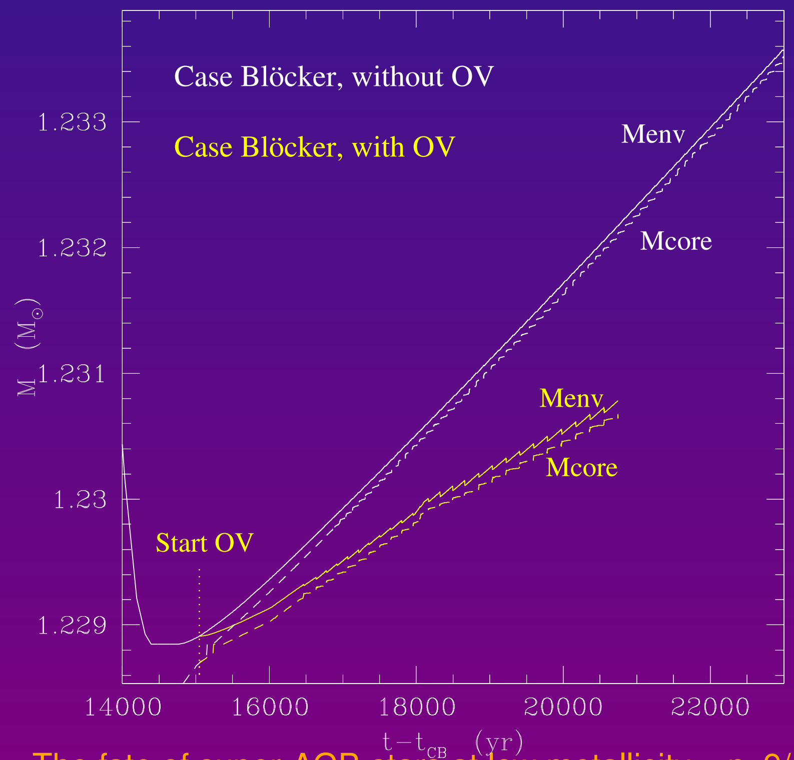
- Mass loss rate: 1.6×10^{-4} $M_\odot$/yr $\Rightarrow$ star loses 3.3 $M_\odot$.
- Core growth from 1.228 $M_\odot$ to 1.240 $M_\odot$.

$\Rightarrow$ will end as a planetary nebulae and a ONe white dwarf.

AGB: Blöcker, with OV

- Model has evolved through 28 thermal pulses.
- Mass loss history follows precious case.
- OV induces:
  - 3DUP occurs ($\lambda = 0.5$).
  - He burning shell is more extinguished.
  - longer interpulses, and stronger pulses ($L_{He} = 4 \times 10^6 \, L_\odot$).
- Effect on the core:
  - core increases slower during EAGB and interpulses;
  - Convective envelope shrinks during 3DUP.

$\Rightarrow$ will end as a PN and a ONe WD



AGB: de Jager, no OV

- This model has been evolved through 136 pulses during 19000 yr.
- Pulses are similar to case $\mathcal{A}$.
- Low mass loss: $\sim 1.9 \times 10^{-6}\ M_{\odot}$/yr $\Rightarrow$ It loses $3 \times 10^{-2}\ M_{\odot}$.
- The core growths from 1.228 to $1.237\ M_{\odot}$.

To reach a core of $1.37\ M_{\odot}$:

- this model needs 3×10^{5} yr.
- In the same time, the star will lose $0.5\ M_{\odot}$.

$\Rightarrow$ will end as a SN and a neutron star.

Conclusions

- $8.5\ M_\odot$, $Z = 10^{-4}$ star ignites carbon off-center before reaching AGB phase.
- C-burning propagates toward the center in a flamme.

- End of AGB phase depends on mass loss and overshoot:
  - Models with hight mass loss rate will end as a PN and ONe WD.
  - Models with low mass loss rate will explode as a SN and become a neutron star.
  - Overshoot seems to have a secondary role.

- Fate of other mass and metallicity ? More soon...