Massive stellar models at Z = 0and the production of ¹²C

S. Ekström¹ A. Coc², E. Vangioni³ P. Descouvemont⁴, J.-Ph. Uzan³, K. Olive⁵ & G. Meynet¹

¹Geneva Observatory, Switzerland
 ²CSNSM, Orsay, France
 ³IAP, France
 ⁴ULB, Belgium
 ⁵William I. Fine Theoretical Physics Institute, University of Minnesota, USA

XXIVth IAP Colloquium - Paris - 2008 7-11 July

CSNSM





Ekström, Coc, Vangioni, Descouvemont, Uzan, Olive & Meynet

UNIVERSITÉ

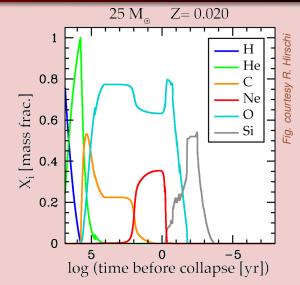
DE GENÈVE

¹²C production in massive Pop III

Introduction

Constraints by Pop III models Looking for extreme values ¹²C production The 3α reaction Variations of some fundamental constants

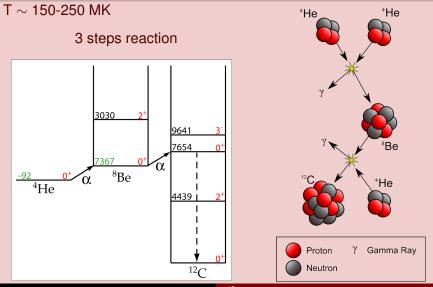
¹²C production during CHeB



Ekström, Coc, Vangioni, Descouvemont, Uzan, Olive & Meynet ¹²C production in massive Pop III

 12 C production **The 3** α **reaction** Variations of some fundamental constants

The 3α reaction



Ekström, Coc, Vangioni, Descouvemont, Uzan, Olive & Meynet

¹²C production in massive Pop III

 Introduction
 12 C production

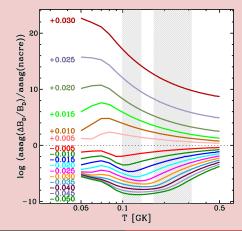
 Constraints by Pop III models
 The 3 α reaction

 Looking for extreme values
 Variations of some fundamental constants

What if fundamental constants are not constant?

$$\Delta \alpha / \alpha \rightarrow \Delta B_{\rm D} / B_{\rm D}$$

affects the ⁸Be affects the Hoyle level



Ekström, Coc, Vangioni, Descouvemont, Uzan, Olive & Meynet

¹²C production in massive Pop III

 12 C production The 3 α reaction Variations of some fundamental constants

What if fundamental constants are not constant?

Variations are allowed by many cosmological models:

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

quintessence theories, ...

 12 C production The 3α reaction Variations of some fundamental constants

What if fundamental constants are not constant?

Variations are allowed by many cosmological models:

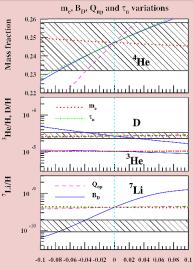
Kaluza(1921), Klein (1926) Jordan (1949), Brans & Dicke (1961) string-based theories

quintessence theories, ...

Changes in the BBN predictions

Coc & al. (2007)

Reconciliation between the predicted and observed ⁷Li abundance



 12 C production The 3 α reaction Variations of some fundamental constants

What if fundamental constants are not constant?

Are they observed ?

 12 C production The 3 α reaction Variations of some fundamental constants

What if fundamental constants are not constant?

Are they observed ?

YES !

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

NO !

Quast & al. (2004) Srianand & al. (2004) Kanekar & al. (2005) Chand & al. (2006)

 12 C production The 3 α reaction Variations of some fundamental constants

What if fundamental constants are not constant?

Are they observed ?

YES !

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



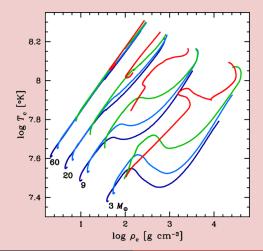
NO !

Quast & al. (2004) Srianand & al. (2004) Kanekar & al. (2005) Chand & al. (2006)

Massive stars need some 12 C Stellar models Evolution with varying $\Delta B_D/B_D$

Massive stars rely on the CNO cycle

 3α is a crucial reaction at Z = 0



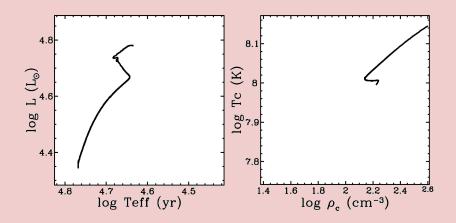
 $\begin{array}{l} \mbox{Massive stars need some} \ ^{12}\mbox{C} \\ \mbox{Stellar models} \\ \mbox{Evolution with varying } \Delta B_D/B_D \end{array}$

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 ¹²C(α, γ)¹⁶O (Kunz & al. 2002)
- computations stopped at the end of core He-burning

Massive stars need some ^{12}C Stellar models Evolution with varying $\Delta B_D/B_D$

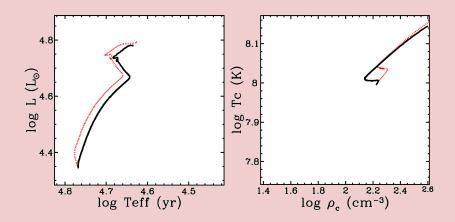
15 M_{\odot} evolution



"normal" case ($\Delta B_D/B_D = 0$)

Massive stars need some ^{12}C Stellar models Evolution with varying $\Delta B_D/B_D$

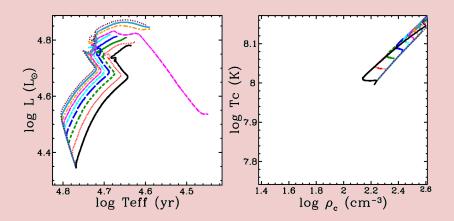
15 M_{\odot} evolution



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

Massive stars need some ^{12}C Stellar models Evolution with varying $\Delta B_D/B_D$

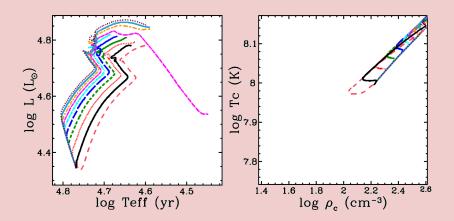
15 M_{\odot} evolution



weak 3α case ($\Delta B_D/B_D < 0$)

Massive stars need some ^{12}C Stellar models Evolution with varying $\Delta B_D/B_D$

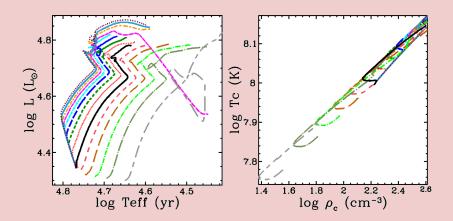
15 M_{\odot} evolution



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

Massive stars need some ^{12}C Stellar models Evolution with varying $\Delta B_D/B_D$

15 M_{\odot} evolution



strong 3α case ($\Delta B_D/B_D > 0$)

MS constraints CHeB constraints Results

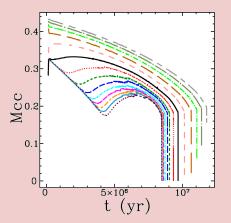
Main sequence constraints

Only one model could not be computed at all:

 $\Delta B_D/B_D = +0.030$

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

No clear exclusion criterion

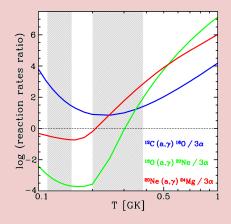


MS constraints CHeB constraints Results

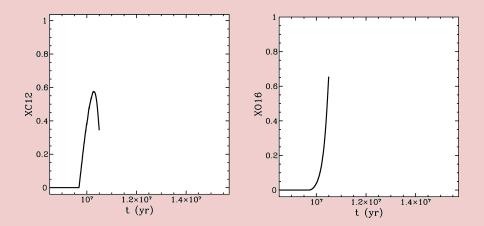
Competition with other reactions

During core He-burning:

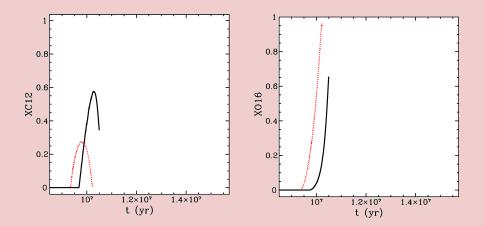
- \rightarrow ¹²C(α, γ)¹⁶O
- \rightarrow ¹⁶O(α , γ)²⁰Ne
- $\rightarrow {}^{20}\text{Ne}(\alpha,\gamma){}^{24}\text{Mg}$



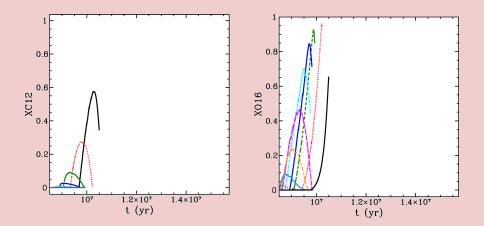
MS constraints CHeB constraints Results



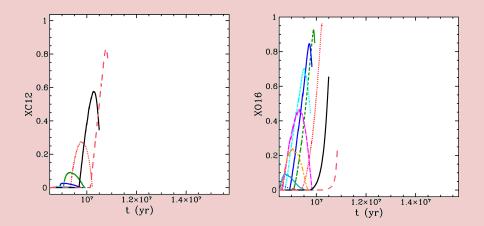
MS constraints CHeB constraints Results



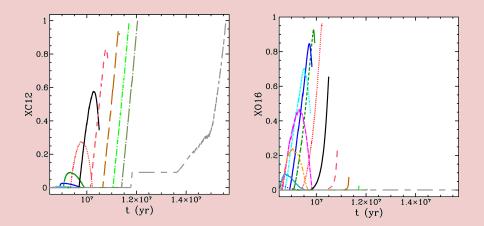
MS constraints CHeB constraints Results



MS constraints CHeB constraints Results



MS constraints CHeB constraints Results



MS constraints CHeB constraints Results

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

 $\Delta B_{\rm D}/B_{\rm D}$ > +0.010:

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

MS constraints CHeB constraints Results

Results

End of core He-burning

 $\begin{array}{l} 15 \ \textit{M}_{\odot} \ \textrm{models} \\ \Delta B_{\rm D}/B_{\rm D} < \text{-0.020:} \\ & \rightarrow \textrm{no} \ ^{12}\textrm{C}, \ \textrm{no} \ ^{16}\textrm{O} \ \textrm{left} \\ & \rightarrow \textrm{core of} \ ^{24}\textrm{Mg} \\ \end{array}$

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

Same trend with 60 M_{\odot} models

lower limit:

 $\Delta B_D/B_D < -0.015$

upper limit:

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

MS constraints CHeB constraints Results

 \rightarrow

Results End of core He-burning 15 M_{\odot} models Same trend with 60 M_{\odot} models $\Delta B_{\rm D}/B_{\rm D} < -0.020$: lower limit: \rightarrow no ¹²C, no ¹⁶O left $\Delta B_{\rm D}/B_{\rm D} < -0.015$ \rightarrow core of ²⁴Ma upper limit: $\Delta B_{\rm D}/B_{\rm D} > +0.010$: \rightarrow no ¹⁶O produced $\Delta B_{\rm D}/B_{\rm D} > +0.015$ \rightarrow core of ¹²C

 $|\Delta lpha / lpha| \le$ a few 10⁻⁵

 $-0.015 \le \Delta B_D/B_D \le +0.010$

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 ¹²C or ¹⁶O (CO-rich UMPs) timescale of variation: how many generations affected? Pop III: no direct observations