Massive stellar models at $Z = 0$ and the production of ^{12}C

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^{12}C production during CHeB

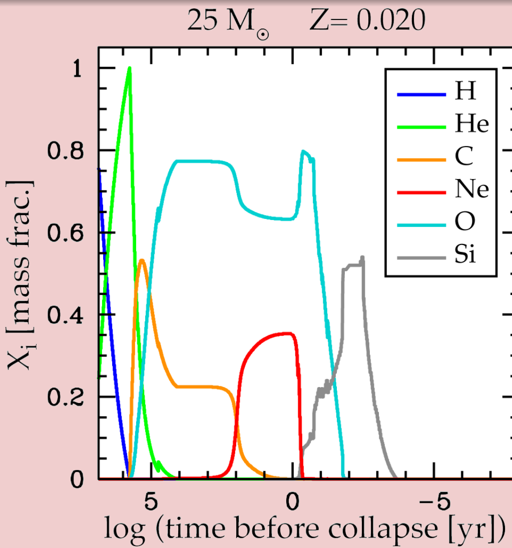
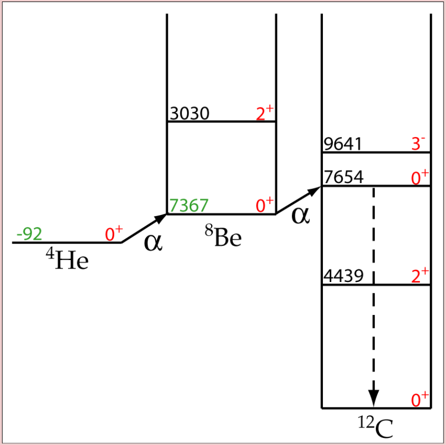


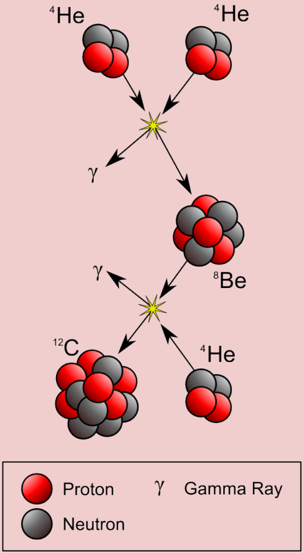
Fig. courtesy R. Hirschi

The 3α reaction

T $\sim$ 150-250 MK

3 steps reaction

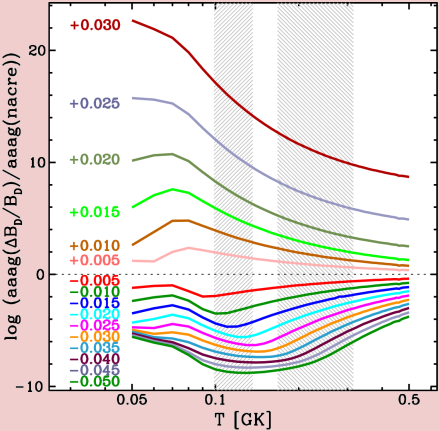




What if fundamental constants are not constant ?

$\Delta\alpha/\alpha \rightarrow \Delta B_D/B_D$ $\rightarrow$ affects the ^{8}Be

$\rightarrow$ affects the Hoyle level



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Variations are allowed by many cosmological models:

Kaluza(1921), Klein (1926)
Jordan (1949), Brans & Dicke (1961)
string-based theories

quintessence theories, ...

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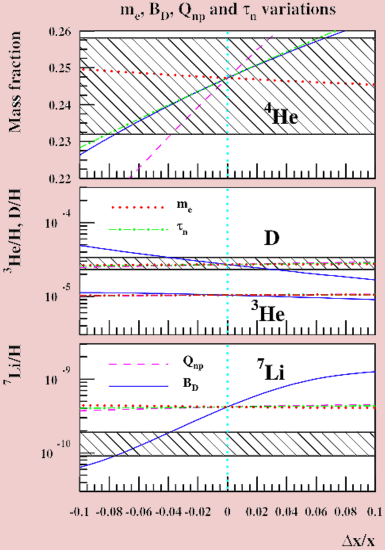
Changes in the BBN predictions

Coc & al. (2007)

Reconciliation between the predicted and observed ^{7}Li abundance



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Are they observed ?

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YES !

Webb & al. (2001)
Murphy & al. (2003, 2008)
Levshakov & al. (2007)

NO !

Quast & al. (2004)
Srianand & al. (2004)
Kanekar & al. (2005)
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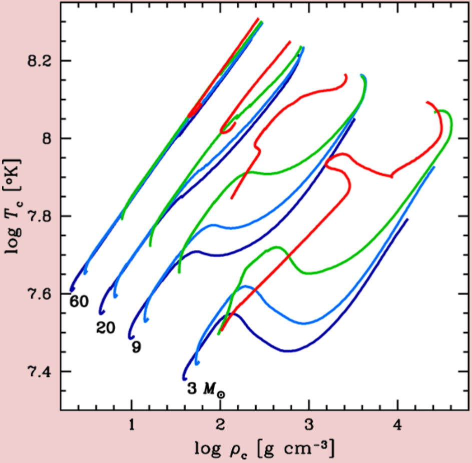
Massive stars rely on the CNO cycle

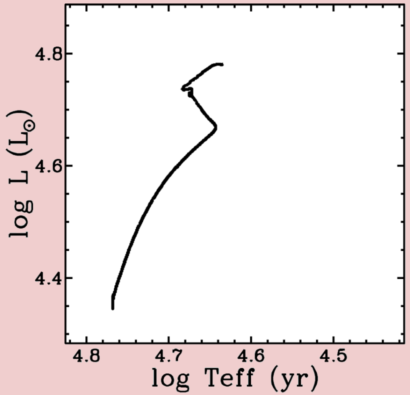
3α is a crucial reaction at $Z = 0$

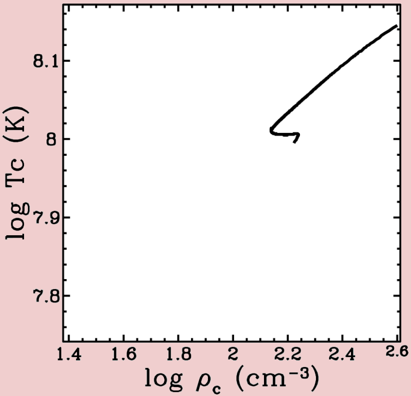


Physical ingredients

- Geneva code (but no rotation !)
- 15 $M_{\odot}$ models
- $X = 0.75325$, $Y = 0.24675$, and $Z = 0$
- no mass loss
- NACRE reaction rates
  except for $^{12}C(\alpha, \gamma)^{16}O$ *(Kunz & al. 2002)*
- computations stopped at the end of core He-burning

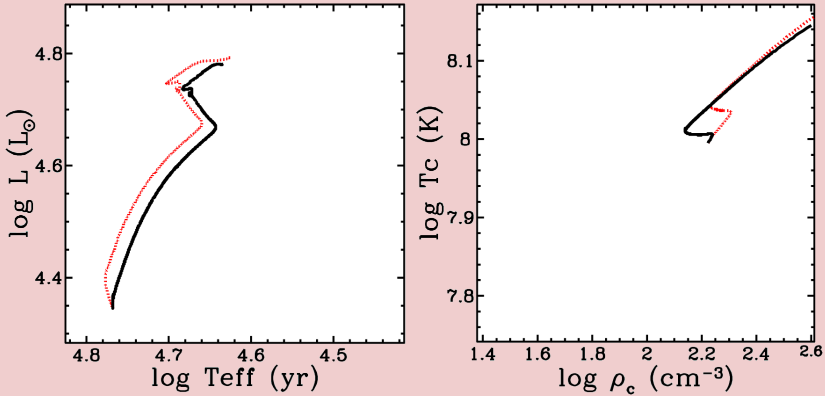
15 $M_\odot$ evolution





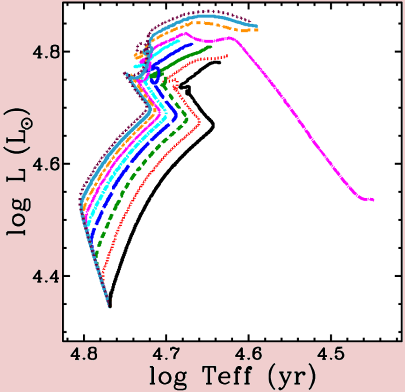
“normal” case ($\Delta B_D/B_D = 0$)

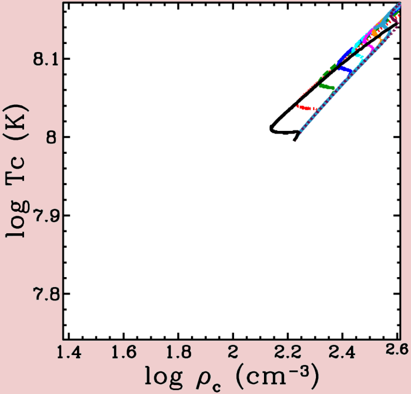
15 $M_\odot$ evolution



weak 3α case ($\Delta B_D/B_D = -0.005$)

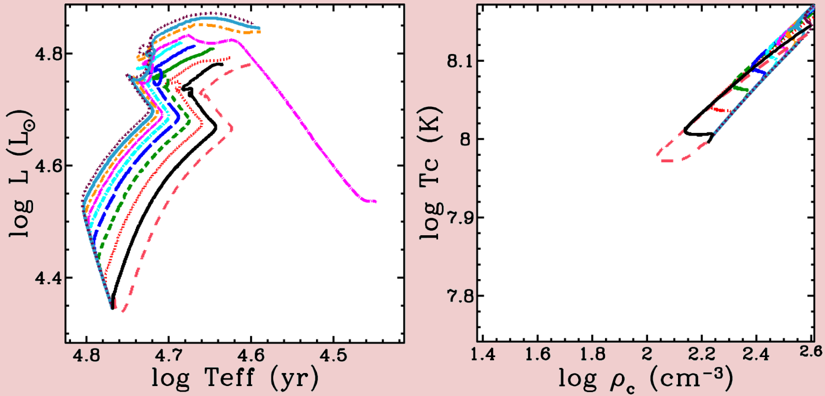
15 $M_\odot$ evolution





weak 3α case ($\Delta B_D/B_D < 0$)

15 $M_\odot$ evolution



strong 3α case ($\Delta B_D/B_D = +0.005$)

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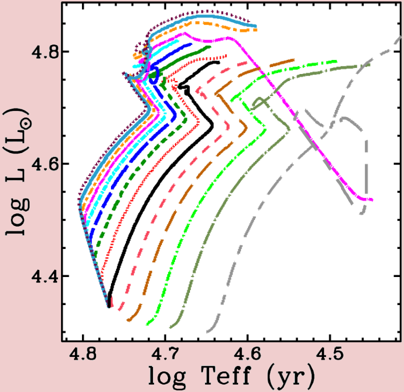
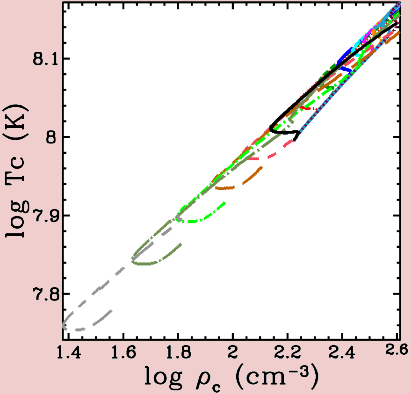




strong 3α case ($\Delta B_D/B_D > 0$)

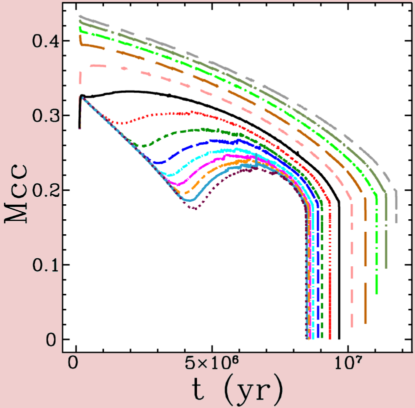
Main sequence constraints

Only one model could not be computed at all:

$\Delta B_D / B_D$ = +0.030

Otherwise: high $\Delta B_D / B_D$
→ long lifetime (max 22%)
→ large convective core

No clear exclusion criterion



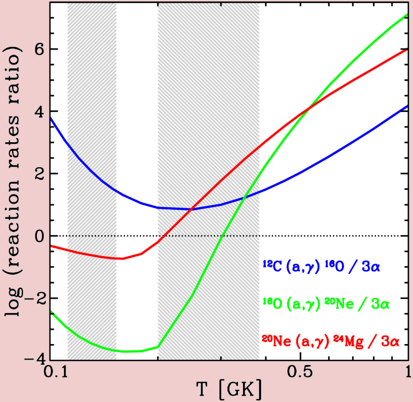
Competition with other reactions

During core He-burning:

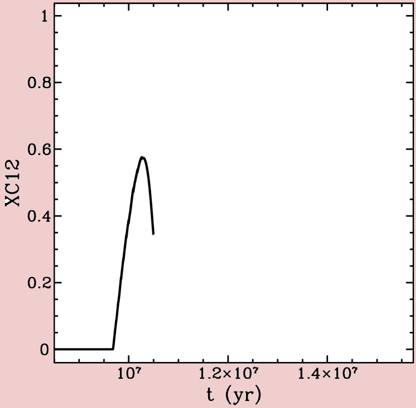
$\rightarrow$ ^{12}C$(\alpha,\gamma)^{16}$O

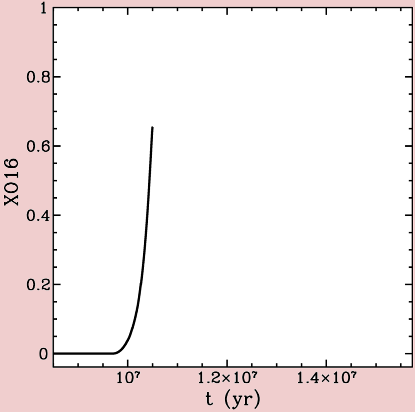
$\rightarrow$ ^{16}O$(\alpha,\gamma)^{20}$Ne

$\rightarrow$ ^{20}Ne$(\alpha,\gamma)^{24}$Mg



Core He-burning constraints





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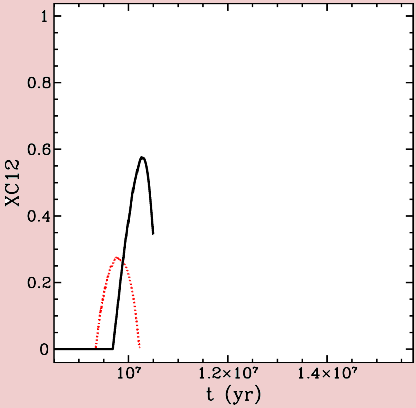

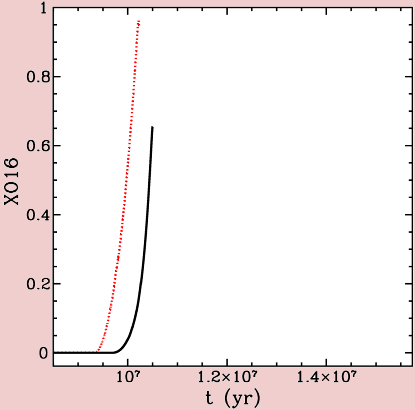

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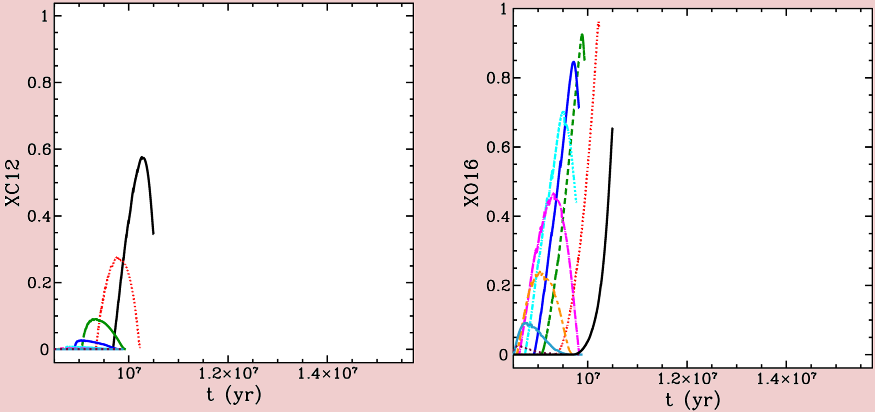

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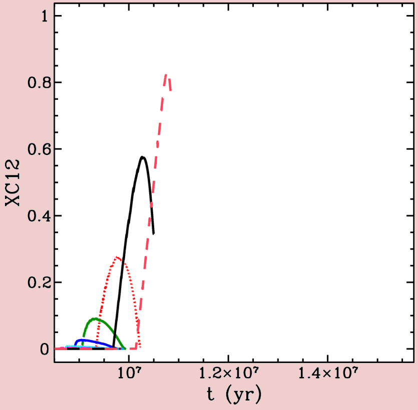

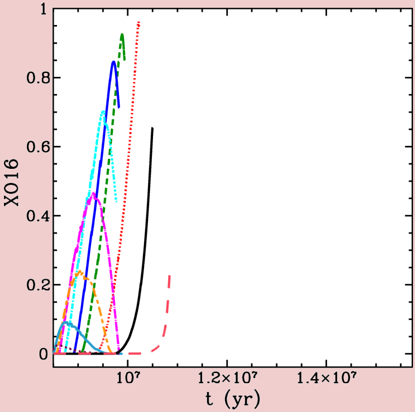

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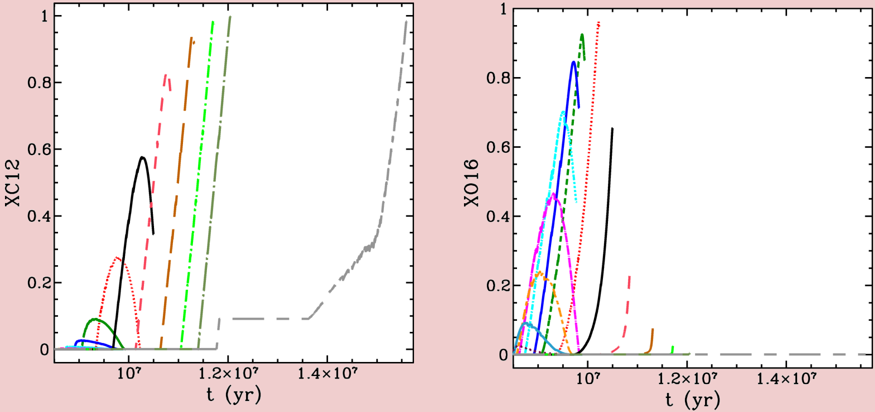

Results

End of core He-burning

15 $M_{\odot}$ models

$\Delta B_D / B_D <$ -0.020:

$\rightarrow$ no ^{12}C, no ^{16}O left
$\rightarrow$ core of ^{24}Mg

$\Delta B_D / B_D >$ +0.010:

$\rightarrow$ no ^{16}O produced
$\rightarrow$ core of ^{12}C

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Same trend with 60 $M_\odot$ models

lower limit:

$\Delta \mathrm{B_D}/\mathrm{B_D} <$ -0.015

upper limit:

$\Delta \mathrm{B_D}/\mathrm{B_D} >$ +0.015

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$$\boxed{-0.015 \leq \Delta B_D/B_D \leq +0.010 \quad \rightarrow \quad |\Delta\alpha/\alpha| \leq \text{a few } 10^{-5}}$$

Discussion

Stellar models can put constraints on the variations of the fine structure constant at a redshift $z \sim 15$

Some points need yet to be clarified:

- Reaction rates
  3α most sensitive (resonant reaction)
  other rates: marginally affected only
- Nucleosynthesis
  follow the advanced stages
  inconceivable not to produce ^{12}C or ^{16}O (CO-rich UMPs)
  timescale of variation: how many generations affected?
  Pop III: no direct observations